Long-term population, productivity, and energy use trends in the sequence of leading capitalist nations

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Long-term Population, Productivity, and Energy Use Trends in the Sequence of Leading Capitalist Nations

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Abstract

There are many theories on why sustainable science, technology, and commerce emerged first in Western Europe rather than elsewhere. A general theory is that the geography of Europe facilitated the development of and diverse and independent states and resultant competition among them. Over the past 500 years, the sequence of leading states began with Portugal and the Netherlands on the edge of continental Western Europe, then moved to the British Isles, and finally moved across the Atlantic Ocean to the United States. The transitions of leadership from one state to another occurred about every 100 years. This sequence suggests that leadership moves from smaller states to larger states (although not to the largest existing state at the time), perhaps because larger states have the flexibility to develop more complex organizational processes and adapt new technology. To explore this theory further, this paper analyzes state population data at the beginning and end of each leadership period. The data reveal an accelerating initial population sequence. Further understanding is gained from comparing the populations of the preceding and succeeding states at the time of each transition: The succeeding state's population is usually about two times larger than that of the preceding state.

It is also seen that over time, the new organizational processes and technologies developed by the leading state are diffused and adapted by other states. Evidence of the effects of this diffusion should be seen in the dynamics of relative productivity and energy use (since the relative advantage of new ideas and technology can be maintained for a short period of about 100 years). This paper investigates these trends in population, trade, and resources to provide insight on possible future transitions.

Keywords: scaling, population, productivity, energy, leadership transition

Introduction

There are many theories on why sustainable science, technology, and commerce emerged first in Western Europe. Stravrianos (1976, page 91) suggested factors related to internal weaknesses and fractiousness, which allowed innovations in trade, commerce, and finance to flourish instead of being curtailed by a conservative but unified centralized empire, such as that found in China at the time.

> "The central fact of modern world history is that capitalism emerged first in Western Europe, which explains that region's rise from obscurity to global

> hegemony. Western Europe's pioneering role is taken for granted today. Yet how surprising that role actually was, given the fact that Western Europe had been the most backward area in all of Eurasia during the so-called 'Dark Ages' following the Fall of Rome. Only now can we see how that retardation later made it possible for Europe to take the lead in social and technological innovation.... The Fall of Rome was not a unique event in the annals of world history. Similar 'falls' had occurred repeatedly across the globe. What made the case of Western Europe unique was that a new imperial 'rise' did not follow the 'fall.'... In Europe, however, repeated attempts at an imperial restoration failed, partly from certain internal weaknesses specific to the area, and partly from the chaos and destruction caused by a ceaseless succession of nomadic invasions.... The repeated demolition of embryonic succession empires in the West cleared the ground for something new to take root. A new Western civilization gradually took shape in which several potentially competing institutions … replaced the monolithic imperial structure that had been so inhospitable to technological progress."

The organization of this study includes a brief summary of both the geographic factors in Europe and the sequence of leading states. Leadership is identified on the basis of economic, political, and military innovations and power. It is not the intent of this paper to further develop theories about these factors but instead to investigate aggregate characteristics (i.e., population, productivity, and energy use) that might influence leadership transitions and the diffusion of innovations. The sequence of leading states suggests that there are periodic transitions of leadership from smaller to larger states (although not to the largest existing state at the time), perhaps partly because the larger states' resources, economies of scale, and flexibility helps them to develop more complex organizational processes and adapt new technologies and energy sources. These trends in population, trade, and resources are investigated to gain insight into possible future transitions (e.g., states that are potential candidates for future transitions, along with the relative rate of diffusion of the innovations).

As Stavrianos (1976) points out in the quote, there was a lengthy process of slow development in Western Europe after the collapse of the Roman Empire. Ideas and innovations from one area were introduced to other areas through trade, crusades, invasions, and plagues. In Western Europe, these ideas and innovations were further developed and integrated to form labor-saving devices (Bernstein 2004). The loss of Constantinople in 1453 motivated countries such as Portugal to explore and find alternative routes to the profitable Eastern spice routes. The Dutch, having inherited much of the capital and banking activity after the decline of Antwerp and Italy during the 80 Years War, were able to develop financial tools to support capital investments in ships for profitable sea and river trade, especially trade in two bulk goods: timber and herring (Bunker and Ciccantell 2005). The Dutch also wrested control of some of the Portuguese Eastern colonies. This combination of innovations (in shipping, commerce, and capital) led to almost a century of leadership by the Netherlands during its Golden Age (about 1585–1685) (Schama 1987).

