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A Common Framework for Evolutionary and Institutional Economics

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Abstract: We present a common analytical framework for evolutionary and institutional economics, conceived as the study of systems that do not tend toward, nor necessarily fluctuate around, a steady state. Using an evolutionary equation, we derive an analytical theory of the relation between resource abundance and the rate of return available under differing institutional structures. We suggest that the recent political and financial turmoil around the world reflects incompatibilities between existing institutional structures and the increasing scarcity of resources. We apply this idea to the most fundamental determinant of any society's prosperity, profitability and even long-term survival, namely its fertility and rate of population growth.

Keywords: evolution, institutions, non-equilibrium theory, resource

JEL Classification Codes: B41, E11, Q01

Institutional structures play fundamental roles in the performance of economic systems, while history teaches that firms, industries and economic systems change continually through time. We would therefore expect the concepts of institutions and of evolution to be central to economic theory (Hodgson 1999). However, from the perspective of general equilibrium theory, the evolutionary and institutional properties of economic systems are only transitory. To the general equilibrium theorist, these properties reflect disturbances in time and structure from an ultimate steady-state, and the concept of equilibrium focuses attention on the steady state rather than on the disturbances.

This situation is analogous to the state of biology before Darwin. According to Robert Trivers, "[i]n the old system, each species was imagined to have been created

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according to some ideal type. Variation was just so much noise superimposed on the ideal type. After Darwin, the variation itself was seen as real and important, while the notion of an ideal type was recognized as a useless abstraction" (1985, 22).

In this paper we will present an analytic non-equilibrium economic theory, along the lines of Chen (2005) and Chen and Galbraith (2011, 2012), and show how it can provide a common framework for evolutionary and institutional economics. The framework puts evolutionary processes of institutions at the center of economic analysis and greatly simplifies the understanding of social change.

Social and biological systems are complex and different systems possess very different characteristics. However, all biological and social systems, as non-equilibrium systems, share two properties. First, organisms and organizations need to obtain resources from the environment to compensate for the continuous dissipation of energy. Second, for an organism or an organization to be viable, the total cost of extracting resources has to be less (on average) than the amount of resources extracted. The economic equivalent of this statement is to say that the total cost of operation has to be less than the total revenue, measured over some reasonable unit of time. Costs include fixed cost and variable cost. In short, organisms and organizations need to satisfy a physical principle and an economic principle.

It is often assumed that there is a fundamental difference between social and biological systems: genetic mutations are generally considered random while human activities are considered purposeful. However, human beings evolve through genetic mutations as well and many animal activities are purposeful. Furthermore, more precise observation shows that biological evolution is not completely random. When, where and how fast genes mutate depends on many environmental factors. The regulation in genetic and epigenetic changes in organisms is directed to enhance their survival under different kinds of environments (Jablonka and Lamb 2006; Moalem and Prince 2008; Rando and Verstrepen 2007). Since a directed and informed change provides a higher rate of return than a completely random one, purposeful changes evolve both in social and biological systems. Therefore there is no reason to segregate the study of social systems from other biological systems.

Nelson and Winter (1982) suggested that an evolutionary theory should be modeled by stochastic processes. We model life and social activities with lognormal processes, which include a term for resources that are obtained and a term for resources that are dissipated. These are stochastic processes with specific physical and biological meaning. Although a stochastic process will generate many different outcomes over time, we are mostly interested in the qualities or average outcomes from such processes. For example, although the movement of individual gas molecules is very volatile, air in a room, which consists of many gas molecules, generates a stable pressure and temperature. We usually study the average outcomes of stochastic processes by looking at the averages of the underlying stochastic variables and their functions.

Feynman (1948) developed a method of averaging stochastic processes under very general conditions, which is usually called the path integral. Kac (1951) extended Feynman's method into a mapping between stochastic processes and deterministic differential equations, which was later known as the Feynman-Kac formula. Applying this formula, we obtain a deterministic equation corresponding to the lognormal process, described above, relating to the extraction of resources and the dissipation of resources. This equation is first order in the time dimension and hence is an evolutionary equation. To solve the equation, we set the initial condition that total revenue be equal to total cost. So our theory is not only an evolutionary theory, but also an evolutionary economic theory.

