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The Ecological Keynesian: Energy, Money, and Oil Cycles in the Global System

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by

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Abstract

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This dissertation focuses on energy-centered great power nations in the 20th and early 21st centuries—the United States, Great Britain, and China—and the economic waves created by their changing rates of energy production. Its goal is a better explanation of energy's entanglement with global production, trade, and monetary systems, and of the crises linking them in the 1970s and 2000s. The post-Bretton Woods monetary-energy regime receives special attention, as does its future, given trajectories of key nations and the need to move toward low-carbon energy sources.

I proceed by integrating ecological economic and political economic thought, focusing on work of William Stanley Jevons and John Maynard Keynes that addresses key integrated macroeconomic-resource questions. I adapt natural resource linkages made by Keynes and Jevons—especially the influence of harvest fluctuations on the economy, and the investment cycles that transmit them—to investigate oil's effect on US internal/external balances after Bretton Woods. In doing so I identify a clear signal of an "oil harvest cycle" regulating those balances.

The oil harvest cycle provides provisional answers to important unresolved questions, such as the exact channels through which oil price shocks affect the economy ("Bernanke's Puzzle"). I also describe how the oil price functions as an adjustment method for sterilized US external balances in the "disequilibrium system" entrenched in the 1970s. Finally, I relate these mechanisms to the "pulsing paradigm" of ecosystems proposed by Eugene and Howard Odum, arguing that an analogous signal appears in the economy via its key natural resource cycles.

For John Maynard Keynes, who sought balance,
and for William Stanley Jevons, who wished to be "powerfully good…not towards one,
or a dozen, or a hundred, but towards a nation or the world."

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Introduction: Signal, Response, Evolution

This dissertation uses as fulcrum two moments from which everything, oil markets not the least, changed. The first, the unilateral floating of the US dollar by the Nixon administration in August, 1971, began the oil-tinged tumult of the 1970s. The second, the entry of China into the World Trade Organization in December, 2001, initiated an energy-economic spike that ended in a near collapse of the global system. These two events provide anchor points for the relationships that form the substance of the dissertation.

I began with a simple question: what is the relationship of energy, particularly oil, to financial-economic crisis, particularly in the United States?

Along the way, a number of secondary questions appeared. Why do postwar recessions in the United States invariably begin with an oil price shock? Why do oil and gold have such a stable price ratio despite very different fundaments and production techniques? What role does energy play in the internal and external political economy of the 20th century's great power, the United States? How is energy related to the rise of its greatest rival for power in the early 21st century, China? In what ways is this relationship similar to the transfer of monetary hegemony from Britain to the United States after World War II?

Of course, no simple answers appeared. At the end of this long inquiry, many questions remain. Yet key findings on energy and the economy have emerged, including some that have eluded both ecological economics and neoclassical researchers.

Oil price spikes in the United States appear to be its de facto means of adjusting to large external imbalances that build up over time in the post-Bretton Woods era, a topic I discuss in Chapters 6 and 7. These price spikes seem to occur in periods, such as the 1970s and 2000s, when normal adjustment mechanisms for external balances have been prevented from operating.

In the 1970s this was the floating of the dollar, which allowed the United States to sever the link between its payments balances and money supply. In the 2000s this was the pegging of the Chinese Yuan to the US dollar and the sterilization both nations used to prevent the China-US trade circuit from affecting the money supply (thus preventing the growing imbalance from adjusting). With this key negative feedback removed, the US-China monetary and trade circuit amplified rapidly, spurring enormous energy growth in China and debt in the US.

This cycle ended, like the one in the 1970s, in soaring oil prices, perhaps the strongest negative feedback mechanism left for US external balances. As shown in Chapters 4 and 5, when the US oil industry receives the signal of a durable price rise, it begins exploration and development (drilling). Eventually the shifting of resources toward drilling, which has an extremely low labor component but high capital needs, squeezes the rest of the economy, reducing investment, lowering expectations, releasing laborers, and generally encouraging all the self-reinforcing components of a downturn outlined by Keynes in his *General Theory* of 1936.

These oil-led downturns help bring the United States back into a semblance of external balance, at least cutting its trade deficit by a large margin. Thus it functions similarly to the price-specie and other mechanisms in the line that began with David Hume's *On The Balance of Trade*, of internal adjustment to external imbalance. The basic contention here is that with no real constraints on capital or labor, it is the energy constraint (or differential with other nations), that for the United States paces growth cycles.

The idea of natural resource cycles driving business or trade cycles is not unheard of, as I show in Chapters 2 and 3. William Stanley Jevons, late in his career, attributed the extremely regular business cycles to differences in agricultural production (driven by periodic sunspot activity). Keynes in the *General Theory* rescues Jevons's idea, suggesting the annual change in investment brought about by good or bad harvests may underlie business cycles, but discarding the sunspots mechanism as unnecessary.

From the standpoint of the Jevons-Keynes harvest cycle we can ask a simple question: if fossil energy, and especially petroleum, now underlies all global production, including agriculture, what would it mean for a resource-driven business cycle? Can the Jevons-Keynes harvest cycle profitably be translated to exhaustible resources? I say yes, and examine US recessions in the post-war era as partly determined by "oil harvest cycles," when US extraction of petroleum (and other exhaustible resources) spikes, inducing downturns and job losses.

We can thus separate out recent periods in US economic history into "fat" and "lean" years depending on the trend of the oil price, or, more precisely, the number of rigs drilling in the United States, the latter being a good indicator of where in the harvest cycle we stand. This basic signal of the oil harvest cycle, I argue, works its way through many macroeconomic indicators, such as the interest rate, money supply, and trade balances. Though I begin from the natural resource perspective in this paper and attribute a heavy influence to it, causation in such a system, with its ceaseless cyclical movements and feedbacks, is invariably complex. Yet heuristics borrowed from ecology, such as the Odums' (1995) pulsing paradigm, aid the analysis. Through this lens, oil or natural resource pulses in the global system are analogous to periodic floods of nutrients into an ecosystem.

Finally I look at resource cycles over longer time spans in Chapters 1 and 2. The oil harvest cycle is the signal of the late 20th and early 21st century, replacing agriculture and coal, perhaps, as the dominant external forcing on the economy. What will replace it? How does the shifting of resource centers help determine the center of the global economy? I examine this in Chapter 1, taking a broad look at the transfer of "workshop of the world" status from Britain to the United States to China.

With that status, eventually, comes the attendant power—economic, monetary, and political. Evolution of the global system's structure is a delicate process, no less because its major movements proceed through punctuated equilibrium. Faced with climate change, ecological and energy constraints, and a newly integrated world, we cannot afford to remain ignorant as to the source and nature of that punctuation.

Chapter 1. The Crown Joules: Resource Peaks and Monetary Hegemony

> "So sensible are they, in that country [France], of the superior value of corn, above every other product."
>
> -David Hume, "On the Balance of Trade," (1752)

A Material Base for the Economy

As imperfect beings, we must live in a physical world, subject to the steady degradation of energy and materials known as entropy. All our efforts, personal and economic, continually oppose this force. Global production and trade systems do so on a massive scale, harnessing enormous amounts of energy to build the physical economy (Georgescu-Roegen, 1971). In this the global system resembles a living organism, which must continually take available energy from its environment to grow and preserve its internal structures and function (Schroedinger, 1992). A thermodynamically open system, Earth receives a stream of solar energy that provided humanity this energy for thousands of years.

Only for the last 300-400 years have we exploited buried stocks of concentrated solar energy, fossil fuels. To focus on the energetics of this process, we must pay attention to physical units of energy supply, such as tons of coal, British thermal units (BTUs), or joules—the latter being the international standard. It also helps to understand the net energy yield or surplus energy from a given fossil source, what remains after the energy costs of producing it have been deducted, tends to decline over time as that source is exploited. (See Cleveland et al., 1984, and this team's long string of later publication on this concept, also known as "energy return on energy investment" [EROI]). Surface coal, for example takes less machinery and labor to mine than that which lies 1,000 meters under the surface, thus using less energy and producing more of a surplus. Equivalently, sophisticated offshore oil operations produce less net energy than did the first shallow wells of Pennsylvania or the early gushers of Texas.

Yet from these sources the global system continually builds and grows. As one high-yield energy source declines, others have generally arisen to take its place. The surplus joules that produce and maintain an increasingly complex global system (Tainter, 1990) must come from somewhere—for example, British coal mines (19th century); American and Saudi oil fields (20th century); or Chinese coal mines (21st century). From these oceans of energy arise massive global flows of trade and money. The latter act in feedback loops that call forth more energy—yet resource limits periodically threaten to slow or halt the system (Odum, 1971).

This relationship is clear in industrial production. Yet global energetics also have a deep and tangled relationship with global monetary systems. Their subtle linkages cross the boundaries of disciplines such as political science, economics, and energy analysis and thus are not well understood. "Energy markets"—in truth a myriad of economic, political, and strategic institutions—link global energetics to dominant monetary regimes. Meanwhile, a materialist approach ties global power and economic institutions tightly to biophysical resources and their control. Contra the idealist thought prevalent in both mainstream economics (and in many of its social science critiques), an energetics approach helps explain monetary and hegemonic regime changes. Much of this story remains to be told.

The "Energy Question"

Ecological economics has for decades focused on the inattentiveness of neoclassical or mainstream economics to biophysical resources. Meanwhile, economic anthropology, especially the studies on money, exchange, and political relationships exemplified by Polanyi (2001 [1944]), allows for a far more comprehensive study of human exchange systems than does neoclassicism. Yet one cannot ignore economic theory and history, which from the early 1800s at least, but especially in the last 100 years, remains relevant to the relationship between energetics and money, even where it obscures the connection.

One finds a tantalizing clue to the nature of this connection just before World War I, as Great Britain reached its peak level of domestic coal production. After the fact, this received little attention as a crucial event in world, or even British, economic history. Few references link Britain's coal peak in any meaningful way to the decline of its global empire and monetary system, or to its replacement by the US, with its rising supplies of fossil fuels, as the global system's energetic and monetary hub.

Yet one historical prediction does stand out. The *Coal Question by* economist William Stanley Jevons (1865) provides the current study with an animating idea: the internal resources of a nation, and by extension those abroad controlled by it, ultimately determine its hegemonic status. Jevons, in essence, said that as British coal became harder and harder to extract—energetically and economically more expensive—Britain would lose its manufacturing advantage over the rest of the world. This would mean a loss of economic and military primacy as well. Though his description drew on the costs of mining alone, with the benefit of the thermodynamics developed by Carnot (1824) and Clausius (1879) around the same time, we can easily translate Jevons's analysis into a more general energetics. In the terms discussed above, Jevons perceived that Britain's declining energy *surplus* threatened to diminish its relative power.

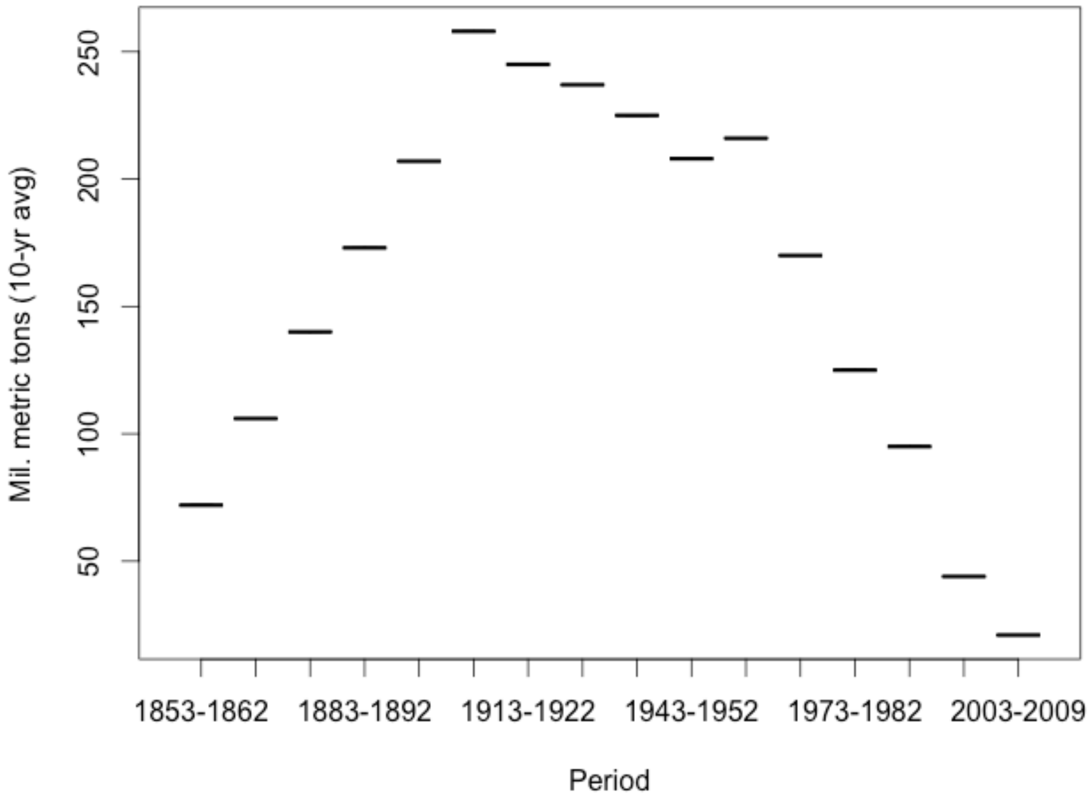

Figure 1. Coal Production in Great Britain, 1853-2009. *Source: UK Department of Energy and Climate Change*

The United States in particular concerned him: in 1865 coal was still being mined "in the light of day" in Ohio, according to Jevons. Meanwhile, in England, mines had already reached several thousand feet of depth; surface coal had all but disappeared.

> Our industry will certainly last and grow until our mines are commonly sunk 2,000 or 3,000, or even 4,000 feet deep. But when this time comes, the States of North America will still be working coal in the light of day, quarrying it in the banks of the Ohio, and running it down into boats alongside. The question is, *how soon will our mines approach the limit of commercial possibility, and fail to secure us any longer that manufacturing supremacy on which we are learning to be wholly dependent? (Jevons, 1865, IV.30)*

With his attention on the increasingly arduous British mining process, he warned that abundant coal was the wellspring of Britain's great civilization and culture, in part anticipating the theories of Leslie White (1943) and his intellectual heirs.

