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Institutional Structures and Policies in an Environment of Increasingly Scarce and Expensive Resources: A Fixed Cost Perspective

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Abstract: In this paper, we provide a model that permits systematic and even quantitative assessment of the policy implications of increasingly scarce and expensive resources. Specifically, we model the return to investment as a function of fixed cost, discount rate, uncertainty, project duration and the volume of output. Institutions can be understood as the accumulation of past fixed investments, which lower the variable cost of economic activities but constrain choices open to future policymakers. How much to invest in fixed assets and how institutions respond to a changing environment are the key questions as the cost of nonrenewable resources rises.

Keywords: fixed cost, institutional structures, resources

JEL Classification Codes: B41, E11, Q01

During the last several centuries, fueled by abundant non-renewable resources, the global economy has been expanding more or less uninterruptedly. Robust economic activities have consumed large amounts of low-cost non-renewable resources and the average production costs of resources are increasing steadily. This may end the long term upward trend of real economic output soon. Conventional economic theories, as adaptive products in a rising economy, assume perpetual economic growth, with only occasional economic downturns, which are due to policy failures. They cannot provide much insight into appropriate institutional and policy responses for economic and social decline based on resource depletion.

An analytical theory has been developed that we believe fits the task (Chen 2005; Chen and Galbraith 2009). The main element is a model of return to investment as a function of fixed cost, discount rate, uncertainty, project duration and

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the volume of output. Institutions can be understood as the accumulation of past fixed investments, which lower the variable cost in economic and social activities and constrain the options of future policies. How much to invest in fixed assets and how institutions respond to a changing environment are the key questions for social institutions. In this paper, we will provide a quantitative and systematic assessment of the policy implications in an environment of increasingly scarce and expensive resources.

Intuitively, when the low cost resources are abundant, increases in the scale of economic activity will generate mild increases in the marginal cost of resources. As a result, economic activities can expand substantially. In general, higher fixed cost systems have lower variable costs and hence have more significant scale economies than lower fixed cost systems. When the size of the economy is large and increasing, higher fixed cost systems provide higher rates of return. In the last several centuries, fixed costs in personal investment, such as in education, and in institutional structures have been increasing over time. This requires increasing amounts of resource consumption.

Among nonrenewable resources, high quality, low-cost nonrenewable resources are extracted and consumed earlier than low quality, high-cost nonrenewable resources. For example, petroleum has a higher hydrogen content and higher energy density than coal. Therefore, petroleum becomes the energy of choice in the transportation industry, which causes petroleum to be depleted faster than coal. Conventional oil is cheaper to extract and is of higher quality than oil sands. Thus, conventional oil has been extracted for many years while oil sand has been only recently produced on a large scale. After many years of global mining activities, high quality mines, which have low production costs and usually are extracted first, have been seriously depleted. To compensate for the declining output of low-cost resources, high-cost sources, such as oil sands, have been developed on a large scale.

When low cost resources become less abundant, increasing economic scale will generate a steeper increase in the marginal cost of resources. This will reduce the return from economic activity in general and limit its scale. With a lower level of marginal return and a smaller scale of economic activity, the level of fixed cost that is optimal for social institutions is also reduced. However, the reduction of fixed cost, with the corresponding increase of variable cost, will make our daily life less convenient. For example, choosing a bus over a car will reduce fixed costs (the cost of buying a car is saved) and reduce resource consumption, but riding a bus is less convenient than driving a car. Hence it is often difficult, and unpopular, to adopt policies that will reduce the fixed costs of a society, and in general such policies will not be adopted. Therefore, high fixed-cost societies are prone to collapse, while low-fixed-cost societies tend to be resilient.

The social system, as part of the biological system, evolves through adaptation as well as selection. For most of the past several centuries, because of the abundance of low cost resources and the technologies that are developed to utilize them, the main trend in human population dynamics has been the expansion of the high fixed cost groups who are more apt at utilizing a large amount of resources, compared to low fixed cost groups who are less apt at utilizing a large amount of resources. However, the increase in the production cost of non-renewable natural resources, together with the increase of living standards, which increases the cost of human reproduction, gradually alters the competitive balance between high resource users and low resource users.