Some factors such as religion (Stark 2005), language, and specific technological inventions have been indentified as potential contributors to the emergence of the modern era in Europe (Mokyr 2002). The factor of geography, however, offers a high-level explanation that is not associated with any bias or value judgment. A recent hypothesis (Diamond 2005) suggests that in Europe, especially in locations where the terrain includes mountains, peninsulas, islands, or water bodies, the geographic factor has been an important contributor to the division of power, leading to the relative independence of the decisions made by states. This situation is unlike what occurred in (Ming) China, which was able to halt the exploration mission of Cheng He in 1433 because there was no option for him to find alternative support. Further analysis that supports the geographic factor concerns the characterization of coastlines by a fractal dimension (Cosandey 1997). The fractal dimension indicates how the coastline length changes when measured with different length rulers. For a smooth coastline, the fractal dimension would be around one; however, for a coastline with many peninsulas, islands, and bays, the fractal dimension would be larger but not quite two dimensional. Western Europe has a larger fractal dimension from its indented coastline than does the Indian Subcontinent, China, or either of the Americas.

Kennedy (1987) suggested that there was a sequence of countries with great power in the West that started with the Dutch and was followed by England and the United States. These countries' leadership roles were based on organizational and technological innovations that advanced capitalist societies. To explore systemic transitions on a quantitative scale, the relative naval power in the Western European states was studied in Modelski (1987) and Modelski and Thompson (1996). They found periodic cycles of sea dominance that moved from Portugal, to Holland, to England, and then to the United States. This sequence of naval power transitions indicates the transitions were associated with the protection of major trade that fueled each successive country's economic development. This European leadership is a part of a wider economic trend that had begun in Sung China by the year 1000 AD (Modelski and Thompson 1996). The move to Europe began when first Genoa and then Venice led with their development of banking and insurance. Portugal's subsequent role with regard to innovations in commerce, trade, and political organization is described in Devezas and Modelski (2006). However, the analysis presented here focuses on sustained capital formation as detailed in Bunker and Ciccantell (2005), which requires the basis of trade to be the more mundane bulk goods (e.g., herring and wood) rather than the mostly luxury goods of the Portuguese.

There has been much discussion about future transitions of power and leadership (Zakaria 2008). Various nations and alliances, such as China and the European Union, continue to evolve. Some have argued that the era of nation-state dominance is ending, as posited in Van Creveld's (1996) "The Fate of the State":

> "The State, which during the three and a half centuries since the Treaty of Westphalia (1648) has been the most important and the most characteristic of all modern institutions, appears to be declining or dying. In many places, existing states are either combining into larger communities or falling apart; in many places, organizations that are not states are challenging them by means fair or foul. On the

> international level, we seem to be moving…towards…more complex political structures.… These developments are likely to lead to upheavals as profound as those that took humanity out of the middle ages and into the modern world. Whether the direction of change is desirable, as some hope, or undesirable, as others fear, remains to be seen."

At a recent systemic transitions conference (Thompson 2008), discussions included analyses of leadership characteristics in areas such as military power, technological innovation, and trade. However, the conditions that drove the diffusion, transfer, and development of technological and organizational innovations along this sequence from smaller, earlier states to larger, later states were not addressed. Some basic characteristics might suggest necessary, but not sufficient, conditions for the leadership dynamics to emerge and for the innovations to diffuse. For example, why did political and commercial (i.e., technological) innovations first become integrated in the small state of the Netherlands rather than the larger country of France? Why did the sequence of states seem to move to larger and larger countries, such as occurred during the first transition from the Netherlands to England (Jardine 2008)? How did England regain its leadership after its first leadership phase ended (Simms 2008)? If a pattern is identified, it could perhaps be used to predict candidates for the next transition.

Each state that was part of the sequence developed a system for international trade, whether it was colonial, imperial, or global. Areas peripheral to the leading states provided relatively inexpensive labor and natural resources for development, while the leading countries were technologically and organizationally innovative. However, the innovations tended to diffuse to the peripheral states, which then developed and possibly became leaders themselves (as in the case of the United States and England); this sequence of events led to a need to continually find new sources of labor and resources. This scenario suggests that there are two competing processes that determine the distribution of relative productivity: (1) leading countries that embrace innovations and have capital have a relative advantage, and (2) there is a tendency for the distribution to flatten through diffusion of the innovation. A major question is whether the relative advantage is increasing faster than the diffusion. If it is, the result will be even greater inequalities. If diffusion is faster, the result will be a "flattened world" (Friedman 2008).