The neoclassical economists who followed Jevons mainly abandoned his materialist pessimism, over the next century severing the link between their theories and the constraints of the biophysical world. By 1974 the Nobel Prize winner Robert Solow could state the following:

> If it is very easy to substitute other factors for natural resources, then there is in principle no "problem." The world can, in effect, get along without natural resources, so exhaustion is just an event, not a catastrophe. (Solow, 1974, 11)

Though this extract unfairly makes Solow's 1974 lecture reflect seem quite unbalanced, he and his fellow economists generally do fail to parse the extent to which substitution can free a society completely based on natural resources (he conflates "natural" and "exhaustible"). Their assumptions, reflecting the system they analyze, favor infinite growth and unbounded technical progress guided by market forces. Yet as pointed out by ecological economists such as Herman Daly, who use this quote from Solow as a familiar stick with which to beat the neoclassicists, to accept the substitution premise means ignoring the fact that "other factors" such as labor and capital are both made and maintained by natural resources (ie., coal, water, iron ore). In fact, much of early ecological economics, as surveyed by Martinez-Alier and Schippman (1987), came from physical or scientific thinkers. For example, the Nobel Prize-winning chemist Frederick Soddy (1933) was dissatisfied by the economic explanations of neoclassical and Marxist economists who mostly ignored the flowing, limited lifeblood of human economies—matter and energy. Jevons did not make this mistake.

The peripheral place of natural resources in economics perhaps stems from the great abundance of the 19th and 20th centuries, when fetishized ideas of "technology" began to paper over the material and energetic foundations of society (see Hornborg, 2009). Economists are not alone among social scientists in neglecting the latter. A "two cultures" divorce between idealists and materialists has allowed Western culture to partly obscure the sources of its wealth and development. One may read Hayak's *Road to Serfdom* ([1944] 2009) and marvel at the self-organized symphony of the market without ever suspecting the tremendous freedoms it granted relatively wealthy urbanites in Paris or London resulted from bondage and domination elsewhere. If the world runs on ideas and not resources, then less must be said of colonialism or ecologically unequal exchange.

Karl Polanyi himself said little about the importance of natural resources in *The Great Transformation (*[1944] 2001), beyond describing the despoiling of the productive powers of the land by its market treatment as a "fictitious" commodity. Yet he argues that the gold standard's collapse brought about the end of 19th century civilization, which led to wrenching global transformation. If we can connect the collapse of that regime to England's increasing inability to "conduct" the global monetary system, and in turn link that failure to the decline of it coal resource, then we may set Polanyi's idealism on a solid, material foundation.

In the run-up to World War I, Jevons's warnings on the effects of declining coal stores on British industry came to pass, with severe consequences for her currency:

> The worst is that Great Britain long ago lost its monopoly in the world market on high productivity. Taking into account only the capitalist countries, the United States, Western Germany, and Japan stand above England's technical level and sell industrial products at a lower price. In this is to be found the definitive cause of the continual deficit in the trade balance, the fundamental reason why the pound sterling no longer serves as an international means of payment. (Mandel, 1972, 30-31)

Ecological economics has long tied what mainstream economists measure as gains in total factor productivity to increased energy use—or, more precisely, substitution of energy-intensive capital for labor:

> From an energy perspective, productivity gains are facilitated by technical advances that enable laborers to empower their efforts with greater quantities of high-quality fuel embodied in and used by capital structures. As Cottrell observed, "productivity increases with the per capital increase in available energy." (Cleveland et al., 1984, 894)

A biophysical perspective would help ground Polanyi's sweeping historical interpretation. Fred Block and Margaret Somers (2014), insightful scholars with decades of experience studying Polanyi's thought, say nothing in their recent book on him about the importance of resources to the formation, circulation, contestation, and triumph of various economic ideologies (they focus on "market fundamentalism"). In this study, however, I argue for a link between strong market liberalism and natural resources. Market fundamentalism seems ascendant when energy resources, especially, become constrained: in the 2000s and 1970s US; 1920s England; and perhaps even in the first bursts of modern liberalism. David Ricardo (1821), seen as the founder of liberal economics, wrote his *Principles of Political Economy* as an argument for liberalizing corn imports into a Britain constrained by the high prices of this energy source for workers. Put another way, doctrines of austerity often seem strongest when expansion of the money supply becomes constrained—and expansion must eventually be backed by something physical, such as gold, silver, or even oil, as I describe further in Chapter 6 and 7.

Jevons provides us with early clues on the importance of easily available energy to industrial development and global competition. The great strength of the *Coal Question* lies not only in its application to British coal, but also to American oil, which allows us to reframe it as *The Energy Question.* As such, we can apply it generally, bringing laws of thermodynamics into service to analyze issues, such as monetary regimes, which would otherwise seem far removed.

Oil: Good as Gold

Some may argue that the growing role of oil in the British economy, and abundant foreign coal available for import, made Britain's coal peak a trivial event. Yet these facts illustrate the shifting center of the global energy system, which I connect to a fundamental transformation of global power arrangements. America's tremendous coal resource, and its grip on the global oil system, helped it gather around 80% of the gold in the world (Mitchell, 2009, 414) by the end of World War II. It became a massive global creditor in large part through its resources and industry, which allowed it to develop and run the Bretton Woods system, successor monetary regime to the British-centered gold standard. Likewise, when fuel extraction in the US became more costly and, more importantly, its control over global oil slackened in the late 1960s and early 1970s, the Bretton Woods system fell apart (Mitchell, 2009, 419). The rise of other fuels and availability of external resources did not matter. Britain's 1913 coal peak and the US 1970 oil peak marked, arguably, the height of political economic power these two nations would enjoy—the concusion of their ascendant periods. Spiro (1999, 152) summarizes regime theory and contends that the "golden period" of legitimate US hegemony ended in the early 1970s; Ruggie (1982, 391) touches on Britain's hegemonic decline after World War I.

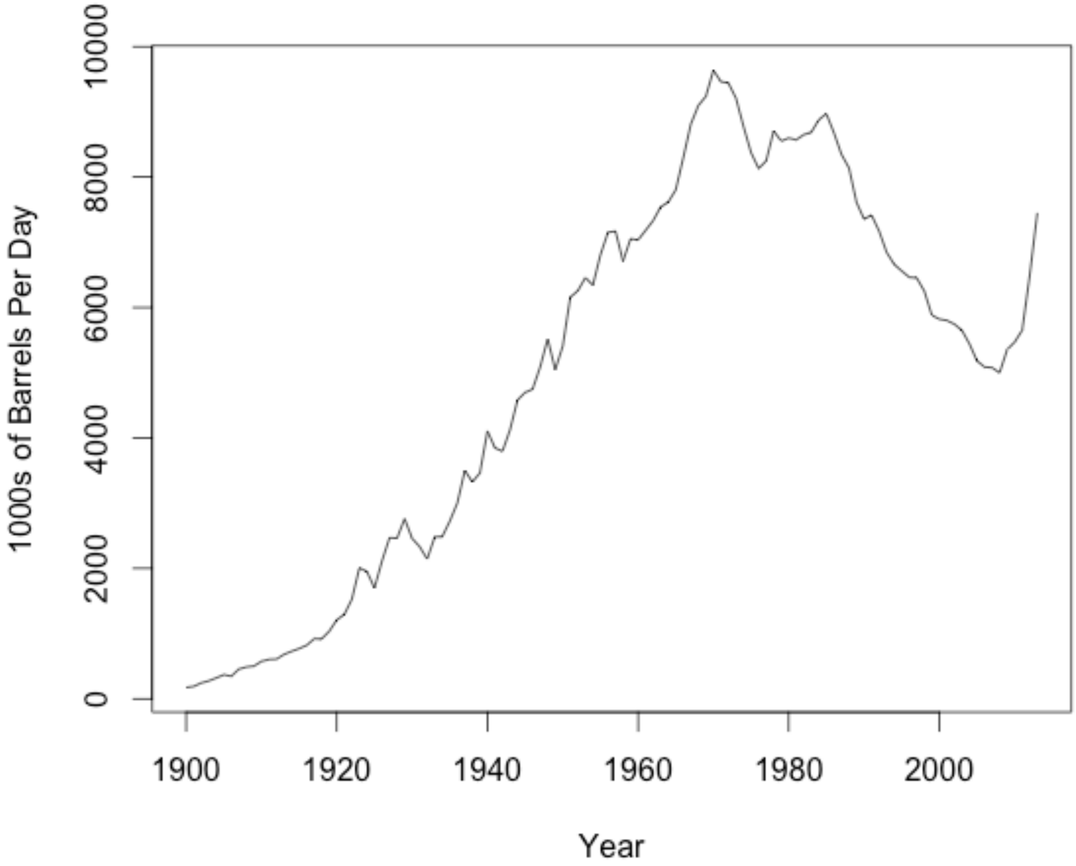

Figure 2. US Field Crude Production, 1900-2013. *Source: US Energy Information Agency*

The “golden period” designation resonates. Britain’s weakening, and the ensuing World Wars, ended the Hundred Year’s Peace described by Polanyi (2001), a disintegration he attributes to the collapse of the international gold standard, the prevailing world monetary regime. The failure of the pre-war gold standard began in 1913 and lasted until a final breakdown in the interwar period, which according to Polanyi helped plunge the world into its last general war. The US decline after 1971 also involved going off gold—though this time, the global hegemon departed from a more managed, less automatic system (Bretton Woods). In both cases, I argue that the end of unrivaled domestic energy supply growth made the institutions of a fading energy-monetary regime untenable.

How does this link to Block and Somers’s “market fundamentalism”? Spiro (1999, 135-137) provides a nice explanation of the way the US in the 1970s moved much of the global capital circuit from multilateral institutions, where capital was allocated according to some government consensus, into markets. “Letting markets work” was the order of the day, and prime proponents included William Simon—former bond trader, treasury secretary, and the first energy “czar” under Richard Nixon and later Gerald Ford. Simon, positioned at the nexus of global energy and finance, was a key founder of several US policy organizations (eg., Heritage Foundation) dedicated to propagating market fundamentalism, which for Spiro conceals an illegitimate exercise of power.

Markets may redistribute, or they may not—all depends on how they are set up. Hegemonic powers by definition have the final word on that, and those in decline, their competitiveness fading, have more incentive to leverage their power to produce market outcomes heavily tilted toward their own benefit. Thus the prose of “market fundamentalism” can obscure deep state involvement in the mechanics of market design and operation, which in turn help preserve or strengthen a status quo threatened by increasing competition[1].

Despite these clues, linkages between a nation’s energy resources and its international monetary position or ideology receive little attention in academic writing. As evidenced by a comment made by the Fed chairman in 1978 to business executives in the White House arguing for President Carter’s unprecedented energy policy legislation, those in power give it more thought: “…G. William Miller, the ostensibly independent chairman of the Federal Reserve Board, argued that passage of the compromise [energy] bill—any bill, really—was essential to the stabilization of the value of the dollar against foreign currencies” (Press CQ, 1981, 481).

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[1] While this would seem applicable to 1920s Britain and 1970s US, Britain’s ascendant position in the early 1800s complicates the matter with regard to the corn laws and Ricardo’s development of early liberal theory, though the “energy constraint” linkage does not depend on hegemonic position in the same way.

Bernanke et al. (1997) provide another notable exception, though their interesting study on the connection between oil prices and the Fed's monetary policy focuses on prices, omitting energetics and physical realities of the type Jevons examined, which limits its scope and obscures a larger story.

What is that larger story? It may help to outline the central ideas of how energy resources interact with monetary arrangements. The basic idea is fairly simple. Dynamics of the global capitalist system so far require continuous expansion, both a physical and a monetary process. As noted by ecological economists such as Georgescu-Roegen (1971) and Cleveland et al. (2000), economic growth necessitates an increase in overall material and energetic flows (or throughput).

Such physical expansion also requires monetary expansion, unless prices are to fall—the latter a situation most economists and policymakers see as destructive. This mechanism can be crudely understood by thinking of a pool of "goods" on one hand, and "money" on the other. Holding the size of the money pool constant, an increasing pool of goods means each good commands less money than it did before. Consider an economy of ten identical goods, each priced at $10, and a $100 total money supply. If another ten identical goods come into existence (perhaps from mining) while we have only $100 to circulate, those 20 goods fall to $5 each.

In the past, this type of deflation—John Stuart Mill (1848) gave an early explanation of it—came in periods of precious metal shortages. Gold and silver were the most important monetary commodities for many years. If they became scarce, deflation could set in. Eichengreen and Flandreau (1997, 8) point out that "it took more than twenty years of deflation, from 1873 to 1896, before gold discoveries in the Klondike and elsewhere reversed the trend and inaugurated a period of inflation."

Only when the monetary system has a physical base, or is tied to some other absolute standard of value, does such deflation become necessary. In the British-centered gold standard era that prevailed until 1913, virtually all the world's circulating currency was convertible to gold or silver—often through an international reserve currency such as the pound sterling. The Bretton Woods agreement similarly fixed currencies to the dollar, which in turn converted to a fixed amount of gold—one could buy an ounce for about $35 from 1946 to 1971.

Economic expansion in such monetary regimes required growing amounts of gold and silver—mined somewhere in the world—to cover an increasing pool of goods and services. Central banks often held precious metals as reserves, in some combination with the reserve currency of the given monetary power—first England and then the United States (other dependable currencies, such as Swiss francs, served on a smaller scale). The monetary hegemon's ability to command enough gold and silver to redeem foreign holdings of its currency upon demand—or to credibly assure financiers it could do so—provides monetary stability.

Britain could do this until 1913; the US, until 1971. After that, the growth of the global economic system, I argue, overwhelmed the ability of the monetary hegemon to cover it. The causality here is likely complex or systemic, but Mitchell (2009) and Galpern (2002) both come to the same conclusion: monetary hegemony depends in large part upon a growing domestic supply of, or colonial control over, energy resources. Once this falters, a "top" or "master" currency, in Strange's terminology (1971) , becomes strained.

Why? These powers emerge first as manufacturing leaders—"workshops of the world"—which rely on large, increasing domestic energy supplies, often in addition to foreign sources enjoyed at a colonial discount. Once a significant portion of the energy supply is imported, exchanged for hard currency on the open market, a nation's financial position changes irrevocably—and the nation with it. When a nation begins to pay market prices, or what passes for them, for an energy resource it had previously imported at a colonial discount, the situation is exacerbated.

