Interdisciplinary Modeling: A Case Study of Evolutionary Economics

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Abstract

Biologists and economists use models to study complex systems. This similarity between these disciplines has led to an interesting development: the borrowing of various components of model-based theorizing between the two domains. A major recent example of this strategy is economists' utilization of the resources of evolutionary biology in order to construct models of economic systems. This general strategy has come to be called "evolutionary economics" and has been a source of much debate among economists. Although philosophers have developed literatures on the nature of models and modeling, the unique issues surrounding this kind of interdisciplinary model building have yet to be independently investigated. In this paper, we utilize evolutionary economics as a case study in the investigation of more general issues concerning interdisciplinary modeling. We begin by critiquing the distinctions currently used within the evolutionary economics literature and propose an alternative carving of the conceptual terrain. We then argue that the three types of evolutionary economics we distinguish capture distinctions that will be important whenever resources of model-based theorizing are borrowed across distinct scientific domains. Our analysis of these model-building strategies identifies several of the unique methodological and philosophical issues that confront interdisciplinary modeling.

Keywords: models, modeling, evolutionary economics, Universal Darwinism, analogy

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1. Introduction.

Within the last ten years, the philosophy of science literature has begun to give more attention to issues surrounding the practice of scientific modeling (Godfrey-Smith 2006, 2009; Matthewson and Weisberg 2009; Morgan and Morrison 1999; Odenbaugh 2005; Weisberg 2007a, 2007b). In depth analysis of models is most prominent within scientific domains that study exceedingly complex systems – e.g., biology and economics. Often times within these domains, mathematical models are constructed to work out the consequences of some set of idealizations and assumptions about the complex system under study. By analyzing these idealized models scientists hope to learn something about the way real-world complex systems operate. Such practices have proved extremely fruitful, and consequently, current biological and economic theorizing is pervaded by the practice of modeling.

This similarity between biology and economics has led to an interesting development: the borrowing of various components of model-based theorizing between the two domains.[1] For instance, economists have long used optimality models in order to determine which of a set of possible strategies will maximize utility given certain constraints. Later on, optimality modeling was introduced to population biology, in which it is used to investigate which of a set of strategies (i.e. phenotypes) will maximize fitness given a set of design constraints (Maynard Smith 1978, 1982). Recently, however, the exchange has often run in the opposite direction with economists utilizing the resources of evolutionary biology in order to construct models of economic systems. This general strategy has come to be called *evolutionary economics*.

Evolutionary economics has been a source of significant controversy among economists, which has led to several articles aimed at evaluating the approach (Aldrich et al. 2008; Cordes 2006; Hodgson and Knudsen 2006b; Witt 2003b). Unfortunately, evaluation has proven difficult since there is little consensus as to what exactly distinguishes the approach from others in economics. Ulrich Witt (2008) attempted to answer this question in his article, "What is specific about evolutionary economics?"[2] In doing so he distinguished several schools of thought within the field by drawing two distinctions, which take place at what he calls the "ontological" and "heuristic" levels. Witt's analysis has been widely influential and the types of distinctions he draws are utilized throughout the evolutionary economics literature (even by his opponents).[3] However, we will argue that Witt's analysis inaccurately characterizes the positions of various economists as well as conflates various philosophical and methodological issues that confront different kinds of evolutionary economics. One reason these inadequacies are troublesome is because they have led to an inability to understand and evaluate evolutionary economics as a research strategy. More importantly, however, the troubles within economics point to a need to investigate the unique philosophical and methodological issues that surround interdisciplinary modeling in general.

[1] By "borrowing" we merely mean making use of an element of model based theorizing in the construction of a model in a domain other than the one in which it was originally developed.

[2] Witt's 2008 paper is a culmination of an influential series of papers evaluating evolutionary approaches to economics (Witt 1992, 1999b, 2003a).

[3] Indeed, Witt's paper is aimed at elucidating what various economists within the literature have taken to be an "evolutionary" approach to economics. The influence of Witt's analysis of evolutionary economics can be seen, for example, in Aldrich et al.'s paper (2008).

In this paper, we propose an alternative structuring of evolutionary economics and use it as a springboard to discuss more general issues concerning interdisciplinary modeling. We begin by critiquing Witt's characterization of evolutionary economics and suggest an alternative carving of the terrain aimed at capturing the different ways in which economists have utilized the resources of evolutionary biology to construct models of economic systems. We then argue that our categories capture distinctions that will be important whenever resources of model-based theorizing are borrowed across distinct scientific domains. Therefore, the aims of this paper are twofold. First, we want to clarify the nature of different kinds of evolutionary economics so that the approach may be sufficiently evaluated. Second, we hope our analysis will help to illuminate the more general philosophical and methodological issues that confront interdisciplinary modeling.[4]

The paper will proceed as follows. In the subsequent section we review Witt's attempt to characterize the literature of evolutionary economics. Then, in Section 3, we critique his analysis. In Section 4 we identify three kinds of evolutionary economics: evolutionary embeddedness, analogical modeling, and Universal Darwinism. In the final section we provide more general definitions of these categories, elucidate several relationships between them and identify major philosophical and methodological issues relevant to each type of interdisciplinary modeling.

2. Witt on Evolutionary Economics.

Witt characterizes various forms of evolutionary economics by drawing distinctions at what he calls the "ontological" and "heuristic" levels. Each level is dichotomous, yielding four main approaches within evolutionary economics. In this section we present Witt's distinctions as a starting point for our analysis.

Witt's ontological distinction is meant to distinguish between naturalistic approaches to economics, which deem important the biological background of economic evolution, and non-naturalistic approaches, which suggest that economics can be studied without reference to the historical background of biology. That is, according to Witt, one's ontological stance specifies whether the domain of inquiry of economists is unified with (interdependent with, reliant upon, or beholden to) the domain of inquiry of biologists.