The problem of how a new technology diffuses through a larger group is a field of interest. In some cases, the new technology, whether hardware or organizational, begins in small groups and diffuses to larger groups. As the innovation is used in the larger organization, scaling barriers to coordination and communication might occur. An example of this scaling process occurs when state-level policy is adopted and adapted on a national scale.

Trends in Population, Productivity, and Resource Use

The remaining sections of this paper examine the simple characteristics of population, relative productivity, and resource use within the nations that formed the sequence of leading capitalist countries. The population influences both the scale and complexity of the state organization. For example, a larger population produces more only if it is efficiently organized. Therefore, the historical sequence of leading nations does not start with most populous nation but instead with a limited population where new organizational structures could be explored. The diffusion of technological and social ideas from these leading countries might be demonstrated by their relative productivity and resource use. The trends are then analyzed with regard to how they might indicate potential future directions and factors.

Population

Perhaps the size of the population size (and not, for example, the size of the physical land area) is a major factor that influences the transfer of leadership. If there are too few people in a country, the development of new institutions and complex organizations might be difficult. If there are too many people, however, the scale of the previous organizational structure may make it difficult to transfer new innovations, and it might also be difficult for them to evolve.

A population trend among the leading nations was investigated by Modelski (1987). While the absolute population at the beginning of a country's leadership period increased at an accelerating pace from 1.25 million in Portugal in 1500 to 100 million in the United States in 1914, the percentage of the world population that this number represented increased in discrete steps — from 0.3% for the cases of Portugal and the Netherlands, 1.5% for Britain I and II, and 5.4% for the United States. The percentages seemed to increase by a factor of about 4 to 5 between pairs in this two-step cycle. This cycle might rely on the first nation leading innovation and then the second maturing and optimizing the process. However, it is not clear why the relative global population would be an indicator of a country's ability to organize and scale its innovations and internal capital formation. To further explore this issue, the population growth of leading nations can be separated into growth within a leadership period and quantum jumps during a transition between countries.

At the beginning of the leadership sequence, there was a wide range of population sizes in the countries of Western Europe. Such a wide range meant that there were states that were the right size to test various organizational forms and assume a leadership role. While it is difficult to collect data on the population distribution in Western Europe throughout the 500-year period, perhaps the current population distribution might indicate some remnants of the original fracturedness. In the early part of the period, nation states were just beginning to form, and they continued to coalesce until the middle of the 19th century in Germany and Italy. The cumulative distribution of national population sizes (Figure 1), however, indicates that there were two groups of states: (1) smaller states that never integrated with larger states and (2) states that formed from aggregations. The Netherlands was the largest of the small states; it remained independent after a succession of attempts was made to integrate it into the larger states of Spain, France, and Germany. The five larger states were Germany, the United Kingdom, France, Italy, and Spain. Of these five, only Spain and France were close to the shape and size they are today at the beginning of the period. Thus it appears there has been a wide distribution of populations among the Western European nations.