The Chinese Coal Question

The case of China today is particularly intriguing. In the 2000s China expanded its energy supply—mostly with coal—at an astonishing rate. By 2009, however, it faced for the first time a negative trade balance for coal, its foundational energy source. This situation, common to the US and British trajectories as well, presents a limit to growth that by now even near-sighted policy makers can see coming. Once a country loses self-sufficiency in industrial applications and begins to buy a significant portion of its energy resources abroad, expansion becomes a more expensive proposition and naturally slows. While China has for years imported a great deal of its oil, its 2000s export-fueled domestic expansion rested on coal.

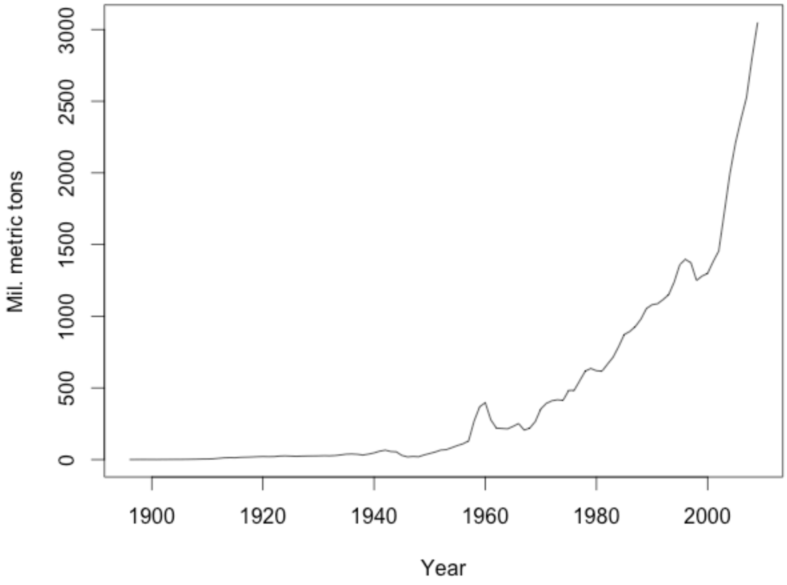

Figure 3. Coal Production in China, 1895-2009. *Source: Professor David Rutledge, California Institute of Technology*

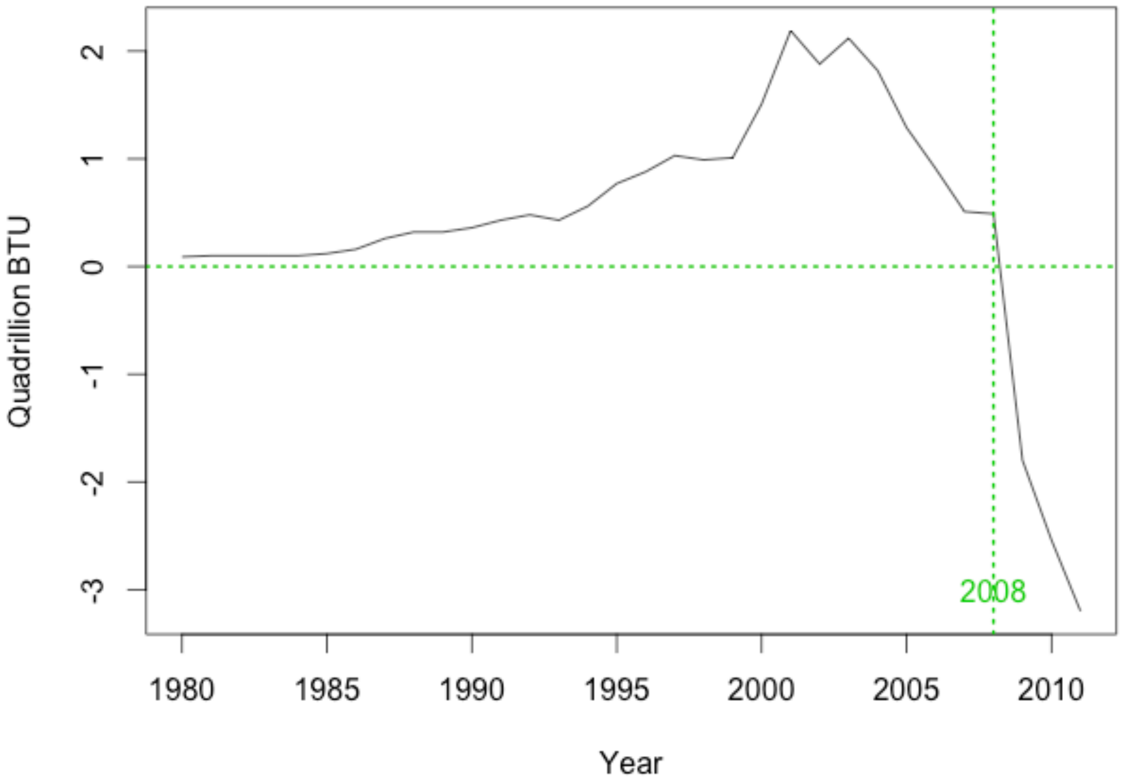

Figure 4. China's Net Coal Exports, 1980-2011. ***Source: OECD data***

Of course, China, while a global economic power, has not yet become the monetary hegemon. In fact, it seems to have fused to the US system, raising interesting questions about the evolution of the world's political economy. The manufacturing center for the global consumer market, its currency essentially pegged to the dollar[2], China functions as a dollar stabilizer, recycling "Walmart dollars" in the same way that Middle Eastern countries have recycled petrodollars since the 1970s—through US Treasury bills and other investments. China's pegged manufacturing explosion helps explain the strange story of the dollar over the last 15 years, when it remained a stable currency during massive monetary expansions and military-driven deficit spending. The future role of China's Yuan—and the potential replacement of the dollar as sole international reserve currency by some combination of global currencies—lies in a tight reciprocal relationship with future global energy patterns.

China's new position in the global monetary system may in part be determined by what Jevons might have called the "oil question." Oil accounts for about half of global trade by value, the effect of which has been "almost to constitute oil a currency in itself" (Galpern, 2002, xix). In fact, as Mitchell (2009) explained, oil remains a crucial element of the US dollar's hegemony, and of the post-Bretton

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[2] That peg has been allowed to crawl slowly since the mid-2000s.

Woods (or Bretton Woods II) monetary system. Denominated in US currency, and by far the world's most important commodity by total trade value, oil has for 70 years helped keep the dollar stable by creating demand for it.

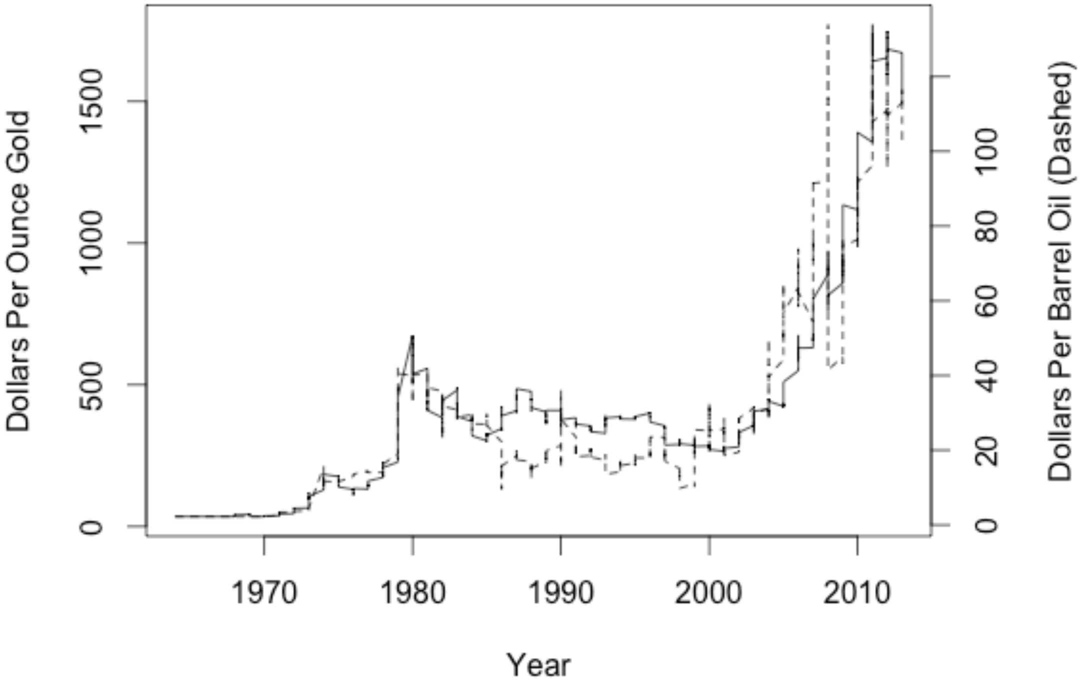

Figure 5. Oil and Gold Prices, 1964-2013. *Note: London spot prices, nominal. Source: IMF International Financial Statistics.*

Oil prices have also tracked gold prices very closely over the past 40 years—a phenomenon unique to these two commodities and worthy of further exploration. One explanation, without micro-level detail, is that oil has become, like gold and silver, a monetary commodity—a credible base for monetary expansion. It holds or gains value over time (with rare exceptions) and is highly liquid and convertible, being always in demand everywhere. Further, oil prevents, in many ways, unlimited expansions of the US money supply. Large-scale dollar expansions, such as those in the 1970s following the floating of the dollar and the end of Bretton Woods, ultimately result in rising oil prices as the pool of money overshoots that of oil, leading producers to raise prices—the root of some so-called "oil crises." While other types of goods also see monetary-based inflation, oil—along with gold—seems especially sensitive and fundamentally different from "normal" commodities. Money is a claim on limited physical resources, and money cannot be expanded indefinitely without a commensurate increase in their prices. I explore these topics at greater depth in Chapters 6 and 7.

From here, we may argue that the rate of oil discovery and production paces economic expansion—just as metal mining did, according to Mill. This holds in a physical, kinetic sense (try moving anything without oil—or, more generally, energy), but also in a monetary sense. In short, if the dollar is pegged to anything today, it is pegged to a barrel of oil, though moving within a band, but generally staying at one level: around $20 from 1986-2001; climbing after China's December 2001 WTO entry through the 2000s; correcting during the 2008 crisis and then stabilizing around $100 from 2009 until the 2014-2015 price decline. The 2000s oil price increases can be seen partly as a long devaluation—its effects largely hidden by sterilization operations of the US and Chinese central banks—to accommodate the Chinese-led (and coal-fueled) expansion. Interest rates dropped and remained low, and the Chinese economy acted as a pontoon that kept the dollar and the American economy afloat.

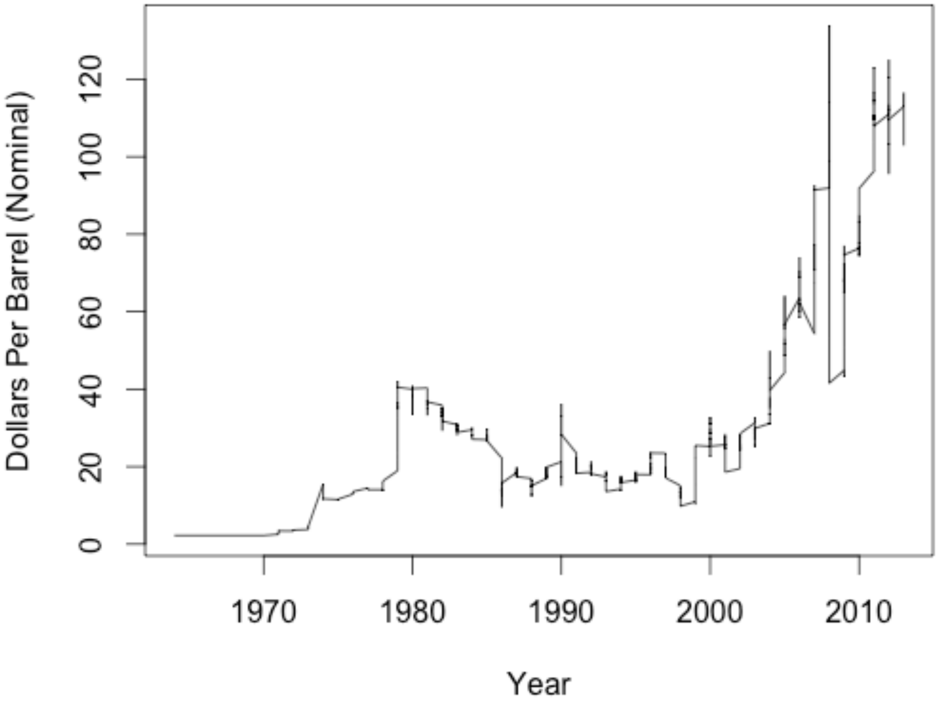

Figure 6. Crude Oil Prices, 1964-2013. *Note: London spot prices. Source: IMF International Financial Statistics.*

In the *General Theory* Keynes (2006), following Jevons (1878), explained that the root cause of business cycles may lie in agricultural fluctuations. Mill (1848), as shown above, attributed deflationary periods to a lack of precious metal for circulation, connecting mining cycles to economy-wide price cycles, though as Eichengreen and Flandreau (1997, 8) point out, economists such as Alfred Marshall were skeptical of this. Nevertheless, we may extend the resource harvest cycle idea to coal mining and, another discovery-based extractive procedure, oil production.

If oil has supplemented or replaced gold and silver as the primary physical backing for the current monetary system, we might understand the early 1970s recessions and the ongoing crisis that began in 2008 as points when slowing of a previously rapid increase in the energetic base held up the expansion of the global economy.

The two decades it took to open the Klondike in the late 1800s and ease deflationary conditions (Eichengreen & Flandreau, 1997, 8) might be mirrored, then, in the opening of Alsaka's North Shore and the UK's North Sea oil resources in the 1970s—or in the addition of shale oil and other unconventional hydrocarbons from fracking and other such processes after the 2008 crisis, which relieved some of the pressure on the American economy. With technological change these opening periods seem to grow shorter, yet so do the high-yield periods that follow.

To restate, oil extraction sets the pace of the world's growth because its slackening physically constrains it, and because it functions as a de facto base (or limiter, as we see in Chapter 6) for the monetary system in place since 1973. Coal—far smaller as a fraction of global trade by value—has a more domestic effect. For global production engines such as 19th century England, dependent on coal-fired manufacturing, the decline of export competitiveness that comes with a plateau and decline of the coal base (and its net energy surplus) makes it difficult to sustain the large trade surpluses that validate their role as lender of last resort. In fact, Britain's decline as a global capital equipment provider (Eichengreen & Flandreau, 1997, 21) is often cited as an explanation for its loss of monetary hegemony and the failure of the interwar gold standard.