The ontological options on this definition are monism and dualism. The dualist treats the domain of inquiry of economists as distinct from the domain of inquiry of biologists in the sense that they ignore, "possible influences on economic evolution that result from its historical embeddedness in evolution in nature" (Witt 2008, p. 550).[5] In contrast, the monist claims that these domains cannot be addressed independently. They believe that, "the mechanisms by which the species have evolved in nature under natural selection … have shaped the ground for, and still influence the constraints of, man-made, cultural forms of evolution, including the evolution of the human economy" (Witt 2008, p. 550). Therefore, the monist claims, information concerning biological evolution (of economic agents etc.) must be taken into account when studying economic systems.

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[4] We use the term interdisciplinary modeling to refer to any type of model building in which two or more scientific disciplines are involved in the *construction* of a scientific model. This is to be distinguished from constructing a model that *applies* within two or more disciplines or is somehow involved with a topic at the intersection of two or more scientific domains.

[5] Witt's example of such an influence is the influence of human genetic endowment on economic behavior.

At the heuristic level, Witt distinguishes between the strategies of utilizing “generalized Darwinian concepts” and appealing to a “generic concept of evolution”. Economists who find most useful the Darwinian concepts of variation, selection, and retention employ the former strategy. According to Witt, these generalized Darwinian concepts are used either metaphorically or by direct analogy in order to describe economic evolution. The alterative strategy is employed by those who find useful an abstract conception of evolution in the most generic terms, which Witt identifies as that of, “the emergence and dissemination of novelty” (Witt 2008, p. 559 footnote 8). According to this approach, in *biology* emergence and dissemination of novelty occur according to the Darwinian principles of variation, selection, and retention. However, in *economics* (and perhaps other domains as well), this generic conception of evolution may occur according to other principles.

From these two distinctions, Witt generates a 2 x 2 matrix (Table 1 below), the cells of which are meant to represent the various positions that have been taken within the literature that might be called “evolutionary economics”.

Table 1 Witt’s 2 x 2 matrix (Witt 2008, p. 555)

		ontological stance	
		monistic	dualistic
heuristic strategy	generalized Darwinian concepts (variation, selection, retention)	**Universal Darwinism**	**neo-Schumpeterians** (Nelson and Winter)
	generic concept of evolution (novelty emergence and dissemination)	**naturalistic approaches** (Veblen, Georgescu-Roegen, Hayek, North)	**Schumpeter** (1912)

Within this matrix, the dualistic approach includes both Joseph Schumpeter’s account in *The Theory of Economic Development* and the neo-Shumpeterians that followed (Schumpeter 1934). The monistic approach to economics encompasses both what Witt simply labels “naturalistic approaches” and Universal Darwinists, such as Geoffrey Hodgson (Aldrich et al. 2008; Hodgson 2002; Hodgson and Knudsen 2006a, 2006b). Witt claims that the “naturalistic” approach is employed by a diverse group of economists who are not commonly identified with each other. However, he cites Thorstein Veblen (1898) as responsible for the introduction of the monistic approach to economics.

With his heuristic distinction, Witt attempts to distinguish between approaches that utilize a generic concept of evolution, and those that generalize the Darwinian concepts of variation, selection, and retention. Witt sees Schumpeter as typifying the generic concept approach because his seminal contribution to economics was the identification of an evolutionary process of intrinsically generated change. For Schumpeter, the source of variation is entrepreneurial innovation. If innovations are successful, Schumpeter reasoned, then they will disseminate through the economy. According to Witt, "this is exactly the generic evolutionary heuristic that focuses on the endogenous emergence of novelty and its dissemination" (Witt 2008, p. 555). Additionally, some economists who take a monistic approach focus on generic principles of evolution as well, and here Witt lists Veblen again since, "he repeatedly emphasized human inventiveness and imitation as important drivers of the development of institutions and technology" (Witt 2008, pp. 559-60). In short, the generic concept approach avoids the Darwinian principles of variation, selection, and retention, appealing instead to a more abstract understanding of evolution that is able to apply to economic systems as well as biological ones.

This heuristic strategy was abandoned by neo-Schumpeterians in favor of making explicit metaphorical use of Darwinian concepts to describe the evolution of economic systems. In a similar spirit, according to Witt, Universal Darwinists have been explicit in their employment of Darwinian concepts, suggesting that the principles of variation, selection and retention that have been abstracted from the study of biological systems are applicable to economic systems. Since both groups make direct use of the concepts of variation, selection, and retention Witt unifies them under the heuristic strategy he calls "generalized Darwinian concepts".

3. Criticisms of Witt's Categories.

Although we admire Witt's project of distinguishing the various approaches that have been forced under the banner "evolutionary economics", we have several objections to the resulting characterizations. First, Witt's distinction between dualistic and monistic approaches misconstrues the views he cites as representatives.[6] For one thing, there is a significant difference between Universal Darwinism, which claims that the Darwinian algorithm is instantiated in some economic system(s), and Veblen's suggestion that economists need to pay attention to the influences on economic systems that arise from their embeddedness in biological evolution. Claiming that economic systems are Darwinian is to claim that they are of the same type as other Darwinian systems; e.g., biological populations. In contrast, Veblen's suggestion does not imply that economic systems are of any particular type; only that the influences of biological systems must be taken into account.

The problem with this conflation is exacerbated by the fact that it grossly misrepresents the idea of Universal Darwinism. Universal Darwinism does not require any monistic claims about the importance of the relationship of biology to other evolving systems. It claims only that biological evolution is one instance of the algorithm instantiated whenever variation, selection, and retention are present in a system. It is true that Darwin's philosophical views imply a stance

[6] In addition, Witt causes some confusion by calling the distinction between monism and dualism an ontological one. Both camps agree on how the world *is*, but disagree about the import of biological evolution for economic inquiry. As such the distinction is a heuristic one not an ontological one. Recognizing this difference is important because ontological claims and heuristic strategies require very different methods of evaluation.

somewhat similar to Witt's monism[7] but, as Hodgson (a proponent of Universal Darwinism) correctly explains, "Darwin's commitment to universal causal explanation was logically independent of, and additional to, his theory of natural selection" (Hodgson 2002, p. 269).