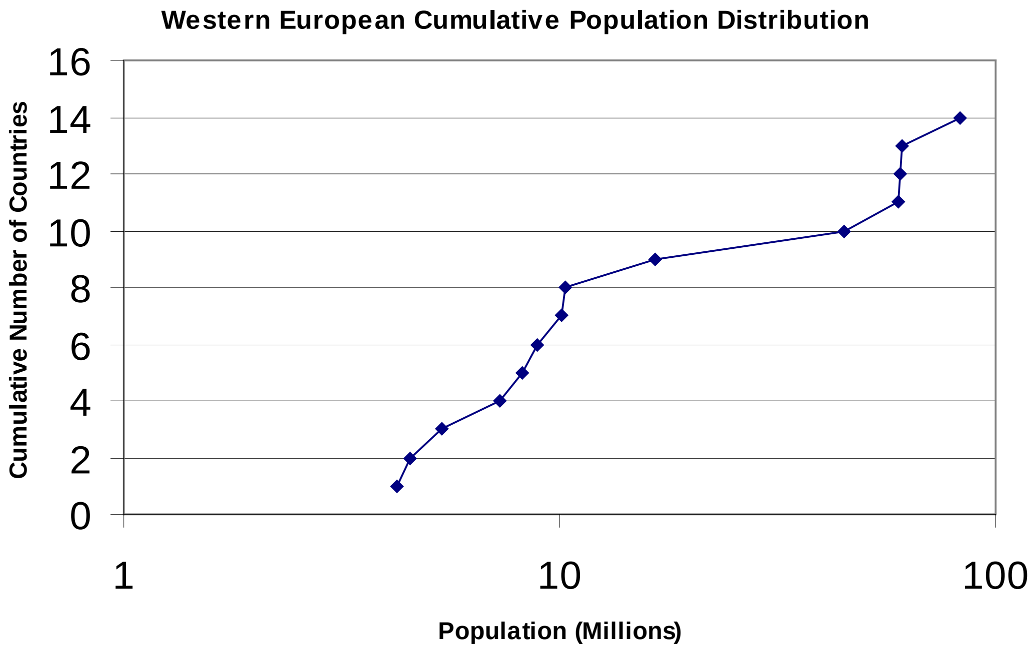

Figure 1: Cumulative distribution of the national populations in Western Europe in 2002. The wide gap between nations with populations between about 10 and 80 million might be due to the aggregation dynamics during the formation of modern Europe.

The sequences of the estimated population sizes of the leading nations near both the beginning and end of their leadership phases as identified by Thompson (2008) were collected (see Figure 2 and Table 1). Uncertainties in these data were introduced as a result of indirect estimation methods and changing boundaries. Included in the second consecutive phase of English leadership are Ireland and Scotland, which contributed many innovations; these countries were added to England/Wales to form the United Kingdom.

The sequential ratios of the populations at the beginning of the leadership phase seem to follow a trend, such that the population of the nth new phase is n times the population of preceding state. This would mean that the initial population size grows as n!, starting with the initial population of approximately 1 million in the early state of Portugal.

However, including both the population at the beginning of the phase and that at the end of the phase suggests a slightly different interpretation. Except for the first transition (between Portugal and the Netherlands), the beginning population of the new leader is about two to three times more than that of the previous leader (Figure 2). This fact can be reconciled with the previous analysis showing factorial (n!) dependence being due to the rise in the internal population growth rate during the leadership duration. This result suggests that the diffusion of leadership characteristics continues in phases to countries about twice as large as those that led in the preceding phase.

This insight into transition characteristics might help identify other possible contenders that had populations large enough to accept leadership roles at the transition times. The populations of competing states (identified by Kennedy 1987) are shown in Table 1. In early transitions, the populations of the competing states were much larger than the population of the leading state. Only in the last transition to the United States were the populations of the competing countries smaller.

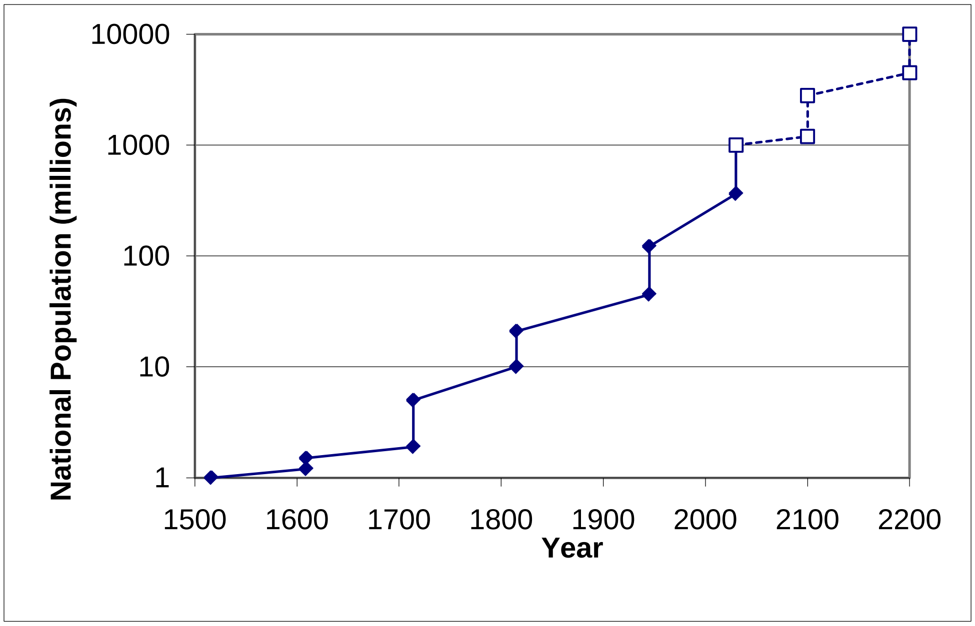

Figure 2: Growth of population in the sequence of leading countries, starting with Portugal in the 16th century, followed by the Netherlands, England, the United Kingdom, and the United States. Future population projections (see "Future" section) show high income OECD countries estimates and global estimates.