Like interwar Britain, the post-Bretton Woods US has also spent decades operating an unstable monetary system. While it lost the ability to completely control this system in the early 1970s, due partly to its oil peak and the loosening of its grip over Middle Eastern oil, the dollar remains the global reserve currency. Many authors see this arrangement as unsatisfactory, contributing to global instability (e.g. Rajan, 2011).

The US was by some accounts reluctant to take the hegemonic lender of last resort role from England in the 1920s-30s (Eichengreen & Flandreau, 1997, 21), and after Bretton Woods ended, no clear rival emerged to take its place. Yet today, while one can imagine China taking a greater role, or an agreement dividing responsibility for stabilization among the largest economies[3], the US does not seem eager to relinquish its privileged position at the center of the global monetary system, as meager as the justification for its singular reign has become. (Britain, after World War II, likewise fought unsuccessfully to keep sterling as a top global reserve currency.) This likely has weakened a US economy too dependent on the artificial advantage it receives from seigniorage and the ability to manipulate global markets.

Beyond Chinese Coal and Global Oil Peaks

Jevons's warning applies, I argue, not only to England in the 1910s and 1920s—or to the US in the 1970s—but also to contemporary China. As the world's current production hub, China occupies a strange place in its hierarchy. Like the US before it, China has deep ties to the declining economic hegemon (in the case of the US,

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[3] The use of special drawing rights, or basket of currencies, are common proposals.

England; in the case of China, the US), a kind of symbiotic relationship. Yet if there is to be another hegemonic succession, or redistribution of power atop the global hierarchy, its nature, given differences between the pairings in geography, historical relationships, culture, and so on, seems unclear.

One constant, however, is the foundation of China's rise: abundant domestic energy. *The Coal Question* describes China's process—and some of its current problems—as well as it described England's. The growth in China's coal production, astounding from the 1990s to the 2000s, began to slow in the late 2000s. In fact, as noted above, China became a net importer of coal for the first time in 2008-9, another turbulent period for the global economy. While many researchers (Sexton et al., 2012; Kallis & Sager, 2015) have examined oil price spikes as a trigger for the 2008 global economic crisis, I argue that China's approaching coal peak also played a significant role by slowing growth in the world's economic engine. Likely spurred by nature itself and the return considerations that originated with Jevons, the Chinese leadership recently set a self-imposed coal production peak for 2015[4].

The question looms: what happens after that? If the extraordinary exploitation of domestic coal resources in China kept the global economy moving for the past few decades, what happens when it plateaus and declines? How will global monetary and power relations change beyond the China peak? What region will drive global growth? What will fuel it? Where will the next burst of high-gain, high surplus joules for the global economy emerge, given that current substitutes yield less surplus energy than traditional fossil fuels—especially those more easily extractable reserves that built the infrastructure of the world's greatest economies? How far will shale oil "revolutions" increase the global hydrocarbon base, given climate, environmental, and seismic concerns with these short-lived wells? Can renewables produce enough surplus energy to maintain and expand Western living standards?

Following the work of Tainter (1990), we ask whether—challenged by increasingly obvious and destructive climatic changes—we will take another step up the energy surplus ladder, working breeder reactors again, for example, or begin stepping down. If we step down, what will become of this complex, self-organizing society we've built? Is energetically and economically cheap energy truly the mainspring of our culture and civilization, as Jevons and others have claimed? By engaging with such pressing questions, social science might regain its connection to the long-estranged physical world and its natural sciences—both in need of its insight.

Much of the world remains in a holding pattern when it comes to energy resources and economic growth. It is not clear where the world's next great burst of joules will come from, or even if there will be one—at least one similar in scope to the coal

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[4] The intense pollution burden placed on the Chinese people by the post-2001 growth spurt is another factor possibly limiting China. The US also began to address pollution problems around the time when its most important domestic energy resource (conventional oil) peaked, in 1970.

booms of 19th century Britain and 21st century China, or to the oil booms of the 20th century American and Middle East-centered system. Climate change complicates this picture enormously, as it further constrains our potential sources of joules while promising a host of other disruptions.

Labor and capital are not the only factors of production controlling growth and contributing to monetary crises. Energy may be the most important of all, underlying the other two (for energy as the "missing" factor of production, see Kümmel, 1989). I have argued that energy resources, especially oil, have joined gold and silver as monetary commodities above all others. Meanwhile, in the domestic sphere, coal serves as a key fuel for industrial products, exports, and thus a foundation for a favorable balance of trade position, as demonstrated by China.

I argue that, as predicted by Jevons in the *Coal Question*, the peaking of England's coal production helped upend its position as monetary hegemon, as well as the gold standard system that rested upon it. England's control of Middle East oil resources, as outlined by Galpern (2009), was too weak to avoid the passage of master currency status—and political economic hegemony—to the US in the post-World War II era. It could simply not compete with energy-rich nations such as the USSR and US. The US in turn began to lose hegemonic control of the monetary system in the 1960s and early 1970s, when its domestic oil production peaked and Middle Eastern oil producers began to exercise greater control over their resources, weakening the formerly comprehensive US grip.

Nevertheless, since the early 1970s, the US has tended a floating currency version of the Bretton Woods arrangement, without capital controls, known as Bretton Woods II, that has kept the dollar at the center of global finance. The collapse of its major rival, the USSR, in 1989, buttressed the US coalition of oil producers and financial centers. The rise of China and its coal-fired trade surplus in the 2000s also kept the dollar, to which the Chinese currency is pegged, as the master currency, through recycling of "Walmart dollars" into US Treasury securities and currency. China now acts much like England did during its gold standard reign, and the US did during its Bretton Woods I supremacy, lending money that countries use to finance imports from China. Such is the strange symbiotic situation in which the US—the fading hegemon—and China, its poorer financial backer, find themselves.

Adding to the complication, China has neared its coal peak, its slowing production increase a possible contributor to the global economic downturn in 2007-2008. Central bankers have long taken into account gold (Eichengreen & Flandreau, 1997, 24) and oil prices (Bernanke et al., 1997) when determining interest rate movements. Chinese leaders would also logically take resource supplies and costs into account when deciding to raise interest rates and slow their economy—an act which may have upset the fragile, US-China debt loop of the 2000s (see Chapter 6).

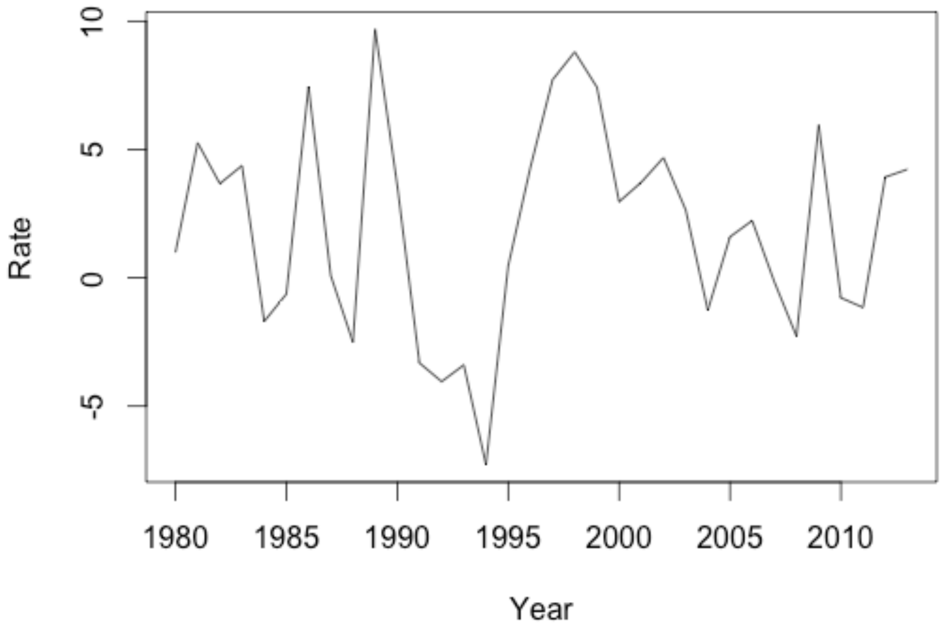

Figure 7. Real Interest Rates in China, 1980-2013. *Source: World Bank*

What monetary system lies beyond the China peak, beyond coal and shale oil, is not clear. It is apparent, however, that the global economic system is stuck, waiting for a direction to be set, and the next regime to emerge: a new monetary system, tied to a new energy system, with a new leadership structure.

Chapter 2. Energy's Economy: Mr. Jevons, State Power, and Sunspots

> It is curious to notice the variety of the explanations offered by commercial writers concerning the cause of the present state of trade. Foreign competition, beer-drinking, over-production, trades-unionism, war, peace, want of gold, superabundance of silver, Lord Beaconsfield, Sir Stafford Northcote, their extravagant expenditures, the Government policy, the wretched Glasgow Bank directors, Mr. Edison and the electric light, are a few of the happy and consistent suggestions continually made to explain the present disastrous collapse of industry and trade.
>
> --William Stanley Jevons, *Commercial Crises and Sun-Spots* (Jevons, 1878, 33)

> "It will only be when we get a response from nature, in the form of greatly diminished return in…surplus energy, that we can expect the present industrial revolution to slow down."
>
> --Fred Cottrell, *Energy and Society*. (Cleveland, 1987, 56)

The Jevons-Keynes Harvest Cycle

To what degree do changes in energy systems influence changes in political economic systems? Put another way, how much does "resource availability set the general direction of social change," as sociologist Fred Cottrell believed (Cleveland, 1987, 56)? How closely may we tie energy events and structures to political economic events and structures without straying into determinism, or the idea that all human culture is mere window dressing for various sets of energy conversions?

For the 19th-century British economist William Stanley Jevons, energy could explain a great deal. By the end of his life Jevons was convinced the source of the business cycle lay in sunspots—or at least in agricultural fluctuations brought on by some periodic change in the amount of solar radiation reaching Earth's surface (Jevons, 1878, 33). This theory has not gained widespread acceptance. It does, however, resonate with some ideas of ecological economists. For example, Robert Costanza (1980), argued that energy was the primary basis of economic value, partly because solar radiation was the only net input into the earth system, a different idea with a similar core: our human economy must be paced and measured by something physical, something external to it[5].

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[5] Even in ecological economics, Costanza's argument proved controversial. See for example, the critique in Georgescu-Roegen (1986).

In this chapter I clarify a major distinction between neoclassical and ecological economy, with Jevons himself as a branching point in economic thought. In *The Coal Question* he tied the fate of Britain as a military and industrial power to the depth of its mines, reasoning that as coal became more expensive to produce, it would lose manufacturing advantage to other nations, especially the rising United States, which as Britain's mines ran ever deeper, "would still be working coal in the light of day" (Jevons, 1866, IV.30). We may call his approach the political economy of energy and capital—or biophysical political economy.

The main part of this dissertation concerns phenomena closely tied to the effects of changes in energy availability on political economic systems. The sunspot debates, however, deserve some attention for what they say about the later development of economic theory—and how easy it became to ridicule writers who attributed political economic movements to biophysical causes. Jevons's view was not uncommon in his time, as a number of serious writers investigated the very similar return periods of sunspot events and business cycle peaks. The idea, however, sounds funny to modern economic ears. While scholarly researchers occasionally revisit the work, it is just as often held up for academic ridicule or used as a cautionary tale for students who might one day be tempted to mistake correlation for causation (Sheehan and Grieves, 1982; Plosser and Schwert, 1978). "Sunspots" are now economics jargon for extrinsic random variables (Cass and Shell, 1983), while Jevons's idea is dismissed as a "mistake" (Duffy and Fisher, 2005)[6].

For example, a team in the *Journal of Monetary Economics* in 2006 claims that sunspots, as tongue-in-cheek stand-in for extrinsic random variables, coupled with self-fulfilling expectations, models the entire Depression better than earlier real business cycle models—mainly due to the "possibility of indeterminacy of equilibria" (Harrison and Weder, 2006, 1328). In other words, economic actors do not know where the economy will come to rest. Sunspots are used in this article as an example of nonfundamental shocks, a "measure of changes in expectations or confidence that is determined independently of economic fundamentals" (Harrison and Weder, 2006, 1331). They stand in for randomness and non-economic forcings, illustrating the strong interplay of the latter with expectations.

More straightforward analyses of sunspots as causes are not promising. Aldrich (1987, 245) recounts criticism beginning with the work of a General Strachey in 1878, which poked a large hole in Jevons's theory by reordering years at random and finding similar correlations in the periods of sunspots and economic cycles. Jevons, straining at the bounds of probability and statistics, was perhaps ahead of his time, and lacked the requisite armory—signal processing methods such as Fourier analyses for cyclical phenomena, for instance—to convince his profession that probability was the true language of economics.

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[6] In physical science, meanwhile, "sunspots" works as a catch-all term for residuals not explained by the model.

What was he trying to accomplish? In search of scientific certainty, Jevons looked for an analytically plausible "deep cause" (Jevons, 1878, 33). According to Mirowski (1984, 346), the sunspot theory also fit into Jevons's research program because it shifted attention from endogenous factors that might cause economic fluctuations. The stable capitalist economic system was merely being buffeted by external, regular, natural shocks—though this would not always be easy to gauge: "In the first fifteen years of this century statistical numbers were thrown into confusion by the great wars, the suspension of specie payments, and the frequent extremely high prices of corn" (Jevons, 1878, 33)[7].

Jevons held in equal contempt the idea that the regular business cycle return periods of his time could be caused by "endogenous" political economic factors, a few of which he lists in the quotation that begins this chapter. The classical economists who preceded Jevons attributed commercial crises to various phenomena, with overproduction ("glut") a locus of debate. Writers as diverse as Karl Marx and Thomas Malthus believed gluts to be a reoccurring feature of production and cause of misery, while David Ricardo and Adam Smith generally denied the possibility of overproduction, arguing, essentially on the basis of Say's Law, that all supply creates its own demand (Tabb, 1999, 65). Mirowski (1984) claims the sunspot theory created for free-trade enthusiast Jevons a useful explanation of how markets worked well on their own, but tended to be thrown off by external physical factors—not through faulty internal dynamics or contradictions, as Marx argued.