Universal Darwinism refers to a theory originally proposed by authors such as Donald T. Campbell, Richard Dawkins, and Daniel Dennett (Campbell 1969; Dawkins 1983; Dennett 1995).[8] According to these authors, Darwin's principles of variation, selection, and retention are not unique to biological evolution, but are shared by evolutionary systems in other scientific domains as well.[9] For instance, Dennett argues that natural selection is an algorithmic process, a key feature of which is substrate neutrality; i.e. its results are dependent upon its logical structure, not the physical instantiation of the process (Dennett 1995).[10] Economists who adhere to Universal Darwinism argue that this algorithm is instantiated in some economic systems. Unfortunately, Witt's categories misleadingly suggest that Universal Darwinism includes an additional commitment to his monism. However, these two heuristic strategies involve logically independent claims and, as such, ought to be understood and evaluated independently.

Witt's heuristic distinction is not without its own problems, as neither "generalized Darwinian concepts" nor "generic concept of evolution" is able to unify the set of approaches it is supposed to. First, Schumpeter's heuristic strategy of focusing on endogenous emergence of novelty and its dissemination is not mirrored by the approaches advocated by other naturalists. The unifying feature between these other economists is merely their focus on the embeddedness of economic systems in a biological background. While they all are potentially interested in the emergence of novelty and its dissemination, Witt's characterization is misleading since it implies that each of these economists is committed to a similar heuristic strategy of utilizing a generic conception of evolution.

Even more distinct are the heuristic strategies employed by neo-Schumpeterians and Universal Darwinists. Witt, however, unifies the approaches of these economists under the heading "generalized Darwinian concepts". This is perhaps the most confusing part of Witt's characterization. Witt first identifies the neo-Schumpeterian approach with the heuristic use of Darwinian metaphors to conceptualize economic evolution. He then suggests that this same heuristic strategy is employed by Universal Darwinism, which he claims, "relies on an abstract analogy to, rather than a metaphorical use of, Darwinian principles: Campbell's (Campbell 1969) variation, selection, and retention principles" (Witt 2008, p. 559). This explanation is puzzling, however, given that making metaphorical use of Darwinian principles is different from drawing analogies with those principles.[11]

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[7] An important part of Darwin's view is the claim that everything, including intentionality, must be explained within a naturalistic causal framework. This belief is similar to that held by Veblen (Witt's paradigmatic monist), who suggested that human intentionality must be explained in causal terms and these causes would inevitably include reference to biological systems.

[8] Dennett never actually uses the phrase "Universal Darwinism", but it is clear that the core of his view is the same as those defended by Dawkins and Campbell.

[9] This is not intended to imply that all evolutionary systems will have to be Darwinian in this sense. For example, Hodgson (2002) has argued that some systems in economics are Darwinian while others are Lamarckian. The Universal Darwinist only claims that the principles of Darwinian evolution are not domain-specific, but are substrate neutral.

[10] Dennett gives the example of long division, which works equally well with pencil and paper as with skywriting (Dennett 1995, p. 50).

[11] An account of the relationship between metaphors and analogies in science is beyond the scope of the paper.

Setting these difficult conceptual issues aside, Witt's placing of these groups under the same heuristic strategy also leads to a gross misrepresentation of the approaches of these economists. Neo-Schumpeterians do make metaphorical use of biological evolution, noting that elements of economic systems sometimes act in similar ways to elements of evolving biological systems. But Universal Darwinists emphatically do not see themselves as making any metaphorical nor analogical use of Darwinian principles (Hodgson 2002; Hodgson and Knudsen 2006b). Instead they see variation, selection, and retention as *the* principles that govern evolution both in biology and in economics. The relationship claimed is one of identity (of the principles).[12] While Neo-Schumpeterians employ biological evolution as a heuristic metaphor, Universal Darwinists claim that the Darwinian algorithm is actually present in economic systems.

In sum, Witt argues that evolutionary economic approaches may be categorized according to an ontological distinction and a heuristic one. Unfortunately, his neglect of key distinctions forces him to conflate or ignore importantly different philosophical and methodological issues as well as misrepresent the authors that he attempts to categorize. Similar problems can be found throughout the evolutionary economics literature (e.g., Hodgson 2002). Such confusions make it impossible to adequately evaluate the diverse set of modeling strategies that have been called evolutionary economics. In the next section, we respond to these problems by differentiating three kinds of evolutionary economics. Our alternative analysis is motivated by the need to distinguish just such philosophical and methodological issues that confront interdisciplinary modeling.

4. Distinguishing Three Kinds of "Evolutionary Economics".

As an alternative we want to distinguish three kinds of evolutionary economics that are differentiated by whether economists (1) incorporate *assumptions* informed by biology, (2) make analogical use of biological *models*, or (3) directly apply Darwinian *theory* to economic systems. An important result of our alternative analysis is that it distinguishes several philosophical and methodological issues confronting the diverse strategies that have been called evolutionary economics. Disentangling these issues is required if evolutionary economics is to be adequately evaluated. In addition, economic modelers borrowing from evolutionary biology can be seen as a case study of a more general occurrence in science: the borrowing of modeling resources across domains of inquiry. Thus, in the following section we analyze more general definitions of the three categories distinguished below.