Leadership Period	Leading Country	Population Size (million)		Competing Countries	Ratio of Populations	
		Beginning of Period	End of Period		Beginning of Period	Transition Time
1516–1609	Portugal	1.37	2	Spain(7), China (103)		
1609–1714	Netherlands	1.55	2	France (20), England/Wales (4.4)	1.13	0.75
1714–1815	England and Wales	5.78	10	France (21)	3.7	2.9
1815–1945	United Kingdom	20	52	France (30), Germany (21), Russia (45)	3.4	2.0
1945(–2030)	United States	140	364	Germany (65), Japan (73), USSR (140)	7	2.7

Data sources: McEvedy and Jones (1978) (The projected United States 2030 population is from the U.S. Census Bureau Population Projection based on the 2000 Census.);

Table 1: Population of leading and contending countries during various leadership periods from 1516 to the present. The leadership periods correspond to the global war periods identified in Modelski (1987). The ratio of populations is the population of the new leader divided by the population of the previous leader. This ratio is studied by using two different population evaluations. The column labeled "Beginning of Period" compares the countries' populations at the beginning of their respective leadership periods. For example, the population in England and Wales in 1714 divided by the population in the Netherlands in 1609 = 5.78/1.55 = 3.7. The column labeled "Transition Time" compares the countries' populations in the year of transition. For example, the population in England and Wales in 1714 divided by the population in the Netherlands in 1714 = 5.78/2 = 2.9.

Relative Productivity

The leading countries developed innovations in international trade. Innovations associated with the five leadership periods include (1) government support by Portugal, (2) capital stock market by the Dutch, (3) colonial mercantilization by the English, (4) industrial organization and infrastructure by the United Kingdom, and (5) application of science and technology by corporations in the United States (Bunker and Ciccantell 2005). These innovations led to relative competitive advantages. Other countries were able to adopt and adapt these practices, which led to a gradual loss in the leading country's competitive advantage. Eventually another state took leadership with a new organization or institution to establish a competitive advantage.

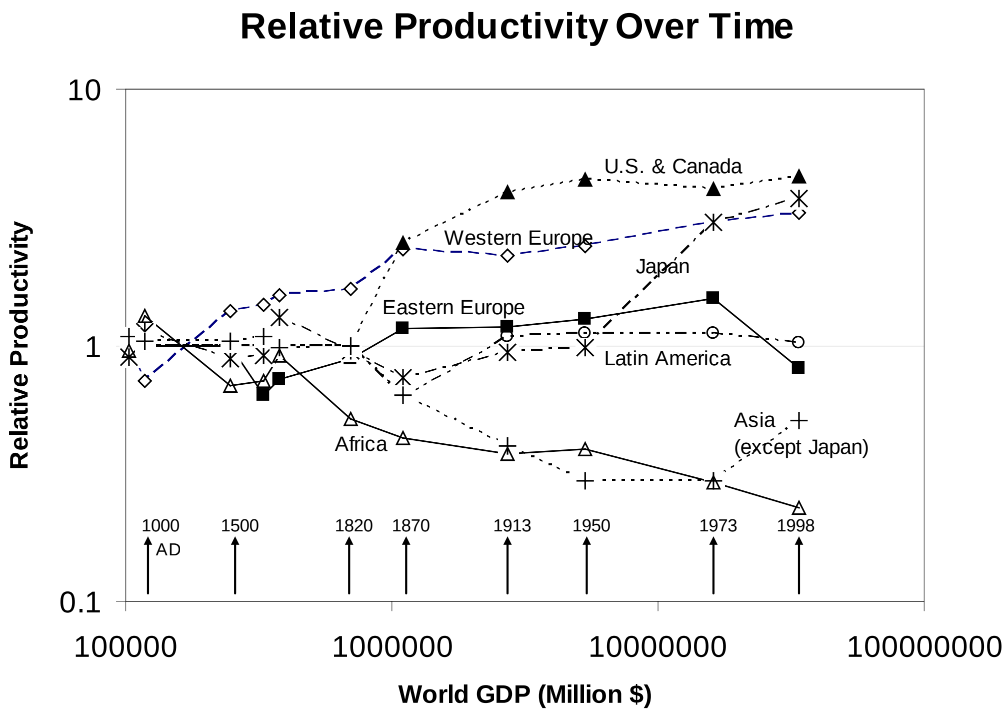

Figure 3: Relative productivity of large regions. The x axis is the annual level of GDP in millions of dollars. Some time markers indicate the year that these markers were achieved. Data are from Maddison (2007).