The biophysical idea preceded Jevons and outlived him. He cites a writer a generation earlier who argued for a "Physical Economy" that would search out the "physical groundwork" for these cycles, noting the extremely regular periodicity of business cycles, poorly explained by diverse and disconnected events (Jevons, 1878, 33). The founder of the Wall Street Journal and the inventor of the Dow Jones Industrial Average, Charles Dow, also placed a great deal of stock in Jevon's sunspots work. Recent research argues that "Jevons's sunspot theory provided the basis for the computation of the Dow Jones Industrial Average in 1896 by Charles Dow and for the introduction of informational efficiency to describe stock market behavior" (Caldenty and Vernengo, 2010, 11). Yet Dow, while borrowing much from Jevons and his sunspots work in his own search for economic periodicity, remained uncertain as to the ultimate cause of cycles he believed Jevons correctly described (De Goede, 2005, 103-14). Later writers such as Nicholas Georgescu-Roegen (1971) sought something similar in "biophysical economics" and, later, "ecological economics"—a discipline primarily concerned with linking, or re-linking, the physical world to diverse models of economic systems and social life.

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[7] See Chapter 1 on corn as energy for workers and David Ricardo's liberalism as a response to this early industrial energy constraint.

Physical factors, however, become rarer in the 20th century as explanations of the business cycle. Perhaps more fairly, they became part of a litany, grouped with the potpourri explanations Jevons noted. Yet despite the problems with sunspots, it is clear that varying harvests, transmitters of solar fluctuations and Jevons's proximate cause of the business cycle, could influence both expectations and investment. John Maynard Keynes calls Jevons's idea "extremely plausible" given the importance of current investment in his *General Theory* (Keynes, 1997 [1936], 329):

> Jevons's theory, that the trade cycle was primarily due to the fluctuations in the bounty of the harvest, can be re-stated as follows. When an exceptionally large harvest is gathered in, an important addition is made to the quantity carried over into later years. The proceeds of this addition are added to the current incomes of the farmers and are treated by them as income; whereas the increased carry-over involves no drain on the income-expenditure of other sections of the community but is financed out of savings. That is to say, the addition to the carry-over is an addition to current investment.
>
> This conclusion is not invalidated even if prices fall sharply. Similarly when there is a poor harvest, the carry-over is drawn upon for current consumption, so that corresponding part of the income-expenditure of the consumers creates no current income for the farmers. That is to say, what is taken from the carry-over involves a corresponding reduction in current investment. Thus, if the investment in other directions is taken to be constant, the difference in aggregate investment between a year in which there is a substantial addition to the carry-over and a year in which there is a substantial subtraction from it may be large; and in a community where agriculture is the predominant industry it will be overwhelmingly large compared with any other usual cause of investment fluctuations. Thus it is natural that we should find the upward turning-point to be marked by bountiful harvests and the downward turning-point by deficient harvests. The further theory, that there are physical causes for a regular cycle of good and bad harvests, is, of course, a different matter with which we are not concerned here (Keynes, 1997 [1936], 329-330).

Keynes carefully separates the physical causes of the changing bounty of the harvests (for Jevons, regular changes in solar radiation) from the effect of those harvests on current investment. In an essay on Jevons written later, Keynes writes that "it is now generally agreed that, even if a harvest period can be found associated with the solar period or with more complex meteorological phenomena, this cannot afford a complete explanation of the trade cycle…Nevertheless, Jevon's notion, that meteorological phenomena play a part in harvest fluctuations and that harvest fluctuations play a part (though more important formerly than to-day) in the trade cycle, is not to be lightly dismissed" (Keynes, 1963, 280). Meanwhile, other writers, including a number cited by Philip Mirowski (1984), also found evidence for the influence of harvests on the economy, though not for sunspot cycles as the direct cause.[8]

Keynes goes on to note in the *General Theory* that economic changes since Jevons's time have increased the importance of other kinds of "harvests"—and the resultant stocks of agricultural, mineral, and finished products. The debate becomes more complex. Now we have not only natural-energetic causes of the business cycle, but also a changing biophysical input mix as the economy evolves. As its foundations changed, fossil fuels becoming the base of agriculture and all production, so we might reason, would the proximate causes and periods in Jevons's framework.

From this we might conclude that the period of business cycles may have grown more irregular than the ten years of Jevons or the "eight to ten years" of Thomas Malthus:

> I really think that the progress of society consists of irregular movements, and that to omit the consideration of causes which for eight or ten years will give a great *stimulus* to production and population, or a great *check* to them, is to omit the causes of the wealth and poverty of nations—the grand objective of all enquiries in Political Economy. (Malthus [via Tabb, 1999, 64])

Mirowski states that while Jevons's work on the physical causes behind business cycles has not been dismissed completely, sympathetic authors tend to attribute his agriculturally induced periodicity to the "pre-modern" world, before the great fossil fuel age (Mirowski, 1984, 354). Leaving the idea of sunspots behind, we can thus move to something more relevant—first, weather-induced economic fluctuation, and, more generally, the influence of changing natural resource availability on the economic system over longer periods.

Agriculture no longer rules the world. The productive matrix and its fuels have changed. Fossil energy (petroleum in particular) has assumed a significant role in regulating the economy's growth cycles (see for example Hamilton, 2005; Cleveland et al., 1984). The climate is also changing, lending new urgency to the idea that weather-induced agriculture cycles might influence business cycles. If there is a relationship, then greater variability in weather might produce greater volatility in business cycles. We return here to uncertainty and expectations—climatic patterns

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[8] Financial panics, notably, often occur in September and October, harvest time, when agricultural yields for the year become known in the Northern hemisphere. The year's tallies are made, and people begin planning for the next one. Will storage be drawn down? A bad harvest means it will be, putting less investment and money into local economies, the explanation favored by Keynes.

in the past were more stable and predictable, but have now shifted their historical probability distributions (Hansen, 2013).

By the later part of the 20th century our climate had already begun to change. The years 1998 and 2008 were notable for extreme weather. Both 1998 (the Asian financial crisis) and 2008 (the Great Recession) are also familiar dates of financial calamity, though in both cases the downturn began in a previous year. It may also be remembered that in 2008 there was a major food crisis around the world. Though the linkages remain largely unexplored, another signal seems to now influence agriculture and the economy—a far more volatile one.

There exist recent results correlating weather patterns and "surprises" in commodity prices and inflation. For example, a paper published in the *Review of Economics and Statistics* in 2002 found significant and large influences from the El Nino Southern Oscillation (ENSO) on commodity prices, inflation, and world economic activity, approaching 10% to 20% in magnitude (Brunner, 2002). Stretching further back, the historic drought of the Dust Bowl, from 1930-1939, coinciding with most of the Great Depression, is generally agreed to have affected the business cycle. The relevant question is by how much.

Jevons mentions a "whole controversy about the connection of Indian famines with the sun-spot period," which he assumes will be familiar to readers of *Nature* (Jevons, 1878, 36). Variations in the monsoon, in latitudes besides the European, fit better with business cycle patterns than did European grain harvests. Fluctuations in Western European trade must stem from "communication with the Indies," or trade with "India, China, and probably other parts of the tropical and semi-tropical regions." Here the global capital circuit links Monsoon to Bourse. Jevons inferred that countries with the most trade with the warmer latitudes, including major colonial powers of the time, stood to be the most affected—especially those which grant long credits to their customers, which extend over a number of years and in agricultural crises would be more likely to default. The famines of 1878 in India he connects to the tribulations of the Glasgow Bank and its Indian trade. In the globalized, multinational world of today this type of effect, sunspots aside, bears further investigation. Expanded mechanisms to dampen climate-induced agriculture fluctuations jump out as a policy prescriptions.

I take two key points from the history of Jevons's sunspots theory and Keynes's efforts to make it respectable. The first is the tendency of modern economics to scorn biophysically based theories and idealize the circular flow through economies as independent of changes in their underlying physical base. The invocation of "technological change" and smooth substitution often ward off any concern over the effects of diminishing returns from that base (the classical example is Barnett and Morse, 1963). Any remaining effects largely end up in the "sunspots," or random extrinsic variable, bin.

Yet the second crucial point is that, on the contrary, resource signals or "pulses," extended beyond agriculture to modern fossil sources, especially oil, have important effects on the economy. Further, their cyclical nature and predictable patterns—especially with regards to economic disruption—make it difficult to construe them as random. For the remainder of this chapter, I will present in the broadest term's energy's regular effect on economic and monetary systems, while turning to specific effects on the US internal balances in Chapters 4 and 5, and US external balances, in particular with relation to China, in Chapters 6 and 7.

Changing Surplus and the Organization of Political Economies

To begin we must compare our modern crises to previous ones, searching for drivers in newer resource cycles—especially oil discovery and production. Variations of the "energy yield" or surplus from existing energy extraction techniques (Carbajales-Dale, 2014) also deserve attention. In the twentieth century, and the beginning of the first, the "true but mysterious periodicity" (Jevons, 1878, 33) has evolved, but certainly not disappeared.

We have advantages in tracing this signal. Jevons called for more precise measurements of heat and solar radiation. He lamented the state of such observations, longing for "half a dozen" researchers to go out and measure the strength of the sun's rays over time (Jevons, 1878, 33). He accepted the possibility of ridicule if no variation is found, admitting that the sunspot period may be a proxy for another meteorological cause.

Benefitting from today's science, we may precisely observe changes in radiative forcings, in global warming's alteration of hydrological patterns. We have superb data on fossil energy extracted and traded each year around the globe. In this we have far more to work with than did Jevons, who due to his work on coal, and on trade cycles that fluctuate with natural causes, should be claimed as an early ecological economist—and a brilliant one. The young but already advanced Keynes in 1905 that he had become "convinced that he [Jevons] is one of *the* minds of the century" (Felix, 1999, 54).

Jevons's object was the signal underlying the epiphenomena of the economic surface; he found one linked to energy, or, more broadly, resources. For Jevons and Keynes the root of the business cycle most likely lied in the *varying concentration and storage of solar energy by plants*. In fat years these "batteries" get fully charged; in lean years they are drawn down. A century earlier, the French Physiocrats, predecessors of Adam Smith and theorists of the Tableau Économique, foundational to modern economics, held a similar view: agriculture was the fount of all wealth. It determined the surplus conveyed into the social system and then distributed among the classes. Surplus also lies near the heart of Keynes's handling of harvests and trade cycles. The social surplus, analogous to the harvest carryover, is a powerful idea of the classical economists, obscured by the rise of marginalism in the late 19th century.

Crucially, agricultural surpluses in a country such as France were often traded. A year of poor harvests would reduce this surplus, thus reducing the magnitude of its trade counter-flow, often English manufactured goods. The agricultural country, bringing less to markets, calls forth fewer goods from the manufacturing country. Manufacturing capacity built for expected larger trade volumes, and its financiers, must struggle through losses. A reduction of demand hurts profits, causes marginal businesses to fail, and delays new investment. The entire system, running on increasing magnitudes of trade, slows.

How are agricultural and mineral harvests different? How can we compare their yields and the patterns inherent in them? Agricultural surpluses might be thought, traditionally, to vary regularly over the course of a few years. Mineral harvest cycles, the exploration and production periods of fossil fuels, are longer and marked by high initial yields that fall as fields are exhausted. At a certain point the yield becomes lower than the system can handle with a smooth adjustment—for whatever reason—and a crisis occurs.

The price of fuels rise sharply, new resources are brought on, and the cycle repeats as the latter are drawn down. Boom years of harvest come after lean years of energy investment, when markets are oversupplied with energy, no longer a constraint[9]. The energy surplus allows for higher growth rates than in the price adjustment and investment period. In this dissertation I examine several such periods, in particular those occurring after Britain yielded "world's workshop" status to the United States, and the US yielded it to China.

In essence Jevons described a regular pulse of energy driving economy cycles. This idea would later be elaborated by Howard Odum's "pulsing paradigm" (Odum, 1988)[10] for both nature and economies, though there is no indication Odum knew of Jevons's work. These pulses, similar to the "persistent gales" of creative destruction envisioned by Schumpeter (2013 [1942]), may also drive complex adaptive cycles and systems at the edge of chaos (Gunderson and Holling, 2002, 34; Lansing, 2003). This latter position is crucial for self-organizing systems, which explains why Odum declared they must organize around a source of pulsing or develop one of their own (Odum, 1988, 1134). Technological and resource pulses are complementary and generally coupled. Innovation frees up previously occupied resources, exploits old ones in new ways (such as coal and the steam engine), or both, acting similarly to a pulse of energy in an ecosystem.

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[9] Ideas of constraint from ecology, including Liebig's Law of the Minimum, may be useful for investigating limiting factors in economies, and could conceivably be paired with production functions, such as the Cobb-Douglas, modified to include energy and other binding factors.

[10] This may also have analogies with various theories of the universe posed by modern physicists, but the subject lies beyond the scope of this work.

Several convincing resource-driven explanations of societal change have appeared in recent years. Joseph Tainter (1990) studied dozens of diverse historical societies and found a regular pattern. Like Jevons, Tainter sorted through a welter of explanations—some conflicting, some complementary—to find his pattern: declining resource productivity produces a diminishing payoff to complex social organization. He relates social complexity, which he measures as the number of possible social roles, to available resources.

For Adam Smith, the extent of the market in a given sector determined the complexity of the division of labor (Smith, 1904 [1776], I.3). Yet the extent of any market will, of course, be limited by available energy. In other words, the expanding and interlinking markets that drive globalization's increasing complexity are threaded together by cheap fossil fuels and their large energy surpluses.

As available energy resources decline in productivity (surplus), while costly social structures are built up around them, a new injection or pulse, attained through discovery or conquest, becomes necessary for expansion. Otherwise that structure is at risk of contraction and devolution. This, according to Tainter, makes it fragile, vulnerable to other factors (ie., social unrest, environmental stress, invasion) to which historians attribute collapse. He gives the example of the agriculturally based Roman Empire's later stages, when high increasing resource returns from conquest gave way to punishing maintenance costs. Exacerbated by emergency expenditure needs, these complex structures built in times of plenty eventually ate up diminishing resources surpluses and induced a steady devaluation of the Roman coin (Tainter, 1988, 135-149).

The key argument is that major fluctuations in political economic systems, especially the relative fortunes of great nations, often stem from changes in net resource yields—especially available energy. The sunspot theory is mostly useful as an example of how energy pulses through an economy, creating waves in other systems as it goes—and as an example of how this idea has been treated historically. In agriculture we convert solar energy to a form readily absorbed by humans, who then convert it to work. Work, in its physical sense, done by humans or capital equipment, builds and sustains economies. As Odum's (1971) path-breaking work indicated, the best physical analogy for an economy is not a machine, but an ecosystem, built upon successive trophic layers, external energy inputs, and internal exchanges.