4.1. Evolutionary Embeddedness. One way to utilize biology within economics is simply to recognize that the agents within economic systems are themselves products of biological evolution. We call this tactic, *evolutionary embeddedness*. This approach to economic modeling incorporates information about the biological evolutionary history of economic agents in the form of assumptions within the economic model. Evolutionary embeddedness is not the utilization of biological concepts, analytic tools, models, or theoretical principles in order to

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[12] It is true that such an identity entails an analogy between all systems in which it holds. However, Universal Darwinists are interested in the operation of the principles themselves, not in the analogy between two similar systems.

describe or explain the evolution of economic systems.[13] Indeed, this approach, in and of itself, is mostly silent about the nature of economic evolution. Instead, it merely incorporates information provided by evolutionary biology in order to better understand economic agents. Veblen advocates this approach when he urges economists to pay attention to how biological history provides the backdrop for economic systems. In addition, Christian Cordes describes what he calls Witt's "continuity hypothesis" in just these terms: "According to the continuity hypothesis, the historical process of economic evolution can be conceived as emerging from, and being embedded in, the constraints shaped by evolution in nature" (Cordes 2006, p. 531).

An example of the evolutionary embeddedness approach can be found in Arthur Robson's discussion of the biological evolutionary history of preferences, beliefs and rationality (Robson 2002; Robson and Samuelson 2011). Assumptions concerning these three concepts are key to economic models of human decision-making. Within an economic model, beliefs are the probabilities with which agents think various outcomes will occur conditional on the information available to them, preferences are the rankings agents assign to the set of outcomes given their beliefs, and rationality describes the extent to which agents succeed in choosing the appropriate course of action in light of their beliefs and preferences. Robson's work investigates the biological basis of various assumptions made concerning these components of decision-making models within economics. He contends that there are some decisions related to individuals' fitnesses that Nature "knows more about" than individual agents. For instance, Robson argues, "because individuals see only a small sample [of other individuals], requiring them to learn what consumption choices lead to more offspring will be less effective than having them adhere to the rankings of these choices set by Nature" (Robson 2002, p. 93). In other words, there are some preferences that biological evolution would have shaped (since they are important for survival and reproduction) that are relevant to economic decision-making. We can therefore investigate the biological history of those preferences and compare them with the assumptions made within economic models. Robson goes on to argue that considerations of biological evolution entail that the assumptions underlying the expected utility theorem are inadequate when considering behavior in the face of uncertainty about how others in the group will be affected by the potential outcomes (Robson 2002, p. 97). He also discusses how biological evolution might influence agents' beliefs about outcomes, as well as help to determine how their rationality is bounded.

Another example of the evolutionary embeddedness approach is Robson and Hillard Kaplan's investigation of hunter-gather societies in order to provide evolutionary explanations for current human characteristics and preferences important to economics (Robson and Kaplan 2006). In addition, Theodore C. Bergstrom has utilized game-theoretic models of the evolution of altruism in order to argue for the assumption that economic agents are not entirely selfish (Bergstrom 2002).

In each of these examples, the strategy is to look at the results of biological evolution in order to evaluate the assumptions made within economic models. As Robson and Larry Samuelson explain in the introduction to their survey of biological explanations of preferences:

> [W]e view human preferences as having been shaped by years of evolutionary selection. When thinking about whether [this economic model] is a reasonable representation of preferences, or which more specific or more general models might be useful alternatives, our first step is to ask

[13] Of course one is employing biological concepts in some sense, but only insofar as the results of biological evolution are important for the study of economic systems. The concepts themselves are not borrowed in the sense of being used to describe anything about the economic system.

> what sorts of preferences are likely to emerge from this evolutionary process. The more readily we can provide evolutionary foundations for a model of preferences, the more promise we see in using this model in theoretical and applied economic analyses. (Robson and Samuelson 2011, p. 224)

4.2. Analogical Modeling. Another strategy that some economists employ is to use various components of models, modeling strategies, or specific concepts that have been developed in order to model the evolution of biological systems for use in studying economic systems. This brand of evolutionary economics makes analogical use of models developed (or advanced) in order to investigate the evolution of biological systems and employs them in the building of models of economic systems.[14]

In different situations, an economist might borrow some part of the formal structure of a model (e.g. mathematical equations), other underlying assumptions of a biological model (e.g. infinite population size or path dependence), or merely make analogical use of some biological concepts (e.g. genotype) that play a particular role in modeling biological systems. These borrowed components are then used in the construction of an economic model.[15] There are several ways to utilize analogies with biological evolution in order to construct economic models. For instance, one might draw analogies with generic biological concepts (e.g., Nelson and Winter's economic analogues for genotypes and phenotypes described below), abstract away to more generic principles that apply to both systems (e.g., Witt's "novelty emergence and dissemination"), or utilize analogies to motivate the employment of a specific modeling strategy (e.g. Frenken's use of NK-models described below). This approach is not committed to specifically *Darwinian* evolution actually occurring in economic systems (as Universal Darwinism is), but merely claims that there are similarities between the two types of systems that may be fruitfully exploited for purposes of economic modeling. The similarities highlighted by these analogies will vary from one case to the next. What unifies this type of evolutionary economics is that analogies are drawn with *the components of biological models themselves* for purposes of constructing models of economic systems.

Much of contemporary analogical modeling draws inspiration from Richard Nelson and Sidney Winter's seminal work, *An Evolutionary Theory of Economic Change* (Nelson and Winter 1982). Nelson and Winter explicitly identify economic analogues of biological concepts in order to construct various evolutionary economic models. Here is a typical expression of the analogy they intend to draw between biological and economic evolution:

> The comparative fitness of genotypes (profitability of routines) determines which genotypes (routines) will tend to become predominant over time. However the fitness (profitability) clearly depends on the characteristics of the environment (market prices) confronting the species (collections of firms with similar routines). The environment (price vector) in turn depends,

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[14] The use of biological analogies has a long history within economics (see Hodgson 1993 for an extended discussion). Two particularly clear early attempts to utilize biological analogies in order to construct an economic model are given by Alchain (1950) and Penrose (1952).