To test the relative speed of intensification and diffusion, the relative productivity (defined as the ratio of gross domestic product [GDP] per capita of a region to the global average) is explored in Figure 3. The relative productivity is plotted as a function of GDP (with a log-scale) instead of as a function of time. If the GDP grew exponentially at a constant rate, the x scale would be proportional to the time difference. Since the GDP grew slower at earlier times, this graph emphasizes the more recent, quicker, and more dynamic global economy. As expected, before the modern era, the relative productivity was initially quite uniform. (In 1500, the GDP was about $250 billion.) Then it diverged, with Western Europe's productivity increasing, followed by that of its Western colonial offspring (United States, Canada, and Australia), and then by that of Japan (in the 1970s). The relative productivity of Asia (except for Japan) and Africa decreased. The productivity of the two remaining areas (Latin America and Eastern Europe) hovered around the average relative productivity. Recent dynamics reveal a sharp rise in non-Japanese Asian productivity, although it is still below the average. If innovations were to diffuse around the world faster than the rate at which current leaders could generate any additional competitive advantage, the expectation would be that the relative productivity would converge again. However, current data show that the increasing competitive advantage is still growing. It is possible that with rapid change and growth in China, India, Russia, and Brazil, this trend might soon reverse.

Energy Resource Use

It is suggested that periodic waves of technological innovations might be linked with the waves of national leadership (Dent 2005). The energy transitions seem to qualitatively correlate with recent leadership transitions (LePoire 2009). A look back shows that the Dutch added peat to the mix of wood and wind, and the British led the Industrial Revolution first by using wood and then by switching to coal, which was used as a substitute energy source as forests were depleted. The coal mines spurred on the positive feedback cycle of technology development by driving the production of iron, engines, and further coal use. The British period of world leadership saw the expanse of railroads and deployment of English capital throughout the British Empire, which was powered primarily by coal. However, leadership transitioned to the United States during the first half of the 20th century, which was powered first by oil developed in Pennsylvania and later by oil discovered in large deposits in Texas and elsewhere. When the supply of domestic U.S. oil became insufficient to supply the county's continued growth, the nation depended on large reservoirs found in other locations, including the Middle East. The energy crises of the 1970s — first in 1973 during the OPEC (Organization of Petroleum Exporting Countries) oil embargo and later in that decade as the relationship between the United States and Iran deteriorated — led to price increases. These in turn encouraged investments in energy efficiency. This energy efficiency wave is seen to be only partially complete, with its peak being projected to occur somewhere around 2025 (Figure 4; LePoire 2004). The developed countries seem to be leading in the energy efficiency effort, motivated by the reduced importance of energy prices in determining economic activity.

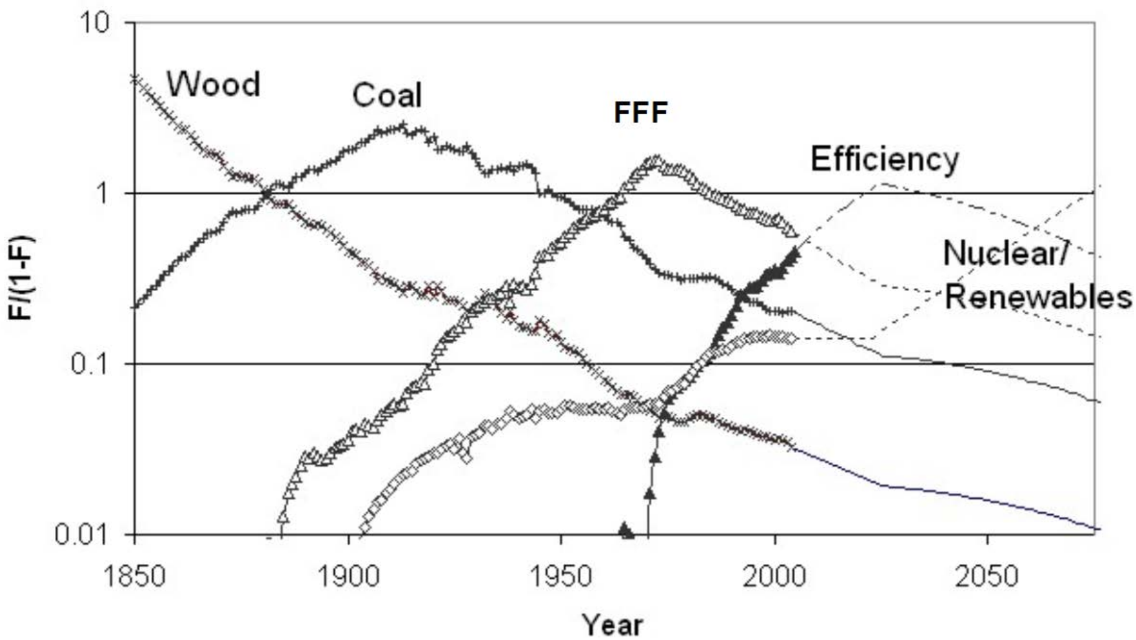

Figure 4: Historical energy trends after energy efficiency, as measured by energy intensity for the world, is accounted for. Original source of work is Marchetti (1977); updated source is LePoire (2004).