My primary interest lies in fuels that supplanted current solar energy during the Industrial Revolution, of which Jevons was a prime observer. These fuels—oil, coal, and natural gas—and their discovery and production cycles may have produced a new signal for the business cycle, a precise theory of which, much studied elsewhere, is not the central point here. The focus here lies instead on the relationships between energy systems, political economy, and monetary systems.

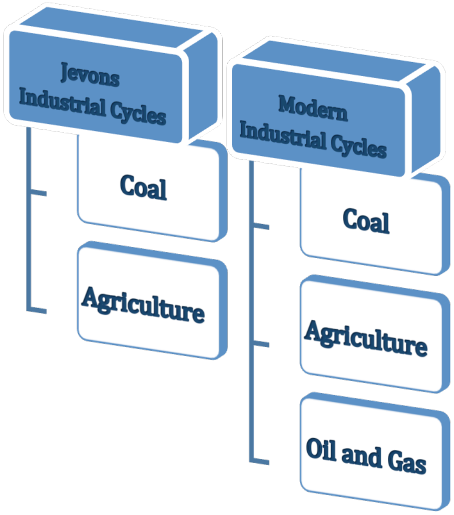

Figure 8. Hydrocarbons and Agriculture at the Base of Global Production

Patterns emerge over time. Nations follow similar and predictable paths as they rise and fall in the global power structure. Available energy can help explain these movements, while adjustments in its circulation causes ripples and great waves in global economic and monetary systems. As will become clear in Chapter 3, energy patterns often explain a great deal of a nation's position in the global system. Yet neoclassical economics consistently underestimates energy's influence, lumping it in with all other commodities. In the next section I examine this treatment.

Energy's Importance in Production: a Neoclassical Blind Spot

As oxygen is to the body, energy is to the economy. Unique among commodities, energy has no economic substitute. It is, after all, the only economic sector named for a fundamental physical entity: we have no "mass" or "force" sector. In *The Coal Question* Jevons put it this way: "Day by day it becomes more evident that the Coal we happily possess in excellent quality and abundance is the mainspring of modern material civilization" (Jevons, 1866, I.1). The politician Gladstone echoed him in Parliament shortly thereafter (Madureira, 2012, 413), while George Orwell informed the literary world in the 1930s:

> Our civilization, *pace* Chesterton, is founded on coal, more completely than one realizes until one stops to think about it. The machines that keep us alive, and the machines that make machines, are all directly or indirectly dependent upon coal. In the metabolism of the Western world the coal-miner is second in importance only to the man who ploughs the soil. He is a sort of caryatid upon whose shoulders nearly everything that is not grimy is supported. For this reason the actual process by which coal is extracted is well worth watching, if you get the chance and are willing to take the trouble. (Orwell, 1957, 53)

Energy ultimately limits industrial production. One cannot run machines without it, and machines are the heart of our global economy—a factory system still, despite the rhetoric around "service economies." Other shortages come into play at specific locations: human labor, water, metals—yet in general energy is the universal limiter and thus regulator of economic cycles. Conventional economic wisdom, however, frames growth as something of a mystery, the theory revolving around mysterious qualities such as "innovation," "total factor productivity" and even the massively aggregated "capital."

Yet before addressing the role of energy in economic fluctuations further, however, it might help to focus on empirical support for the crucial role of energy. Particular attention is paid, in ecological economics, to the marginal productivities of energy inputs (Ayres & Warr, 2010; Kummel 1989), which have a non-linear effect on economic output, depending on the degree of energy availability. Small bursts or reductions influence output on a scale commensurate with energy's cost share of GDP (roughly 2-4% in normal years, 5-7% during oil price spikes—see Aucott and Hall, 2014) but larger supply disruptions ramify through the economy and almost literally bring it to a halt.

These assertions are supported by recent empirical and theoretical work in ecological economics. Much of the work centers on alterations to the Cobb-Douglas model and Solow's growth theory (1956). The central goal is to add energy as a factor of production, yet given the assumptions of Cobb-Douglas type models—such as constant returns to scale and a one-sector economy producing one all-purpose good—it is not a mathematically trivial task to alter the equation and its assumptions.

Using a simple Cobb-Douglas formulation:

$$Y = A(t)(K^{a}L^{b}) \tag{1}$$

We can move to the LINEX model of Kummel:

$$Y = AE\exp[a(t)(2-(L+E/K)) + a(t)b(t)(L/E - 1)] \tag{2}$$

Here E, or "exergy," available energy, joins the familiar K (capital) and L (labor), along with two time dependent functions, a(t) and b(t), which Kummel labels "capital efficiency" and "energy demand" (Ayres & Warr, 2010, 190). Meanwhile in LINEX, A—the nebulous "Total Factor Productivity" or "innovation" coefficient of the neoclassical Cobb-Douglas, works out to unity, allowing it to be set aside.

The first equation is certainly more elegant. In this case, however, LINEX provides insights the Cobb-Douglas cannot by limiting the extent to which the factors of production—capital, energy, and labor—can substitute for one another. It is also forgoing the "cost-share theory": the idea that the marginal productivity of factors of production must be equivalent to their distribution in GDP. Over time this amounted to something like 70% for labor, 25% for capital, and 5% for energy. The LINEX production function allows us to see a different world emerging in the 21st century, one in which automation, capital, and energy to keep the machines running play an increasingly important role in economic growth (Kummel et al., 2008).

LINEX also reflects technical constraints around combinations of energy, capital, and labor. Doing so produces a tight fit to historical experience, vastly reducing or even removing the "Solow residual": the unexplained 50% or so of growth often attributed to "technological progress" or "knowledge" (Stresing, 2008). There would seem to be an urgent need for such models, as neoclassical growth functions that fail to reflect physical reality remain embedded in important policy tools. A Cobb-Douglas function used in the DICE model, one of the most well-known climate-economy models, until 2007 used only capital, labor, and technological innovation variables, assumedly using as baseline settings approximately the same marginal productivities or output elasticities (0.7 for labor and 0.3 for capital) researchers such as Kummel and Ayres have challenged[11].

Work in ecological economics on more realistic production functions upsets the old neoclassical argument that energy can't be that important to the economy, as it accounts for only 5% of GDP, with labor and capital accounting for more like 70% and 25% (Aucott and Hall, 2014). This view leads to confusion among economists when they try to account for economic declines and crises that regularly occur with regularity at the end of energy price run-ups (Hamilton, 2005). The 1970s and 2000s produced spectacularly nasty examples; something is happening here, but they don't know what it is. One wonders, idly, if a production function that explicitly took energy into account had been part of the Keynesian apparatus, whether that system would have lost its hold in the 1970s over economics and, later, government.

Taking energy as an increasingly important factor of production and labor as an increasingly unimportant one clears up much of this confusion. Ayres (2009, 3), illustrates with a simple thought experiment, posed in response to a particularly puzzling downgrading of agriculture by the Nobel-winning economist Schelling, that "*the marginal productivity of petroleum must be far greater than its tiny cost share.*" Ayres uses an example of petroleum input, at 4% of US GDP, being halved, and shows that the effect would be much larger than a 2% loss in GDP. Schelling argues the opposite, but for agriculture. Yet such a cut would clearly ramify across allied industries, transportation, and the entire economy, given that *there is no substitute for liquid hydrocarbons.*

The problem here lies partly in the failure of mainstream economics to account for the lack of substitution possibilities, or the technical requirements of various combinations of capital, labor, and resources that make an economy work (Kummel, 2008). The cost-share theory is simple: since energy is 5% of GDP, it must

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[11] As of 2013 carbon energy surpluses are included in the DICE Cobb-Douglas output function (Nordhaus, 2013), though its default setting is not immediately clear.

contribute something like 5% of the output in the economy? Probably not. Respiration may be a small fraction of our human energy use or brain function, but it is hard to get on without it. This analogy applies to energy and the economy as well. A physics-based approach to economics (rather than a physics-formalism approach—see Mirkowski, 1991) helps us understand this, showing the centrality of various types of work across all industrial, commercial, and agricultural processes. An input-output-based general equilibrium model (GEMs), as Ayres notes, would likely show this effect more satisfactorily. While most GEMs import the underlying neoclassical assumptions, such as perfect competition and maximizing behavior (Bhattacharyya, 1996), they still find much larger effects from energy production declines than one would expect from the marginal productivity assigned energy in mainstream growth models[12] (see for example Hogan and Naughten, 1990).

As noted by Cleveland and his collaborators (1984), growth in energy and GDP are tightly bound[13]. Later work in ecological economics has reinforced this point (Kauffman, 1992; Ayres & Warr, 2005). It is clearly not always the binding constraint on economic output—labor or capital can also play this role. Yet normally energy correlates so tightly with growth—especially in its limiting phase—that it suggests in a world of high unemployment and free capital flows, that energy is most often the prime constraint on capital accumulation. While other resources—water, rare earth metals—could certainly constrain aspects of production in coming decades, energy currently seems the most important to include in production functions.

Labor and capital are, of course, not independent of energy—people eat food, an energy source, and all physical capital is produced with an expenditure of energy[14]. It also takes human labor and some sort of capital to produce energy. A mutually constitutive or reciprocal relationship occurs; the factors are cointegrated. Yet labor is shown by recent work (Stresing, 2008, Kummel, 2008) to be the "weakest" of the three factors in advanced economies from the second half of the 20th century, with

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[12] In Mankiw's *Macroeconomics*, energy is omitted as a factor: it is stated that "the two most important factors of production are capital and labor" (Mankiw, 2003, 44); in Samuelson and Nordhaus (2005, 218), natural resources of all types are aggregated into one factor of production.

[13] This relationship becomes very tight once changes in energy quality (the greater "usefulness" per joule of some sources over others) are factored in. "Energy quality," however, is logically a qualitative concept that seems rather arbitrary when assigned a coefficient and used mathematically. We will proceed without it.

[14] This is one reason leaving food and energy prices out of "core" inflation always seems absurd. We cite the 2000s as a time of low inflation, while the price of "volatile" oil increased 500%, bringing gas prices with it (property, health care, and education prices also rose dramatically). Industrialized US food prices, meanwhile, remain low, as do mass-produced consumer goods.

capital and energy the strongest drivers of output. This is the reverse of the traditional "cost-share theory," where labor receives 70% and capital 30% of the weighting in the production function (with energy cut in at 5% occasionally).

China's economic rise after joining the WTO, and the portion of its spectacular growth attributable to capital, labor, and energy, should be reevaluated in this light. The relative weighting of factors in China likely changed substantially over the 2000s as massive foreign investment built up advanced manufacturing—we can assume labor's importance diminished greatly over the decade. As China became more dependent on automation, one might assume they also become more dependent on capital equipment and fuel[15]. Causes of the financial crisis in the 2000s should also be reevaluated around energy—focusing less on "triggers" such as rising oil and gasoline prices in the US and more on structural components such as the energy differential between China and the US, the financial structures erected to handle them, and China's increasingly costly coal. The latter and high oil prices may both have provided binding constraints in growth from 2007-2009.

Such materialist views of the economy do not please all. "Total factor productivity," "technological progress," and "knowledge"—used to explain the Solow residual left over after capital and labor are accounted for in the traditional production function—provide a sense of comfort, reinforcing the idea that human ingenuity overcomes all constraints, now and forever. Thermodynamics, however, seems the one insurmountable barrier.

Studies advancing energy theories of society or value often generate an outcry against "determinism" or "energetic dogma," even among ecological economists (Rosa, 1983; Georgescu-Roegen, 1986). Yet given their explanatory power, interdisciplinary energy- and resource-focused work exemplified by Hall and Klitgaard (2011), Tainter (1990), and Mitchell (2009) has helped social scientists understand the importance of available energy, its extraction techniques, and its supply and price fluctuations. Energy is the oxygen of global production's anatomy, essential to its function. Yet determinism does not necessarily follow from this—human ingenuity remains unpredictable, and to posit certain physical boundaries and trajectories is not to foreclose possibility. The abundances of our coal, oil, and uranium age would have seemed unlikely to Malthus. The error occurs in taking such historic abundances as given in perpetuity, or in ignoring their effect.

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[15] The idea that increased automation would eventually reduce the value of labor goes back at least to Marx (see Tabb, 1999) who thought it would eventually overturn the labor basis of value constructed by the classical political economists.

Chapter 3. Energy, Money, and the Structure of the Global System

> "Above all, there is the indisputable fact that all struggles between the Great Powers have not turned idly around ideologies or national prestige but around the control of natural resources. They still do."
> --(Georgescu-Roegen, 1975, 350)

Fossil fuels and their high yield of available energy regulate the global economy and structure its hierarchy of nations. When a "pulse" of energy—over months, years, decades, or centuries—enters the global industrial system, we often see overshoot dynamics. The system enters a new mode of production, with new technical combinations. Once it does, it is extremely difficult to return to the old infrastructure, even though the energy resource that provided the pulse likely will yield less over the years (the US and its highway system provides one example of an infrastructural system conceived in a higher-yielding environment, the US oil boom of the early 20th century). As the energy surplus, or marginal resource return, begins to diminish, output declines, slowing the rise of powerful nations[16], and transferring growth elsewhere.

The effects of declining returns often show up in the monetary system. Tainter (1990, 139) gives a historical example discussed in the last chapter—debasement of Roman currency over hundreds of years after the reign of Augustus. As the surpluses available to the rulers of Rome diminished, with more spent on maintenance of lands won through conquest, reducing the precious metal content of official currency was a method of squaring the imperial accounts. While this resulted in high levels of price inflation, the soldiers were paid.

A nation's total primary energy supply and its cumulative growth only indirectly relates to that nation's net energy yield or surplus across various sources. To get at the latter, we can think about energy in terms of the overall economic surplus required to produce it. The more a nation plows its economic surplus back into energy production, the less remains for other sectors. We can take the US as our example, and observe the "petroleum and coal products" sector in the postwar period consuming a large part of the surplus, contracting through the 1960s, and then exploding in the late 1970s and early 1980s, garnering nearly a third of our proxy measure, after-tax corporate profits. After more than a decade of enormous oil investment, its portion of the surplus disappears as prices collapse for nearly 20 years. During this period banking begins to consume 15-25% of the surplus.