[15] It is important to note that the common use of the term analogy would suggest that one could certainly draw an analogy with a system without using that similarity to aid in the construction of a model. Indeed, analogies can play other important roles in science, such as aiding in description or suggesting novel ways to test, describe, or explain a model or theory. Our focus here, however, is the use of analogy in the construction of models since this is where biology actually shapes the economic model or theory. Other uses of analogy (e.g. description) are primarily cognitive aids.

> however, on the genotypes (routines) of all the individual organisms (firms) existing at a time. (Nelson and Winter 1982, p. 160)

Nelson and Winter believe that there are several relationships that hold between behavioral routines, firms, profits, and the price vector that are analogous to the relationships that hold between genotypes, phenotypes, fitness, and the environment. In other words, there is an isomorphism that holds between *some* parts of the functional roles played by these biological concepts and those played by their economic analogues. The functional relationships, however, are not identical. Nelson and Winter argue that there are important dissimilarities between economic and biological evolution. For instance, they emphasize that 'mutations' in routines are not blind, but are goal-directed results of conscious deliberation. For this, among other reasons, the two systems are not identical, but the analogy does identify several important relationships from which economic models can be constructed. Nelson and Winter routinely utilize biological analogies as they go on to construct models of selection equilibrium, the response of firms to changed market conditions, and economic growth. It is important to note, however, that these analogies are intended only to emphasize *some* parallels between the two systems. Disanalogous components will often have to be reanalyzed within economic contexts.

Rather than making analogical use of generic biological modeling concepts, some economists practice analogical modeling by adapting the formal structure of specific models developed within evolutionary biology for use in economics. An excellent example of this kind of analogical modeling is found in Koen Frenken's use of NK fitness landscapes to model the design of complex technological systems (Frenken 2006). As Frenken explains, the NK model "has originally been developed as a model of biological evolution, but its formal structure allows for applications in the domain of the design of technologies and organizations" (Frenken 2006, p. 289). For Frenken, both biological and socio-economic systems contain elements that are interrelated within a similar structure. Therefore, it is possible to adapt the biological NK model in order to model the evolution of technological systems. Similar to Nelson and Winter, Frenken's claim is that there are key components of the relationships that hold between biological roles utilized by the NK-model and the elements in technological systems. Here is Frenken's main argument for utilizing the NK-model:

> In biological systems, for which this generalised NK-model was conceived, an organism's *N* genes are the system's elements and an organism's *F* traits are the selection criteria. The string of genes constitutes an organism's genotype and the set of traits constitutes an organism's phenotype. The genotype of an organism is the level at which mutations take place, which are transmitted in its offspring. The phenotype is the level at which natural selection operates in terms of its relative fitness to the environment…Analogously, a technological system can be described in terms of its *N* elements and the *F* functions it performs. The string of alleles of elements describes the "genotype" of a technological system, and the list of functions describes the "phenotype" of this system. (Frenken 2006, p. 293)

In this case, an analogy is drawn with the roles played by concepts within a particular biological model. The model used to represent these relationships in biology is then adopted for use in the economic context. However, as before, there are important components of the model that are disanalogous and ought to be reconceived for economic applications of the model; e.g. Frenken points to the need to clarify notions of decomposability and modularity.

Some other examples of analogical modeling utilize biological game-theoretic models. For instance, Daniel Friedman contends that biological game-theoretic models can be a fruitful modeling tool for economists, but that, "economists must re-adapt evolutionary theory to economics" (Friedman 1998, p. 18). In addition, Jack J. Vromen suggests that, "what economists call competitive selection pretty much resembles what Sober and Wilson call group selection" and that therefore Sober and Wilson's model, "provides us with a clear, coherent, and comprehensible model to start thinking about evolution in market economics" (Vromen 2001, pp. 205-206).

There are a couple of ways in which economists can utilize an analogical model. First, one can practice what we refer to as *analogical modeling simpliciter*, in which one uses the components of a biological model free of any ontological commitments to the entities, principles, or properties of the analogical model. That is to say, the motivation for employing biological models here may be purely pragmatic, not metaphysical. An economist can consistently utilize the models of evolutionary biology in this way without being ontologically committed to the entities, properties, or principles of the analogically constructed models within any real-world economic system. Of course, using an analogy in this way does involve the drawing of similarities between two systems such that a modeler might be ontologically committed to those similarities (e.g. structural similarities) used to motivate the incorporation of components of the biological model. When practicing analogical modeling simpliciter, however, the modeler is not committed to the truth (within economic systems) of the economic model as a whole, nor the incorporated components not claimed to be similar by the original analogy.

However, one may, in addition, practice what we call *theoretical modeling,* in which an empirical claim is made that some real-world economic system(s) instantiates the analogical model in question.[16] That is, the claim is made that the model – including the incorporated biological components – is true of some real-world economic system(s).[17] Although testing these empirical claims does not require reference to biology, this brand of economic modeling is also appropriately called evolutionary economics since, like analogical modeling simpliciter, the economic model is constructed by identifying similarities (analogies) and differences (disanalogies) with a biological model.

In sum, analogical modeling involves constructing economic models by drawing analogies with components of biological models. Whenever these models are used independent of empirical claims about the truth of the model (within economic systems), the modeler is engaged in analogical modeling simpliciter. If, in addition, modelers make the empirical claim that their analogical model is true of some economic systems, then they are also engaged in theoretical modeling.[18]

4.3. Universal Darwinism. Universal Darwinism (henceforth, UD) is a term first coined by Richard Dawkins in 1983, but perhaps its clearest presentation comes in Daniel Dennett's 1995 book, *Darwin's Dangerous Idea* (Dawkins 1983; Dennett 1995). This approach sees Darwinian

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[16] Our term "theoretical modeling", though not unrelated, should not be confused with Achinstein's use of the term (Achinstein 1964, 1965, 1968). Achinstein uses the term within the context of the debate over scientific realism. We intend only to make a claim concerning whether a modeler believes their model is true of some target system.