Thus, the population dynamics of high resource users and low resource users have reversed since World War II. The fertility rates for most low resource users are still at or above replacement rate. However, the fertility rates in most wealthy countries have dropped below replacement rate. This signals that the cost of raising and especially of educating children to function in a high-fixed-cost society has become so high (and the risk of losing them in childhood so low) that many families and many unattached individuals no longer feel it is worthwhile to reproduce. So the high fixed cost social systems face a choice between immigration or extinction, which they resolve (if at all) by admitting the best-prepared young people from low-cost systems. In this respect, high-resource-using human societies are different from large mammals, who also have high resource use and reproduction costs, but no possibility of accepting immigrants from other species. Unfortunately immigration does not solve the sustainability problem as resource costs continue to rise.

While formal government agencies and conventional economic theories rarely discuss the scenario of long term economic decline, many local communities and individuals have adopted strategies to reduce resource consumption. For example, many communities have relaxed zoning restrictions to allow the mixing of residential and commercial areas so the cost of commuting from home to office can be reduced. Our work simply provides a formal analysis of such strategies.

An Analytical Theory of Production

Many factors affect the performance of social and biological systems. These factors may include fixed cost, variable cost, discount rate, uncertainty, project duration and the volume of output. In this section we will present an analytical theory of the relation between these factors, and apply the theory to the performance of social and biological systems with different levels of resource abundance.

Let K represent fixed cost and C represent variable cost, which is a function of S, the value of the commodity. Assume the discount rate is r, the duration of a project is T, and the level of uncertainty or diffusion is σ. The variable cost, C, can be represented by the following function

$$C = SN(d_1) - Ke^{-rT}N(d_2) \qquad (1)$$

where

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

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

The function *N(x)* is the cumulative probability distribution function for a standardized normal random variable. Formula (1) takes the same form as the well-known Black and Scholes (1973) formula for European call options. Formal derivation and detailed discussion of this result can be found at Chen (2005) and Chen and Galbraith (2009).

Formula (1) provides an analytical formula for variable cost as a function of product value, fixed cost, uncertainty, duration of project and the discount rate of the firm. Suppose the volume of output during the project life is Q, which is bounded by production capacity or market size. We assume the present value of the product per unit to be S and the unit variable cost to be C during the project's life. Then the total present value of the product and the total cost of production are

$$SQ \text{ and } CQ + K \tag{2}$$

respectively. The return of this project can be represented by

$$\ln\left(\frac{SQ}{CQ + K}\right) \tag{3}$$

and the net present value of the project is

$$QS - (QC + K) = Q(S - C) - K \tag{4}$$

Unlike a conceptual framework, this mathematical theory enables us to make actual calculations of the returns of different projects under different environments.

In the following, we will apply the analytical theory to understand how the cost of processing natural resources affects the structure and size of economic systems. We will model the increase of processing costs for natural resources through the increase of the diffusion rate. From (1), when the diffusion rate is higher, the variable cost becomes higher. Intuitively, higher diffusion rates mean more effort is needed to process the same amount of resources. Specifically, the level of diffusion will be modelled as:

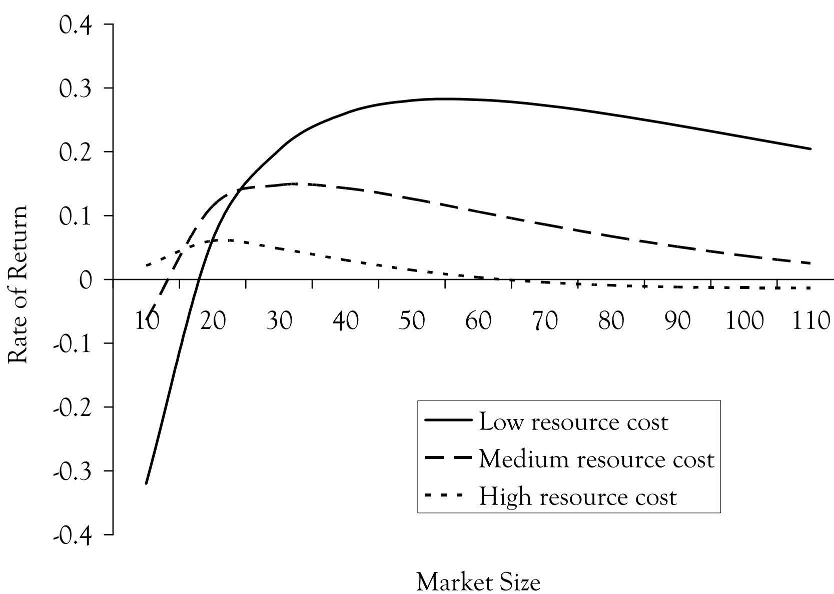
$$\sigma = \sigma_0 + lQ$$

where σ_0 is the base level of diffusion, which corresponds to the lowest cost of resource processing, Q is the total output of resources and $l > 0$ is a coefficient. The size of l represents the abundance of low cost resources. When a low-cost resource is abundant, an increase of resource output will not increase processing costs substantially and l is small. When the low-cost resource is scarce, an increase of resource output will require the production of high-cost resources, which increases the processing cost substantially and l is large.