The main result is a formula that gives variable cost as a mathematical function of product value, fixed cost, the diffusion rate, the discount rate and project duration. From this formula, together with fixed cost and volume of output, we are able to compute and analyze how each factor affects the returns and profits of different institutional systems with different levels of resource abundance in a simple and systematic way. It can be shown that only when the level of fixed cost is higher than zero will variable cost be less than the value of the product. This shows that it is essential to build up institutional structures before a system can generate a positive return (Stiglitz 2002). An institutional structure lowers the variable cost of economic activities and at the same time constrains the possible path of future evolution.

When resources are abundant, institutional systems with high fixed costs and long durations will generate high net present values. When resources are scarce, profit rates are lower, and institutional systems with low fixed costs and short durations are more likely to maintain positive net present values. Intuitively, when resources are abundant, it pays to build up fixed-cost institutions, to reduce variable costs, and to maintain a long production life in order to generate more output. When resources are scarce, using too many resources to build up fixed cost and maintain a long production life will leave too few resources to generate output. This is (partly) why strategies of rapid capital accumulation (Great Leaps Forward) tend to generate hardship when applied in countries where resources are not abundant.

In the last several centuries, with the increasing use of fossil fuels, especially at first in the UK and later in the United States and in continental Europe, institutional systems with higher fixed cost and longer durations have generated large surpluses and hence grew continuously. In more recent times global markets, open trade and credit facilities have made the same strategy widely available around the world. However, fossil fuels are nonrenewable. The rapid depletion of fossil fuel deposits, especially those of high quality, poses increasing strains to the whole world.

From physical and biological principles, those societies that consume the most and control the fewest resources will be most severely affected by resource constraints. More precisely, the key relationship is between *fixed costs* and the cost of resources. Societies with high fixed costs have high standards of living because they make efficient use of abundant resources. But when resource costs rise, they suffer a rapid decline in the available surplus, and hence in profitability and living standards. This is the physical equivalent of financial leverage.

While many criteria can measure social wellbeing, ultimately the condition of a human society as a long-run going concern — the net effect of resource constraints in relationship to fixed costs — can be measured by its biological return. The biological rate of return is the fertility rate, a variable that is (for the most part) freely chosen by individuals, based on the objective conditions that they face. These conditions may also vary for different populations within each country, resulting in differential fertility rates for different groups. Thorstein Veblen long ago made the point that wealth is not a prerequisite for fertility; quite the reverse, because of the fixed costs:

> The low birthrate of the classes upon whom the requirements of reputable expenditure fall with great urgency is likewise traceable to the exigencies of a standard of living based on conspicuous waste. The conspicuous consumption, and the consequent increased expense, required in the reputable maintenance of a child is . . . probably the most effectual of the Malthusian prudential checks. (Veblen 1973, 150)

A Mathematical Theory of Evolutionary and Institutional Economics

Organisms and organizations need to obtain resources from the environment to compensate for the continuous diffusion of resources required to maintain their activities. This fundamental property can be represented mathematically by lognormal processes, which contain both a growth term and a diffusion term.

Suppose S represents the amount of resources accumulated by an organism or the unit price of a commodity, r, the rate of resource extraction or the expected rate of change of price and σ, the rate of diffusion of resources or the rate of volatility of price change. Then the process of S can be represented by the lognormal process

$$\frac{dS}{S} = r\,dt + \sigma\,dz \;, \tag{1}$$

where

$$dz = \varepsilon\sqrt{dt}, \qquad \varepsilon \in N(0,1)$$

is a random variable with standard Gaussian distribution.

According to the Feynman-Kac formula (Øksendal 1998), if

$$C(t,S) = e^{-rt}E(f(S_t)) \tag{2}$$

is the expected value of a function of S at time t discounted at the rate r, then $C(t,S)$ satisfies the following equation:

$$\frac{\partial C}{\partial t} = rS\frac{\partial C}{\partial S} + \frac{1}{2}\sigma^2 S^2\frac{\partial^2 C}{\partial S^2} - rC \tag{3}$$