[17] Precisely what it means for a model to be true is a matter of debate that is beyond the scope of this paper. For a further discussion of this complicated issue see (Mäki 2009).

[18] This distinction is similar to Michael Ruse's distinction between the heuristic and justificatory roles of analogies (Ruse, 1986, pp. 32-35). An analogy-as-heuristic employs an analogy without implying the same kinds of causal relationships within the two contexts. An analogy-as-justification, however, involves the transfer of claims of truth from one domain to the other.

evolution not as specific to biology, but as an algorithm that is substrate neutral. The Darwinian algorithm is constituted by the principles of variation, selection, and retention (Campbell 1969). Proponents of UD argue that whenever these principles are instantiated evolution will occur. Darwin's great contribution was to discover this algorithm at work in biological systems. UD economists maintain that it is at work in at least some economic systems as well. That is, UD in economics amounts to the ontological claim that the Darwinian algorithm is instantiated in economic systems. This algorithm can, therefore, be utilized – often in conjunction with auxiliary assumptions – in order to provide explanations of (at least some) economic phenomena. Adhering to UD commits one to the truth of the propositions that constitute the Darwinian theory of selection within (at least some) economic systems. In other words, UD is simply application of Darwinian theory to the domain of economics.

UD can contribute to economic modeling in two ways. First, if, as some have proposed, all theories just *are* models (conjoined with the empirical claim that the model is true), then UD in economics is simply the application of the most general Darwinian model to economic systems. Less contentiously, those who adopt UD in economics apply the Darwinian theoretical framework within economics by using it to guide the construction, description and testing of more specific theoretical models (in the sense described above). That is, for UD within economics, Darwinism is a theory that is true of economic systems and can therefore be tapped for the construction of economic models, or (with the help of auxiliary assumptions) the explanation of economic phenomena.

One of the contemporary proponents of UD within economics is Geoffrey Hodgson, who, together with colleagues, has produced a series of articles defending the approach (Aldrich et al. 2008; Hodgson 2002; Hodgson and Knudsen 2006b). For these authors, biology and the social sciences both address complex systems that instantiate the Darwinian principles of variation, selection and retention. As Aldrich et al. explain, "Contrary to the misconceptions of some of its critics, the idea of generalizing Darwinism has little to do with biological metaphors or analogies. Instead of drawing analogies, which are often inexact and sometimes treacherous, [Universal] Darwinism relies on the claim of common abstract features in both the social and the biological world; it is essentially a contention of a degree of ontological communality" (Aldrich et al. 2008, p. 579). Furthermore, these authors reference Campbell when they make the stronger claim that, "the evolution of such a [complex] system *must* involve the three Darwinian principles of variation, selection and retention" (Aldrich et al. 2008, p. 583). The idea that Darwinism is required in order to explain the evolution of complex systems is echoed in other presentations of UD as well (Hodgson 2002; Hodgson and Knudsen 2006b). Although these authors claim that Darwinian principles are required to provide explanations of evolving systems, they emphasize that Darwinism is insufficient to provide complete explanations, but does provide, "a general framework in which additional and context specific explanations may be placed" (Aldrich et al. 2008, p. 593).

An example of just such an application of the Darwinian framework within an economic context can be found in Howard E. Aldrich and Martin Ruef's book on the evolution of organizations (Aldrich and Ruef 2006). The authors begin their discussion with the following statement of UD[19]:

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[19] Although these authors discuss four Darwinian principles, the struggle for scarce resources is almost always subsumed by the principle of selection. Indeed, this struggle is usually precisely why selection occurs. Later on,

> Evolution results from the operation of four generic processes: variation, selection, retention, and the struggle over scarce resources (Campbell, 1969)...The four generic processes comprising evolutionary theory are necessary and sufficient to account for evolutionary change. If processes generating variation and retention are present in a system, and that system is subject to selection processes, evolution will occur. Most importantly, as Dennett (1995), Hull (2001), and others have noted, these mechanisms need not be restricted to the biological level. The principles we draw upon are generic ones, applicable to social as well as biological systems. (Aldrich and Ruef 2006, p. 16)

Immediately following this passage Aldrich and Ruef provide a table (Table 2 below) that explicitly defines the Darwinian principles and gives specific examples of how they are instantiated within evolving organizations.

Aldrich and Ruef actually ignore this fourth principle when applying Darwinian principles at the level of organizations.

Table 2 Aldrich and Ruef's table (Aldrich and Ruef 2006, p. 17)

Evolutionary Process	**Definition**	**Example**
Variation	Change from current routines and competencies; change in organizational forms • *Intentional:* occurs when people actively attempt to generate alternatives and seek solutions to problems. • *Blind:* occurs independently of conscious planning	• Within organizations: problemistic search • Between organizations: founding of new organization by outsiders to an industry • Mistakes, misunderstandings, surprises, and idle curiosity
Selection	Differential elimination of certain types of variations *External selection:* Forces external to an organization that affect its routines and competencies *Internal selection:* Forces internal to an organization that affect its routines and competencies.	• Market forces, competitive pressures, and conformity to institutionalized norms • Pressures toward stability and homogeneity, and the persistence of past selection criteria that are no longer relevant in a new environment
Retention	Selected variations are preserved, duplicated, or otherwise reproduced	• Within organization: specialization and standardization of roles that limit discretion • Between organizations: institutionalization of practices in cultural beliefs and beliefs and values.
Struggle	Contest to obtain scarce resources because their supply is limited	• Struggle over capital or legitimacy

The rest of the chapter is dedicated to explaining in more detail how these Darwinian principles are instantiated within evolving organizations. For instance, the authors identify three potential sources of variation: "(1) formal programs of experimentation and imitation; (2) direct and indirect incentives offered to employees; and (3) encouragement of unfocused variation or 'playfulness'" (Aldrich and Reuf 2006, p. 18). As Aldrich and Reuf explain, "[T]he evolutionary approach serves as an overarching framework – or metatheory – within which the value of other approaches can be recognized and appreciated. The evolutionary approach constitutes a set of concatenated principles and uses multiple approaches to explain particular kinds of changes…[T]he models are algorithmic, specifying that *if* certain conditions are met, *then* a particular outcome will occur (Dennett 1995, pp. 48-60)" (Aldrich and Reuf 2006, pp. 34-35)

After presenting this general framework, the rest of the book applies these Darwinian principles in more specific contexts – e.g., within organization ecology, institutional theory, and at the level of the organization.