We will examine how changes in resource abundance affect the structure of and return on economic activity. For simplicity, we will set S =1, r = 0.1, T =15 and σ_0 = 0.4. We will let l take the values of 0.0025, 0.005 and 0.01 to represent different levels of resource abundance. By maximizing formula (3) with respect to the fixed cost and volume of output at different values of l, we obtain the highest possible rate of return from investment projects in different environments. When l = 0.0025, projects obtain the highest possible rate of return of 28% when the fixed cost is 9.5 and market size is 56. When l = 0.005, projects obtain the highest possible rate of return of 15% when fixed cost is 4.5 and market size is 33. When l = 0.01, projects obtain highest possible rate of return of 6% when the fixed cost is 1.7 and market size is 20. Figure 1 displays the rates of return with respect to different sizes of output by three different projects with different fixed costs corresponding to different levels of resource abundance.

From the above calculation, when resources are abundant and cheap, there is an economic incentive to increase fixed cost and market size to fulfil the possibility of a high rate of return. As a result, the rate of resource consumption is high. When the low-cost resources are gradually depleted, the return from the same high fixed cost system will decline gradually. To understand the precise relation between resource abundance, economic structure and rate of return, we will calculate the rates of return

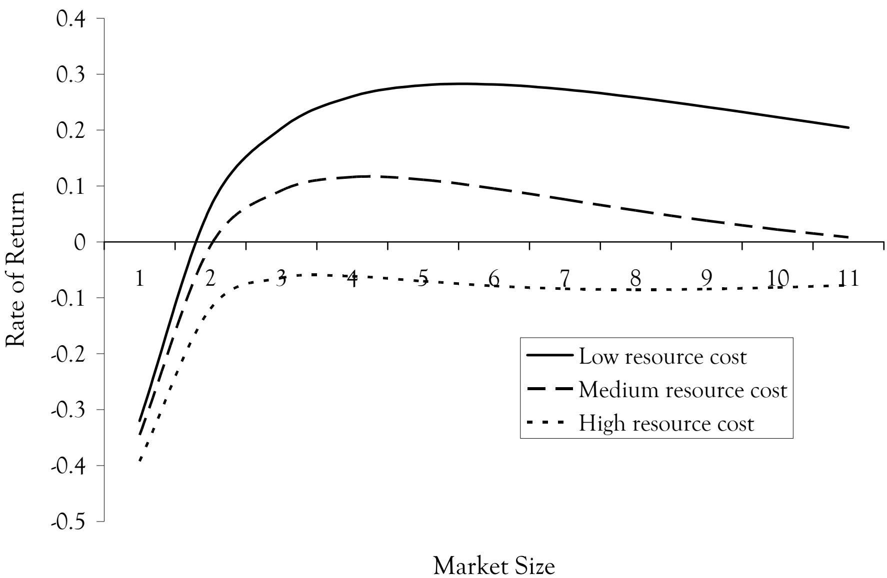
Figure 1. Resource Abundance, Fixed Cost, Market Size and Rates of Returns



for the same high fixed cost system, which provides the highest possible rate of return, at l = 0.0025, when l = 0.005 and 0.01. Figure 2 displays the rates of return with respect to different output scales by the same high fixed-cost production system, at different levels of resource abundance. Compared with Figure 1, when the cost of resource production is moderately higher, represented by l = 0.005, the difference of return between the existing high fixed-cost production system and the potential optimal production system is not large. Furthermore, developing new projects with different levels of fixed cost may require new skills and equipment. Therefore, the incentive to change is small. But when low-cost resources are further depleted, represented by l = 0.01, rates of returns of the high fixed cost production system turn negative at all levels of output, as shown in Figure 2. Reduction of fixed cost and output size are then required to restore economic activities to positive returns.