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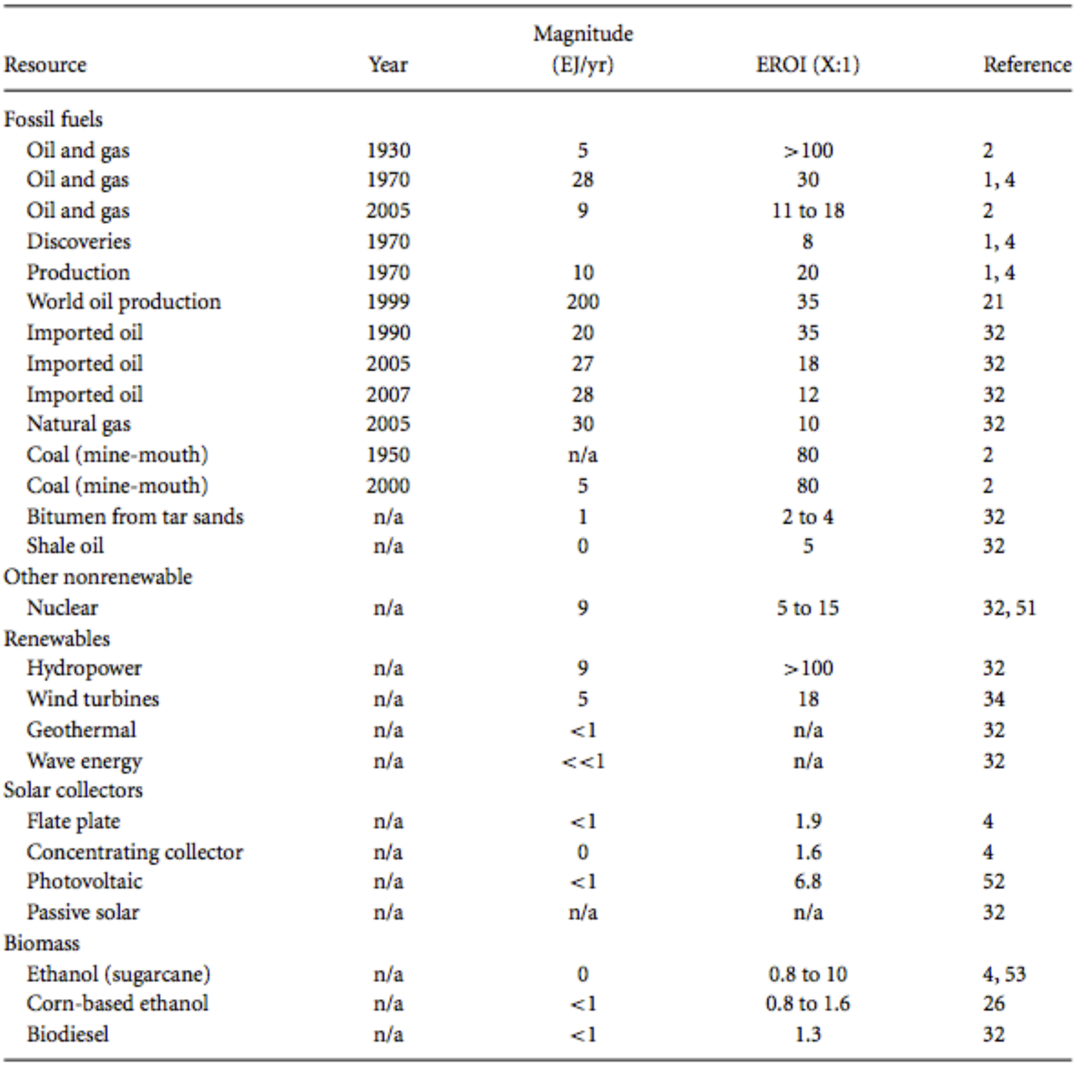
[16] The "shadow price" of a given factor is another way of looking at the issue. As it rises, its constraint on growth increases. At a certain level the global price matrix must readjust.

Table 1. Indicative Energy Return on Energy Invested, Major US Sources. *Source: Reproduced from Murphy and Hall, 2010.*



Resource	Year	Magnitude (EJ/yr)	EROI (X:1)	Reference
Fossil fuels				
Oil and gas	1930	5	>100	2
Oil and gas	1970	28	30	1, 4
Oil and gas	2005	9	11 to 18	2
Discoveries	1970		8	1, 4
Production	1970	10	20	1, 4
World oil production	1999	200	35	21
Imported oil	1990	20	35	32
Imported oil	2005	27	18	32
Imported oil	2007	28	12	32
Natural gas	2005	30	10	32
Coal (mine-mouth)	1950	n/a	80	2
Coal (mine-mouth)	2000	5	80	2
Bitumen from tar sands	n/a	1	2 to 4	32
Shale oil	n/a	0	5	32
Other nonrenewable				
Nuclear	n/a	9	5 to 15	32, 51
Renewables				
Hydropower	n/a	9	>100	32
Wind turbines	n/a	5	18	34
Geothermal	n/a	<1	n/a	32
Wave energy	n/a	<<1	n/a	32
Solar collectors				
Flate plate	n/a	<1	1.9	4
Concentrating collector	n/a	0	1.6	4
Photovoltaic	n/a	<1	6.8	52
Passive solar	n/a	n/a	n/a	32
Biomass				
Ethanol (sugarcane)	n/a	0	0.8 to 10	4, 53
Corn-based ethanol	n/a	<1	0.8 to 1.6	26
Biodiesel	n/a	<1	1.3	32

These effects carry across international boundaries as well. Energy is not only a primary limiting factor for any advanced economy—the constraint that usually bites first—it is also the most important component of global trade and currency movements. Oil is by far the most important commodity in global trade, at roughly 15% of total export value in 2013 (total crude liquids). Coffee, the second most traded commodity by value, accounts for *only about three percent of global trade over the past decade* and is now challenged by natural gas, which went from less than one percent in 1998 to more than two percent by 2013 (UN Comtrade, 2015).

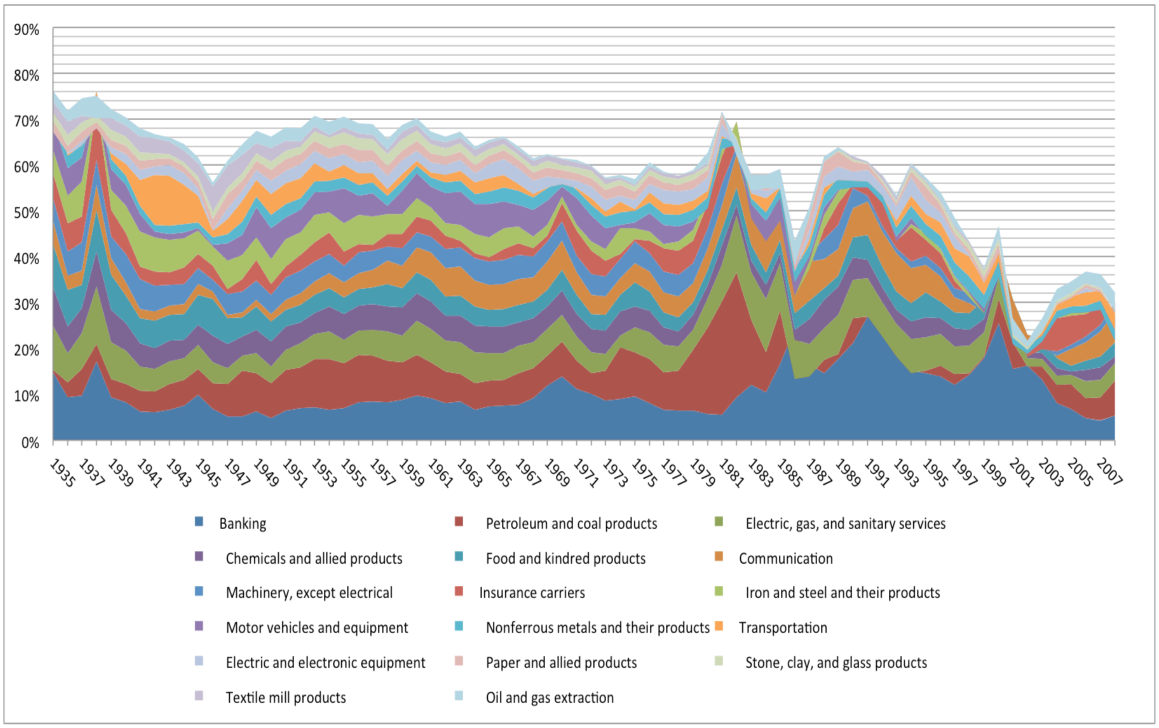


Figure 9. Structural Change in the US Economy: Percentage of After-Tax Profits for Selected Industries, 1935-2008. *Note: Banking, Petroleum and Coal Products, and Electric and Gas, etc. are the first three industries from the bottom. Source: Author's calculations, BEA NIPA tables.*

Considering its size and price volatility when compared to other commodity types, oil would logically influence exchange rates. The importance of exports to growth reinforce energy's status as the crucial factor in global economic competition. While driving local and national economies, energy costs pace global economic competition, the latter at root a race to partition ever-increasing amounts of global value (represented by, for example, monetary gold or reserves).

Figures 10-13 below suggest a modern twist on Malthus (1798) and his observation that agriculture grows arithmetically and population geometrically. Money, as noted by Frederick Soddy (1933) and a number of others, grows geometrically. Energy, however, subject to physical laws, generally falls short of this, whether in the cultivation of crop energy or slowing rates of oil production growth[17]. As visible in Figures 11 and 12 above, the periods of 1967-1979 saw oil production rising far beyond its long-term trend rate, a pace which could not be sustained. The same overshoot dynamics that apply to populations outstripping their agricultural resources may also apply to money and debt outstripping energy. Only through a difficult period of adjustment—involving expansion then contraction of the money supply and a completely new pricing regime for energy—has this imbalance been

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[17] I ignore here the very long-term necessity of entropic degradation, as in, for example, Georgescu-Roegen (1971).

resolved, flattening out near-term energy and money growth rates while bringing on a new slate of resources from intensified exploration and development.

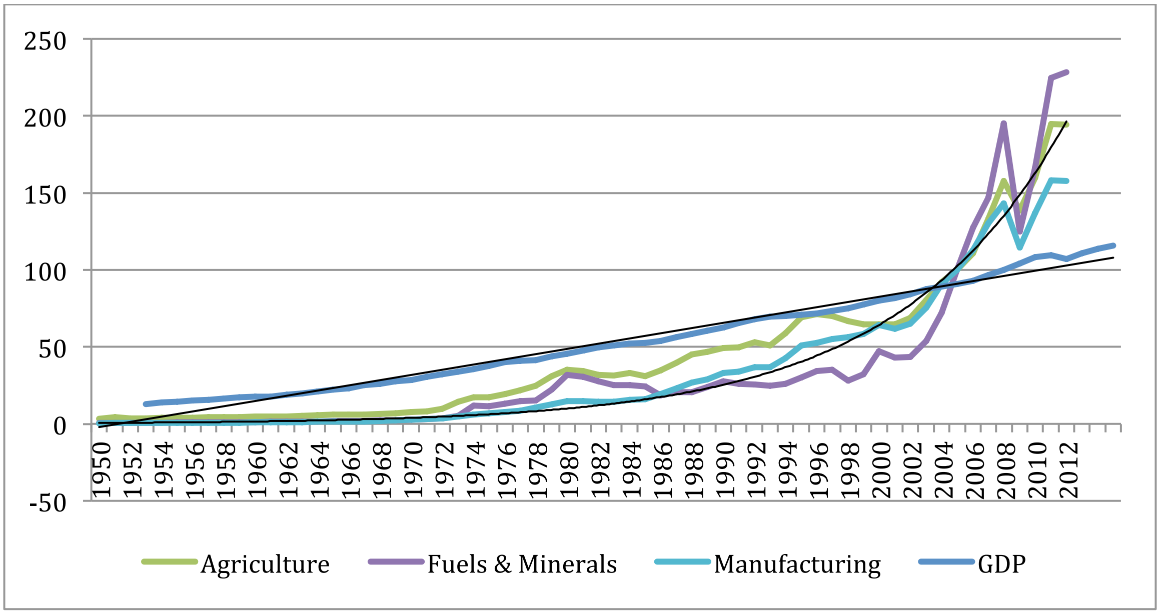

Figure 10. Historical Expansion of Global Trade, 1950-2013, by Value (2005=100).
Source: WTO Trade Statistics

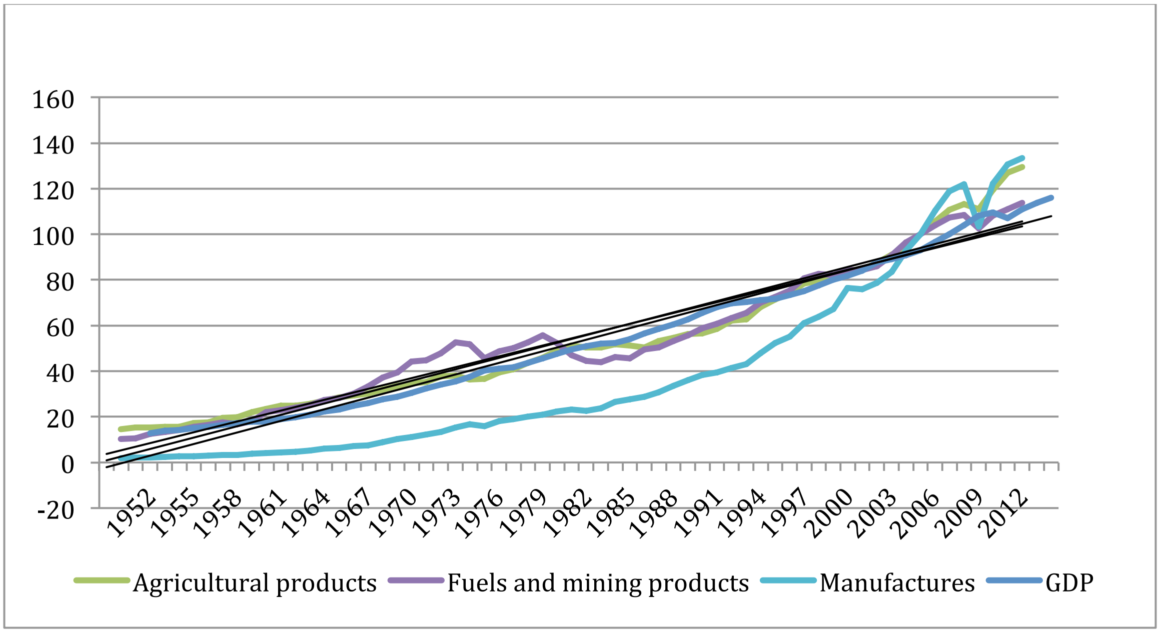

Figure 11. Historical Expansion of Global Trade, 1950-2013, by Volume (2005=100).
Source: WTO Trade Statistics