While patterns in per-capita energy use are illuminating, the energy use transitions may not follow the national leadership transitions. The replacement of human power (relied upon in Roman times) with natural renewables such as wood, wind, peat, and animal power occurred throughout the Middle Ages (Gimpel 1976), in which there were many leadership transitions (e.g., feudal medieval states, southern and northern Renaissance city-states). In the middle of this period, the Dutch used an estimated 500 watts of energy per person (Van der Woude 2003). In the Industrial Revolution, the sequence of industrial stages seems to be the application of agricultural innovations in England starting in the early 18th century, followed by textile industrialization, then steel, and finally mass production. The dominant energy source in the middle of this period was coal; the intensity of coal use in 1890 was about 20% higher than it was in 1860. The current period might be called the information age, where the predominant types of energy used are the fluid fossil fuels (FFFs) of oil and natural gas. Current per-capita FFF energy use in the United States is estimated to be similar it was in 1980, if the efficiency factor is not accounted for (LePoire 2004; Devezas et al. 2008).

Future

While there are many factors to consider when analyzing the continuing development of the global system (e.g., trends in open democratic societies; continual changes in military technology, power, and tactics; and the governments' capacity to address global issues), this paper focuses on trends in three aggregate measures — population size, relative productivity, and energy (i.e., resource) use — in order to obtain insight on potential future transitions. For example, if the trend in the leading country's population size continues, we would expect that the next transition, which would take place in a few decades, would be led by a region with a population that would be slightly more than twice that of the U.S. population at that time (i.e., the leading region would have a population of 2.2 × 365 million, or about 800 million). Current estimates of populations at that time are 1,370 million for China and 500 million for the European Union. Alternatively, as suggested by the early Van Creveld quote, the next leader might be an organization of states. For example, the Organisation for Economic Co-operation and Development (OECD) supports discussion of sustainable growth, increased trade, and economic development. It has been a growing international forum for the sharing of experience in economic, environmental, and social issues over its 50 year history. The collection of 27 high income countries in the OECD (as defined by the World Bank) currently has a relatively slow growing population of about 1 billion people. If the trend is extrapolated further, and if the world population stabilizes in the next century, we would expect about three more leadership transitions (in which the population in the set of leading countries would increase by a factor of about 2.2), such that the set of leading countries would encompass the world population. This scenario leads to the estimate that it would take about 300 years for the global diffusion of innovations to occur, since each leadership period would last about 100 years.

Future relative productivity data will indicate whether a country's competitive advantage from new technologies was maintained or if the diffusion of innovations tended to flatten these advantages. Today, new forms of trade and information exchange are being created with computer-based communications. These extend the historical innovations in trade, which went from mercantile systems to colonial systems and to capital systems. A current approach seems to be to develop areas that have relatively inexpensive labor resources. When the areas have been developed enough so that they have moved into the next economic phase, in which wages are higher, another area with inexpensive labor resources is identified. This process is not sustainable for two reasons. The overall prices, along with the expanding aggregate demand from the developed countries, would increase, and eventually all countries would be developed. The United States continues to be competitive in many trade areas, but its relative advantage might be diminished, as indicated by the trade imbalance in high-technology products (Nanto et al. 2008). In order for the country to maintain its relative advantage, new technologies that could transform society and possibly form the backbone of a new industrial revolution need to be developed. This effort might include the convergence and integration of information technologies, nanotechnology, biotechnology, artificial intelligence, and cognitive science, which are being researched with support from countries throughout the world (Roco and Bainbridge 2002).

Although the relative productivity graph does not indicate a convergence of relative productivity among regions, the divergence has slowed or disappeared, indicating that an inflection point might occur soon. The divergence occurred while the global GDP grew by a factor of more than a hundred. If another factor of a hundred is necessary for convergence, then convergence would take about 225 years if average growth in the global GDP was 2%, or it would take about 450 years if average growth was 1%, results that are consistent with the rate based on the population trend.