Since it takes a long time and great effort to adjust institutional structures, it will be very helpful to estimate the state of resource abundance today and in the near future. We can proceed from two directions. The first is to estimate the cost of resource production directly. In a now classic paper titled "The End of Cheap Oil," Campbell and Laherrere (1998), after carefully examining the data on oil exploration and production, concluded "[w]hat our society does face, and soon, is the end of the abundant and cheap oil on which all industrial nations depend." This seems straightforward enough.

Figure 2. Resource Abundance and Rates of Returns



The second approach is to measure fertility, which can be said to approximate the return on human investment in a low mortality environment. Since we are a human society, the return on human investment is the ultimate measure of a society's success and sustainability. Furthermore, a change of demographics often precedes a change of economic activities. In most wealthy countries, which have high resource consumption rates, as well as in some poor countries, the fertility rates have dropped below the replacement rate for several decades. This means that their returns on human investment have already turned negative for a prolonged period of time. However, there is a time lag between the drop in fertility rate below the replacement level and a drop in economic output. The initial drop in fertility rate reduces the number of dependent children. Many more adults become available as workers. As a result, countries in demographic transition often enjoy a high rate of growth in economic output (Arnott and Casscells 2003), and as noted above, this can be prolonged even more through immigration of workers educated elsewhere. Since most economic observers traditionally focus on economic output alone, information implicit in the demographic transition is commonly ignored.

Concluding Remarks

With the help of an analytical theory, we show that with the rising physical cost of extracting nonrenewable resources, a lower fixed-cost economy will become more stable and sustainable; and there is the possibility of a historical reversal in the positions of today's rich and poor economies. It would not be the first time: civilizations have collapsed for apparently similar reasons since at least the days of the Maya. The most spectacular modern example is the collapse of the Soviet Union, which was a major industrial power, characterized by very high fixed costs, until shortly before it fell apart. The fate of the USSR has been largely subsumed into a narrative about the rejection of ideological communism, but this does not correspond to the facts. Ideological communism had been a dead letter for a long time; it was the industrial system and not the ideology of the USSR that collapsed.

The major policy implications of this paper concern the prevention of system-threatening crises. By lowering fixed costs in a social system, it is easier for economic activities to remain profitable in a broader range of environmental conditions, although it is more difficult for low fixed cost systems to earn high rates of return. For this reason, large institutions (such as the major American banks) that can both dominate a financial system and insist on high rates of return are especially dangerous. Such rates of return may be achievable in low-resource-cost economies, but they are unsustainable as resource costs rise, and the effort to sustain them may accelerate the destruction of capital resources and subsequent system collapse. Other resource-intensive high-fixed-cost systems, such as the global air traffic system, and the global automotive industry, are similarly fragile and unlikely to survive the shock of permanently higher resource costs. This problem is already visible in high rates of bankruptcy among airlines and auto companies. On the other hand, there may be some comprehensive social systems (such as Social Security) which are favored in low-fixed-cost environments, since they are inexpensive to administer, and place resources in decentralized hands (individuals and families). Resources distributed this way may be more likely to support decentralized, smaller-scale, and less resource-intensive economic activity.

Our approach would also appear to contradict the key lessons of the American New Deal and the prescriptions of John Maynard Keynes, but Keynes was prescribing for an economy in a youthful growing stage. After listing many sound economic indicators despite the persistent high unemployment figures, he declared:

> We are suffering from the growing pains of youth, not from the rheumatics of old age. We are failing to make full use of our opportunities, failing to find an outlet for the great increase in our productive powers and our productive energy. Therefore we must not draw in our horns; we must push them out. Activity and boldness and enterprise, both individually and nationally, must be the cure. (Keynes 1932, 156)

Keynes was right in his time. The 1930s saw the largest discovery of oil reserves in world history (Deffeyes 2001). The transformation from a coal-based economy, centered on railways, to an oil-based economy, centered on cars, was partly responsible for the Great Depression, as the railroad economy fell apart before the car economy grew enough to take its place. Yet the abundance of oil also set the stage of economic boom in the 1950s and beyond, and by the 1960s the country was embedding the auto industry into a fixed-cost infrastructure (interstate highways) that dominates our transportation infrastructure to this day. Nevertheless, it is vulnerable, of course, to any significant disruption of oil supply.

Today, fertility rates have dropped below the replacement rate and the average ages have been rising steadily for several decades in most wealthy countries. It is difficult to argue that we are suffering from the growing pains of youth. We are certainly not at a time of rapidly falling energy costs; quite the contrary. Therefore we have to take a different approach.

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