Further examples of applying Darwinian principles to the modeling of economic systems can be found in a series of projects done by J. Miller McPherson (McPherson et al. 1992; McPherson and Ranger-Moore 1991). When describing their model, McPherson and Ranger-Moore claim that, "the theory posits a Darwinian mechanism of systematic variation, selection, and retention of members in groups" (McPherson and Ranger-Moore 1991, p. 19). They then go on to develop an adaptive landscape for voluntary organizations. These projects show how UD can contribute to the construction of specific economic models.

5. Generalization and Analysis of Three Types of Interdisciplinary Modeling.

The distinctions drawn above between three types of evolutionary economics are instances of more general strategies that may be employed whenever the resources of multiple disciplines are involved in the development of scientific models. Understanding the different ways in which scientists can utilize other domains to construct their models provides insight into the potential fruits (and dangers) of various model-building strategies. The three more general interdisciplinary modeling strategies are distinguished by whether the modeler is (1) incorporating assumptions informed by another scientific domain, (2) making analogical use of components of models constructed in another scientific domain, or (3) directly applying a theory developed in another domain. When interdisciplinary modeling approaches are divided in this way, it becomes readily apparent that different philosophical and methodological issues confront the different categories – although multiple categories may face similar obstacles. In this final section, we make these issues more explicit and describe various relationships between these three kinds of interdisciplinary modeling.

5.1. Incorporating Informed Assumptions. When incorporating assumptions informed by other scientific domains the methodological question is just, "is that information useful?" If another discipline can provide a modeler with assumptions that aid in accomplishment of the aims of the modeler—e.g. providing greater explanatory power or more predictive accuracy—then those assumptions ought to be incorporated. Doing so, however, is not without risk. Scientists are not always clear about what the assumptions of their models are, or their source. If assumptions are to be incorporated they will need to be well defined and the motivation for their inclusion made explicit. Furthermore, if one is primarily interested in providing explanations, then one will be especially concerned with the truth of the incorporated assumptions, as their status will affect the status of any model into which it is incorporated.

Within evolutionary economics, the most common assumptions incorporated into models are those concerning the embeddedness of economics within biological evolution. For evolutionary embeddedness the controversial issues have changed with time. Initially it was important that Veblen and others make explicit the commitment to dealing with economic agents as evolved agents, given that the claim was significantly more contentious then than it is now. Presently, however, the question is not whether economic agents are products of Darwinian evolution (since this is widely accepted), but whether or how information about the results of biological evolution can inform economic investigations. The answer to the former question appears to be, “Yes,” given that economists have incorporated such information in order to build more realistic economic models in which agents are less idealized.[20] However, further debate may still be had over what biological information to include and how best to include it. This will depend in large part on the aims of the economists who incorporate the biological information into their models.

In addition, it should be noted that biology is not the only science that might inform assumptions within economic models. Other disciplines, such as psychology or sociology, could also furnish potentially fruitful assumptions for the construction of economic models. For example, Matthew Rabin (1998) argues that considerations of psychological research suggest modifications of the standard economic theory of choice. Moreover, the results of biological evolution will surely be important to modeling throughout the social sciences. Indeed, given that no scientific domain can be studied in isolation all model-based sciences will at least sometimes require that assumptions furnished by other domains be incorporated.

5.2 Analogical Modeling. Many of the important issues that confront analogical modeling are general philosophical issues that confront modelers of every sort and in every scientific domain. For instance, philosophers have investigated the nature of models as well as the strategy of model building (Godfrey-Smith 2006; Levins 1966; Matthewson and Weisberg 2009; Odenbaugh 2005; Weisberg 2007b). Furthermore, within the recent philosophical literature the use of idealizations within scientific theorizing and model building has begun to be taken more seriously (Weisberg 2007a). The importance of these general issues for modeling must not be overlooked. Here, however, we are interested in identifying issues unique to the analogical use of the components of models from other scientific domains.

The main set of issues unique to analogical modeling involves the dangers of transferring assumptions from one domain to another, some of which may be idealizations. Making analogical use of a model is equivalent to incorporating at least one of its components into the model under construction. These will vary from model to model and may not always be made explicit. It is therefore important to clearly define what the assumptions of the original model are, as well as which components are being borrowed within another scientific domain. Once identified, the appropriateness of the incorporated assumptions within the newly constructed model must be evaluated.

For example, in the case of evolutionary economics, once the assumptions of the biological model have been identified, it must be determined whether or not those assumptions can be usefully employed within economic models. Biologists’ models often involve idealizations such as infinite population size, random mating, constant environment, etc. Some of these may be plausibly utilized within economic models, but some may not. For instance, Alexander Rosenberg (1994) has argued that although the assumption of infinite population size is not problematic within biology, the falsity of that assumption is problematic within economics. Rosenberg also criticizes the assumption of a constant environment when attempting to model economic systems. Consequently, analogical modelers need to investigate whether incorporated idealizations (as well as other assumptions) will cause problems when modeling in other domains.