Future environmental and health risks from potential energy production and use are difficult to consistently assess and compare because of uncertainties in the technological solutions to be used, in society's reaction to them, and in the scientific understanding of their impacts (Elliott 2003). Since the 1970s, however, economic factors have been leading to more efficient energy use, while acknowledging the fact that there are many other opportunities for further conservation (Ausubel 2004). Although there are many global issues besides energy accessibility, this issue may be the key for addressing concerns related to water availability, pollution, and illness (Smalley 2003).

It was suggested in the introduction that changes in energy, information, and communication might be coupled. The identified stages in energy use and development may have corresponded to new ways of capturing and communicating information to maintain new social structures with increased complexity. The industrial age blossomed through the refinement and creation of new combinations of existing technologies (e.g., the early industrial revolution combined steam, coal production, iron, and rail). The combinations were facilitated by communication, initially through the printed media and then through telecommunications. The current period relies not only on the electronic movement of information but also on its enhancement through higher levels of data collection, organization, processing, and inference (Tainter 1996); these innovations can, for example, lead to distributed energy production and smart grid transmission.

Returning to consider the relationship between leadership and energy use: Could the recent large growth in China's economy lead to a new phase of energy use? Although such a result is possible, both the current per-capita energy use measure and the current per-GDP energy use measure in China fall far below those in the United States. (China uses about one-tenth of the energy per citizen and has about one-third of the economic output per energy unit.) While China has large hydropower and nuclear energy plans, its predominant energy source is coal, which currently supplies about 73% of its energy demand and is still expected to provide about 40–50% by 2050. However, China, Japan, and “Asian tiger” countries such as South Korea invest a large percentage of their countries’ GDP in research, including new applications of nanotechnologies. They also have a large pool of former citizens who have studied in the United States and would consider returning to their homelands. The time it would take for the world to reach a state of equal energy use can be estimated only if the relative energy growth rates of developed and developing regions are known. This knowledge requires speculation in the dynamic field of energy production and use in countries that might be able to develop in a more energy-efficient manner. Recently, energy growth rates in the developed world have been about 1%/year. If it is then assume that the developing world has an average gain of 0.5%/year relative to this use, it would take about 300 years to make up a factor of 5 at 0.5%/year.

But if the leader is not China, with its world-leading population of 1.3 billion, what other country or entity might take the lead? Another popular concept being discussed is that the world is flattening; that is, through the application of innovations in communication and transportation, effective distances are virtually shrinking. The networked economy allows finance, science, and other knowledge-based work to be performed and integrated in a virtual network across the globe. Thus, it may be that the next leadership phase or transition will not arise from any one country but by countries participating in various collections of networks of organizations. Paehlke (2004) sees the transition toward a global economy as testing the limits of the current nation-state system and democratic governments. The dilemma that nation-state democracies face is that although economic markets are globalizing, the necessary infrastructure is not in place to balance social and environmental needs (Economy 2007; Homer-Dixon 2007). Since a world government would be difficult to support, Paehlke suggests that international trade agreements include provisions for environmental and equity issues. An example of using trade to diffuse environmental concerns is the European Union’s E-waste law, which was implemented in 2005 and with which international manufacturers, such as those from China or the United States, must abide in order to market their products in Europe. This flattening scenario seems to indicate an early phase of a new pulse of environmental activity that has exhibited three logistical periods throughout the 20th century (LePoire 2006).

This flattening scenario would be consistent with the slowing rate of technological change, since the ability of a leader to maintain its relative advantage depends on whether it can generate new ideas faster than the ideas can diffuse or spread (Linstone 1996). If the diffusion rate speeds up or the innovation rate slows down, then leadership becomes more dispersed (Hill 2007). The flattening scenario would also be consistent with the energy flow increase, since bringing the rest of the world to the U.S. level of energy use would increase global energy use by a factor of 5 (i.e., by 500%), since the United States consumes 25% of the energy used worldwide yet has only 5% of the world's population.

Conclusions

Many factors may have contributed to the sequence of leading capitalist Western European states. One of those appears to be the size of a state's population. The sequence by population size suggests that the reason a new phase of leadership occurs is because physical, organizational, and technological innovations require a larger coordination effort and larger economies of scale. This conclusion supports the supposition that Western European industrial growth was facilitated by the fractal nature of the states, with their range of sizes, options, and resources.

The three state trends investigated — population, relative productivity, and energy use — suggest that a global transition is near the inflection point. The estimates are based on population limits, limits on the progress rate and diffusion rate of technological innovations, and the environmental limits on energy use. This conclusion is not surprising since the global system seems to be nearing its furthest extent from equilibrium.

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