with

$$C(0,S) = f(S). \tag{4}$$

Suppose there is a project with a duration that is infinitesimally small. It only has enough time to produce one unit of product. If the fixed cost is lower than the value of the product, in order to avoid arbitrage opportunities, the variable cost should be the difference between the value of the product and the fixed cost. If the fixed cost is higher than the value of this product, there should be no extra variable cost needed for the product. The relation between fixed cost, variable cost and the value of product in this case is the following:

$$C = \max(S - K, 0) , \tag{5}$$

where S is the value of the product, C is the variable cost and K is the fixed cost of the project. When the duration of a project is a finite value T, Equation (5) can be extended into

$$C(0, S) = \max(S - K, 0) \tag{6}$$

as the initial condition for Equation (3). Equation (3) with initial condition (6) can be solved to obtain

$$C = SN(d_1) - Ke^{-rT} N(d_2) , \tag{7}$$

where

$$d_1 = \frac{\ln(S/K) + (r + \sigma^2/2)T}{\sigma\sqrt{T}}$$
$$d_2 = \frac{\ln(S/K) + (r - \sigma^2/2)T}{\sigma\sqrt{T}} = d_1 - \sigma\sqrt{T} \quad .$$

The function $N(x)$ is the cumulative probability distribution function for a standardized normal random variable. From (6), the solution of Equation (3) can be interpreted as the expected average variable cost of the project. Equation (7) takes the same form as the Black-Scholes (1973) formula for European call options, but the meaning of the parameters in this theory differ from that in the option theory. Equation (7) provides an analytical formula of variable cost as a function of product value, fixed cost, diffusion rate, duration of project and discount rate of a firm.

After obtaining the formula for the variable cost, we can calculate the net present value of an investment. It is often convenient to represent S as the value of output from a project over one unit of time. During the project life, we assume the present value of the product to be S and the variable cost to be C. If the project lasts for T units of time, the gross value of the product and the total cost of production are

$$TS \text{ and } TC + K , \tag{8}$$

respectively. The net value of the project is

$$TS-(TC+K)=T(S-C)-K. \tag{9}$$

Gain and Loss Analysis of Different Institutional Structures

Under different levels of resource abundance, maximum net present values of investment can be reached by changing the levels of fixed cost and project duration. Intuitively, in a large and stable market, firms will invest heavily in fixed costs to reduce variable cost, thus achieving greater economies of scale. In a small or volatile market, firms will invest less in fixed costs and maintain a high level of flexibility.

From the second law of thermodynamics, only part of energy obtained can be converted to work. The rest is diffused into heat. Very often the level of diffusion represents the quality and quantity of useful resources, and the abundance of resources can be represented by the (inverse of the) diffusion rate. For example, when a dry cell gets discharged, its internal resistance gradually increases and more energy turns into unusable heat.

Table 1 lists the fixed costs, durations, variable cost, net present values at different levels of diffusion rate when Equation (9) is maximized with respect to fixed cost and duration, assuming a constant discount rate (6%). Low diffusion rates, which represent abundant resources, correspond to the choice of high fixed costs and long durations, and to high net present values. Since fixed costs and durations are more visible than resource abundance, highly valuable investments are often seen to be the result of those investment choices. More generally, high fixed costs and long durations are often associated with progress.

Table 1. Investment Decisions and Values of Investments with Different Levels of Resource Abundance

Diffusion rate	0.1	0.2	0.3	0.4	0.5
Fixed cost	11.9	7.99	5.29	3.54	2.41
Duration	37.6	28.9	21.8	16.5	12.6
Variable cost	0.16	0.31	0.43	0.52	0.6
Net present value	19.5	11.9	7.15	4.29	2.61

In the past several centuries, with continuous improvement in the extraction and use of fossil fuels, the amount of resources consumed has increased steadily. Social institutions make many adjustments, generally increasing the fixed cost and duration of investments to take advantage of this abundance. Because of the high correlation between fixed cost, life span and general prosperity, decision makers often reflexively adopt policies that increase fixed costs, expecting to take advantage of the greater efficiency those systems yield. For example, secondary education becomes mandatory and tertiary education becomes easily available in most wealthy countries, greatly increasing the fixed cost of social life (and so depressing fertility rates).

From Table 1, when resources are very abundant (diffusion rate equals 0.1), the investment that generates highest net present value has a fixed cost of 11.9 and duration of 37.6. The performance of such a level of investment with different levels of resource abundance can be calculated from (9). The results are presented in Table 2.