Despite these dangers, there are ways in which analogical modelers can safely incorporate potentially problematic assumptions and idealizations. It is true that some modelers

[20] For example, agent-based economic modeling incorporates assumptions concerning the decision-making limitations of economic agents. These limits on agents’ rationality are often informed by biology.

may be motivated to practice analogical modeling due to metaphysical commitments; e.g. one who is a Universal Darwinist might be particularly inclined to utilize biological models to investigate economic systems. However, no metaphysical commitment is *required* by the mere analogical use of models – hence our category of analogical modeling simpliciter. In these cases, analogical modeling is employed for purely pragmatic reasons and the plausibility of the incorporated model components will have to be evaluated in light of the interests of the modeler.

Still, although it is possible to engage in analogical modeling simpliciter, most scientists will practice what we have called theoretical modeling – the analogical construction of a model combined with the claim that the model is empirically accurate. When this occurs, it is of course necessary to say something in defense of any false assumptions incorporated via the analogy. An example of attempting to defend false assumptions within analogical models comes from Aki Lehtinen and Jaakko Kuorikoski's discussion of the unrealistic assumptions carried over in the application of rational choice theory outside of economics (Lehtinen and Kuorikoski 2007). The authors contend that, "the assumption of self-interest is not explanatorily important in a model if it can be replaced with another behavioral assumption without changing the analytical results. If it can thus be replaced, the model is *robust with respect to the behavioral assumption*" (Lehtinen and Kuorikoski 2007, p. 127). They then go on to argue that because the explanations of rational choice models are robust with respect to the assumption of selfishness, the models can be safely applied even in domains where that assumption is not realistic. In other words, according to Lehtinen and Kuorikoski, robustness analysis can indicate that some false assumptions are not problematic because they are not important to the explanatory power of the model.

5.3. Cross-domain Theory Application. The issues that confront cross-domain theory application are primarily those that confront the application of all scientific theories. The most important consideration is the available evidence that bears on the truth of the theory within the claimed domain of application. This type of theory application is different from analogical modeling in important ways. For one thing, when a model is constructed by analogy, there is borrowing from a specific initial domain. This is not the case with cross-domain application since it consists in the application of a theory that is not bound to a particular domain. Additionally, theory application – unlike analogical modeling simpliciter – involves the claim that the theory is true of some real-world system. Consequently, one of the major methodological issues confronting this strategy is the need to clarify precisely which claims are constitutive of the theory being applied.

For example, within economics much confusion has been engendered because proponents of UD have failed to sufficiently distinguish their application of Darwinian theory from other claims. The term "Universal Darwinism" might suggest an approach that postulates a wide array of similarities between biological and economic evolution.[21] In fact, as discussed above, the central claim of UD is quite restricted. Economists who endorse UD merely claim that both biological and economic systems instantiate an algorithm constituted by variation, selection, and retention. The case gets muddied, however, when authors attach further claims onto this central thesis. For instance, some have packaged it together with a claim that some of the systems to which the algorithm applies are hierarchically nested (Lewontin 1970; Plotkin 1994). In addition, Hodgson's particular brand of UD includes embracing Darwin's philosophical commitment to

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[21] Holding to the theory of Universal Darwinism does not commit one thinking economics in particular is a place where the Darwinian algorithm applies. Our focus here, however, is on those who do endorse this claim.

causal explanations. This leads him to claim that Darwinism includes positions taken by Veblen and others, that, "all intentionality has itself to be explained by a causal process" (Hodgson 2002, 268). Hodgson himself recognizes that this ontological commitment is logically independent from the central thesis of UD, though he still considers it an essential component of the Darwinian approach to economics. Such a claim may be an essential piece of biological theorizing, but it is not part of *Universal Darwinism*. Perhaps in part due to such add-ons, some have taken criticisms of other positions to be pertinent to the viability of UD (Ruth 1996; Witt 1992, 1999a, 2003a). When only the central claims of the theory are considered, however, it is clear that such concerns are misplaced and require independent treatment. Therefore, in cases of cross-domain theory application it is essential to distinguish the domain-general theory that is being applied from any auxiliary claims made by particular model builders. Of course, once the domain-general theory has been explicitly defined one must provide an analysis of how the theory's principles are instantiated within particular scientific domains. Once the instantiation of the theory has been defined it can then be established what explanatory power the theory has within each domain of application (and this will likely be different for different domains).[22]

UD is the only example of which we are aware in which a theory developed in a particular scientific domain is claimed to be true of another scientific domain for the purpose of constructing models. However there may well be other theories that are found to have domain-general application and could be employed in the construction of models outside of the discipline in which they were developed.

6. Conclusion.

Biological and economic theorizing is pervaded by the use of models. Although philosophers have provided discussions concerning the nature of models and their use in science, the unique issues surrounding interdisciplinary modeling have yet to be sufficiently investigated. The need for this philosophical work is made clear by the confusions that have made it impossible to adequately evaluate the research strategies employed by evolutionary economists. In addition, we suspect that interdisciplinary modeling will become more frequent as model-building strategies within various disciplines develop further.

The categories here distinguished identify key differences between three kinds of interdisciplinary modeling. Although these categories may not exhaust the ways modelers can utilize resources from other scientific domains, they do make progress towards developing a framework with which to understand the practice of interdisciplinary modeling. As philosophers and scientists begin to investigate and evaluate different kinds of interdisciplinary modeling they must be careful to distinguish between the incorporation of assumptions informed by another domain, the analogical use of components of models constructed in another domain, and the application of a theory developed in another domain. Only after the various kinds of interdisciplinary modeling have been identified can we begin to investigate how and when they are most fruitfully applied within scientific inquiry.

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[22] For instance, Cordes (2006) argues that in order for Darwinism to apply within other domains it will have to be watered down to the point where it is in danger of being explanatorily powerless.

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