Table 2. Values of High Fixed Cost, Long Duration Investment with Different Levels of Resource Abundance

Diffusion rate	0.1	0.2	0.3	0.4	0.5
Fixed cost	11.9	11.9	11.9	11.9	11.9
Duration	37.6	37.6	37.6	37.6	37.6
Variable cost	0.16	0.4	0.6	0.76	0.86
Net present value	19.5	10.6	3.06	-2.68	-6.64

But what happens when resources become scarce? From Table 2, net present values of investment decline and eventually drop below zero. Alternatively, given the level of abundance of resources, when the levels of fixed cost and duration are too high, the return on investment will turn negative.

We can apply this, albeit casually, to the relationship between life expectancy (a measure of "project duration") and fertility. Table 3 lists the 20 states and territories with populations larger than one million that have the highest life expectancies. Data include each country's life expectancies and its corresponding fertility rate. Fertility rates in all states and territories except Israel are below the replacement rate. Israel has a large infusion of resources from external sources. So this exception supports the rule: when project duration and fixed cost in a society become higher than resources allow, the biological return will turn negative. The initial drop in fertility rate reduces the number of dependent children and the ratio of dependents over workers. As a result, countries in demographic transition often enjoy a high rate of growth in output and living standards. But over time, the decline of the number of children will translate into the decline of the number of workers and increase the ratio of dependents to workers. This will lead to a long term decline, unless offset by immigration and/or technical change that again reduces resource costs.

Concluding Remarks

We present a common framework for evolutionary and institutional economics as a non-equilibrium theory. Our major purpose is to make it easier to discuss the gain or loss of different institutional strategies under different levels of resource abundance.

Table 3. Data on Life Expectancies and Fertility Rates in Twenty States and Territories with Highest Life Expectancies

State/Territory	Life Expectancy (years)	Fertility Rate
Japan	82.6	1.27
Hong Kong (China)	82.2	0.97
Switzerland	81.7	1.42
Australia	81.2	1.79
Spain	80.9	1.41
Sweden	80.9	1.80
Israel	80.7	2.75
France	80.7	1.89
Canada	80.7	1.53
Italy	80.5	1.38
Norway	80.2	1.85
New Zealand	80.2	1.99
Singapore	80.0	1.26
Netherlands	79.8	1.72
Austria	79.8	1.42
Greece	79.5	1.33
Germany	79.4	1.36
United Kingdom	79.4	1.82
Belgium	79.4	1.65
Finland	79.3	1.83

Source: United Nations (2005–2010).

In particular, all social institutions, as non-equilibrium systems, are subject to evolutionary pressures. This concept is very different from the general equilibrium theory, in which wealthy countries are called developed countries and poor countries are called developing countries. These terminologies imply that wealthy countries will stay wealthy over the long term and poor countries will be developing into wealthy countries if proper policies are implemented. From the established theories, it is difficult to conceive, let alone predict, that serious disruptions of economic activities, such as the current Great Recession, could happen in "developed" countries.

This theory emphasizes that wealthy countries require more resources to sustain themselves than poor countries. It is of course understandable that countries seek to protect their access to resources with military power, long-term contracts, and research, but there is no guarantee that these strategies will work. Assuming that they are not to be rescued by new discoveries or technological change, an increasing scarcity and cost of resources will make large and wealthy countries — and integrated regions — less able to sustain their current institutional structures. It is perhaps not accidental that there is an ongoing trend in the world toward smaller political units, as seen with the break-up of the USSR and Yugoslavia, the velvet divorce in Czechoslovakia and the current pressures on the Eurozone. Breaking up a political unit often has the effect of destroying many high-fixed-cost elements in the system, which reduces living standards and life expectancy in the short run but ultimately may restore profitability.

Our theory suggests that measures to reduce fixed costs, especially waste in both production and consumption and thus the resource requirements of the existing systems, are an important step if one wishes to preserve the prospect for modest profitability in the future. But it also suggests that economic agents will need to adjust to a permanently lower rate of achievable profits, since the high returns available under regimes of high fixed costs and abundant resources cannot be replicated as resources become scarce and expensive.

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