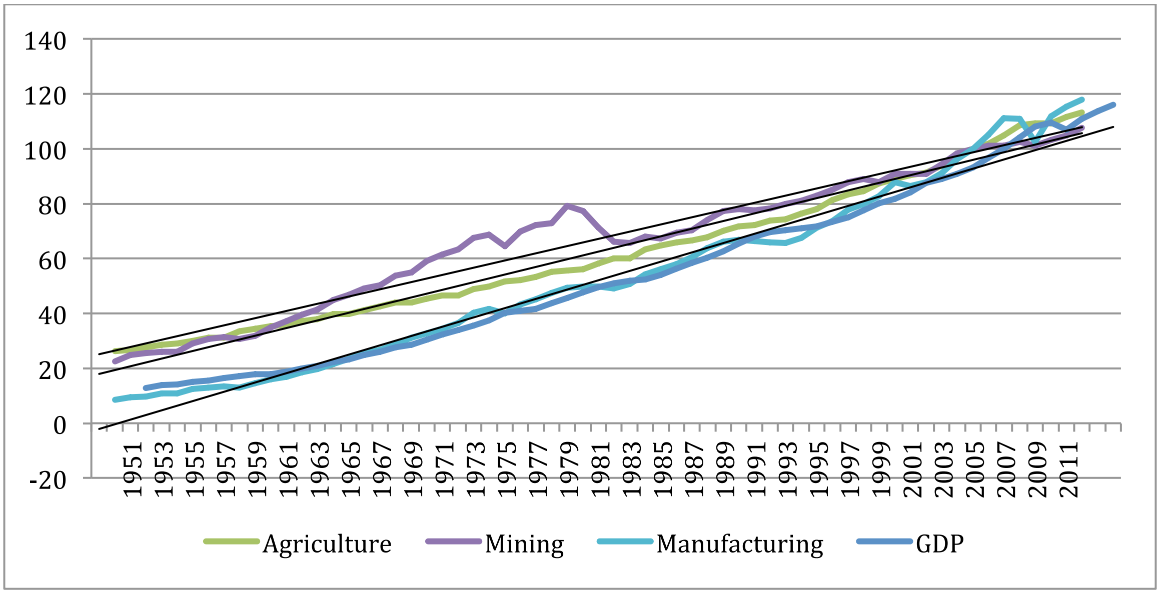

Figure 12. Historical Expansion of Global Production by Volume (2005=100). *Note: oil and gas accounts for the bulk of the mining sector—the overshoot in production through the 1960s and 1970s, or "the bump"—is clearly visible here and in Figure 11, above. Source: WTO Trade Statistics*

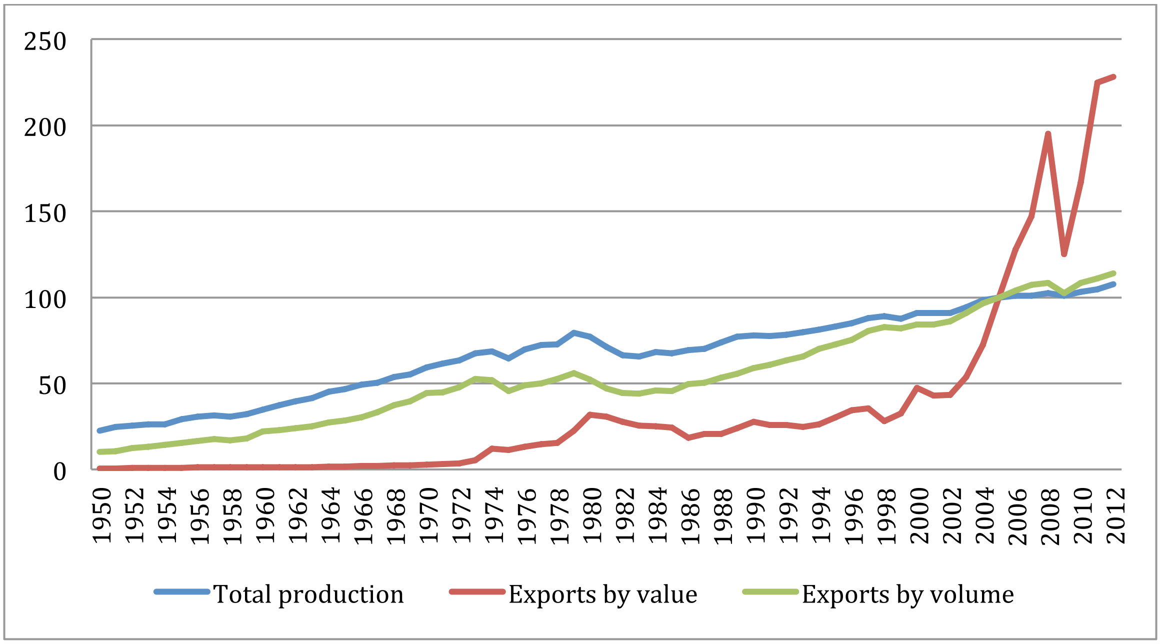

Figure 13. Comparison of Global Expansion in Fuels & Minerals By Value, Volume, and Production (2005=100). *Source: WTO Trade Statistics*

Through most of modern economic history, global trade has been structured by the energy sector—terms of trade adjust to energy productivity, along the lines laid out by Jevons (1866)—while energy itself became the central global flow in the late 19th and early 20th century. Meanwhile, hegemonic states such as Great Britain and then the US take responsibility for overseeing global monetary relations that guarantee and manage this system of flows. Yet a decline in energy production rates, global energy control, or a Hubbert-type peak within that hegemonic power can cause large disruptions in the global monetary and economic systems. The importance of the energy factor in production, discussed in Chapter 2, and the need for the hegemon to hold a "buffer" against production fluctuations, help explain this.

Table 2. Leading Global Producers, Changing Internal Energy Conditions. ***Note: Shale oil and gas drilling in the US has recently brought natural gas production past its previous peak in the early 1970s. Further, when natural gas plant liquids and other liquids are added to produce the metric "Total Oil Supply," the US becomes the top global producer as of 2014, with production levels apparently above those of the 1970s. The conventional crude peak, however, for now remains back in 1970 for the US.***

Nation	Key Source	Peak Production
Great Britain	Coal	1913
United States	Crude Oil, Natural Gas	1970, ?
China	Coal	Expected 2015

As shown by the fundamental contributions of Georgescu-Roegen (1971), Odum (1971), and Cleveland et al. (1984), as well as a generation of ecological economists who followed them, exergy (or useful work) cannot be separated from economic activity. Despite the enduring concept of "decoupling" the two, in practice this means doing either of the following:

1) exporting energy-intensive industries to less-developed nations, producing greater articulation of the global system (this increasing complexity, or division of labor, is engendered by high-yielding energy sources, see Tainter (1990) or Smith (1904 [1776]); or

2) substituting fuels with a higher energy "quality" or usefulness, such as primary electricity from hydropower, for those with less, such as coal (Cleveland et al., 1984).

After accounting for these two mechanisms, ecological economists such as Cleveland et al. (1984) find a deep correlation between energy and growth, as measured by changes in Gross Domestic Product (GDP) or similar. The economic system seems structured around the growth of energy resources in a nearly organic manner[18]. This relationship continues today. Whether one uses as a metric energy surplus or yield, or growth in total primary energy supply (TPES, equivalent to energy production plus imports minus exports), the world's declining return on its fossil base provides one explanation for the declining rates of growth in the United States

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[18] Howard Odum (1973, 223) gets at this organic relationship with his beautiful comparison of high-surplus fossil fuels to the leaves of a tree that get the most sun, produce the most energy, and come out first, enabling secondary and tertiary leaves to grow in places less opportunely placed to collect solar energy. Odum compares the latter to lower-yielding (compared to virgin fossil deposits) resources such as solar and wind energy.

and the world. In the graphs below we see a clear linear correlation between growth in world GDP and in TPES over the last 40 years. A similar relationship holds for the US over the past 50 years.

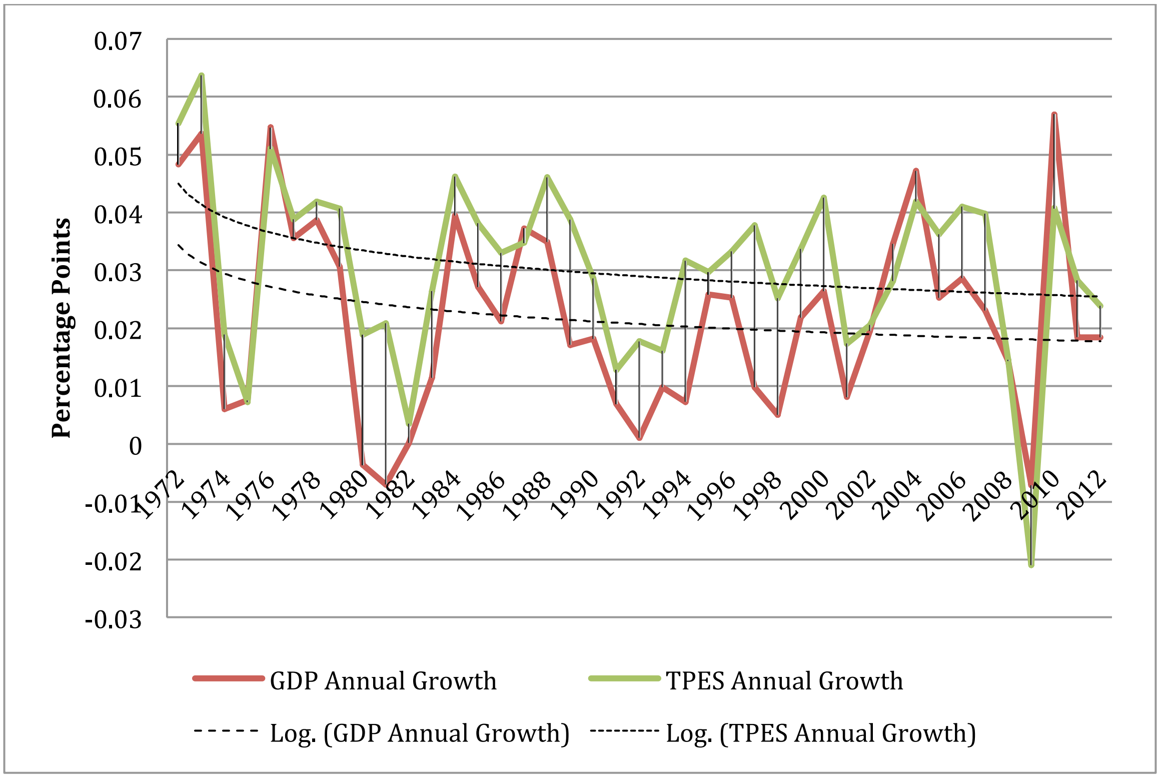

Figure 14. World GDP and Total Primary Energy Supply (TPES) Annual Growth, 1972-2012. ***Source: Data from International Energy Agency (IEA) global energy balances and IMF International Financial Statistics***

Economic growth has, for much longer than the last forty years, been inextricably linked to growth in fossil sources. Despite oscillation about the trend, despite running ever faster to stay in place, the latter proceeds inexorably in one direction. What was true for Great Britain in 1913 and the United States in 1970 has become a reality for contemporary China and the world at large: exhaustible energy supplies limit growth. The world now finds itself with sputtering expansion in its major centers—with one particularly notable exception.

The US has added dramatically to its domestic oil and gas production since the global financial crisis. New energy sources help push economies out of recession. By coaxing an extra million barrels of oil per day from shale oil deposits in North Dakota and two million from those in Texas, the US has pushed ahead of the European Union (EU) in recovery, with higher post-crisis growth rates. If China at its 2001 WTO accession was a case of ready domestic energy waiting for capital, the US shale oil boom was one of ready capital waiting for domestic energy.

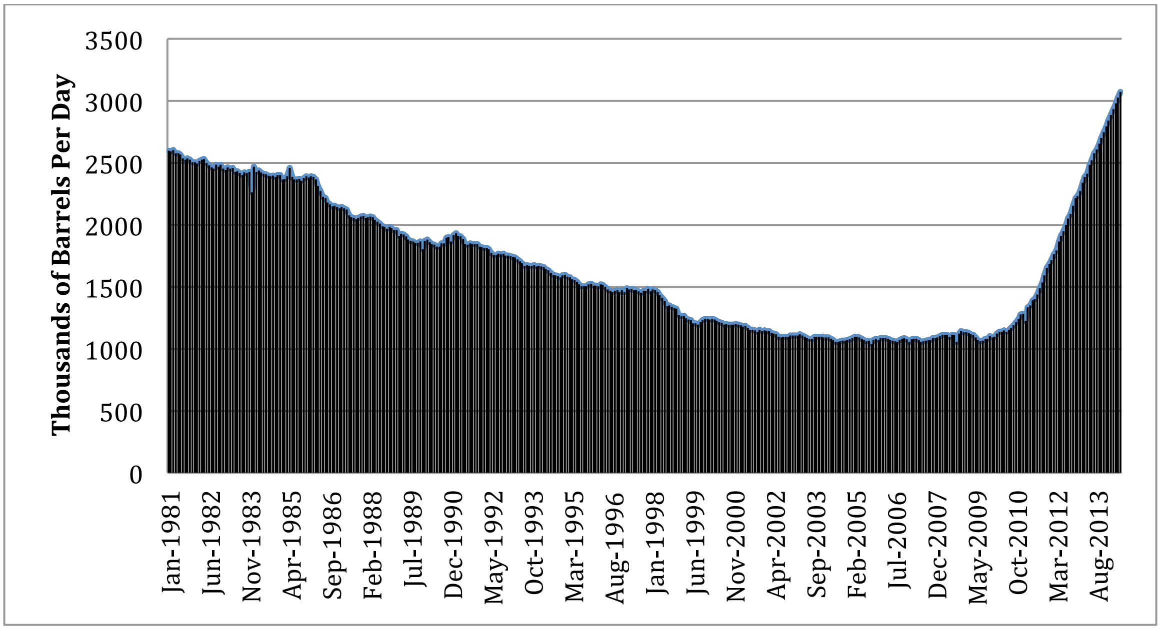

Figure 15. Texas Production of Crude Oil, 1981-2014. ***Source: US EIA***

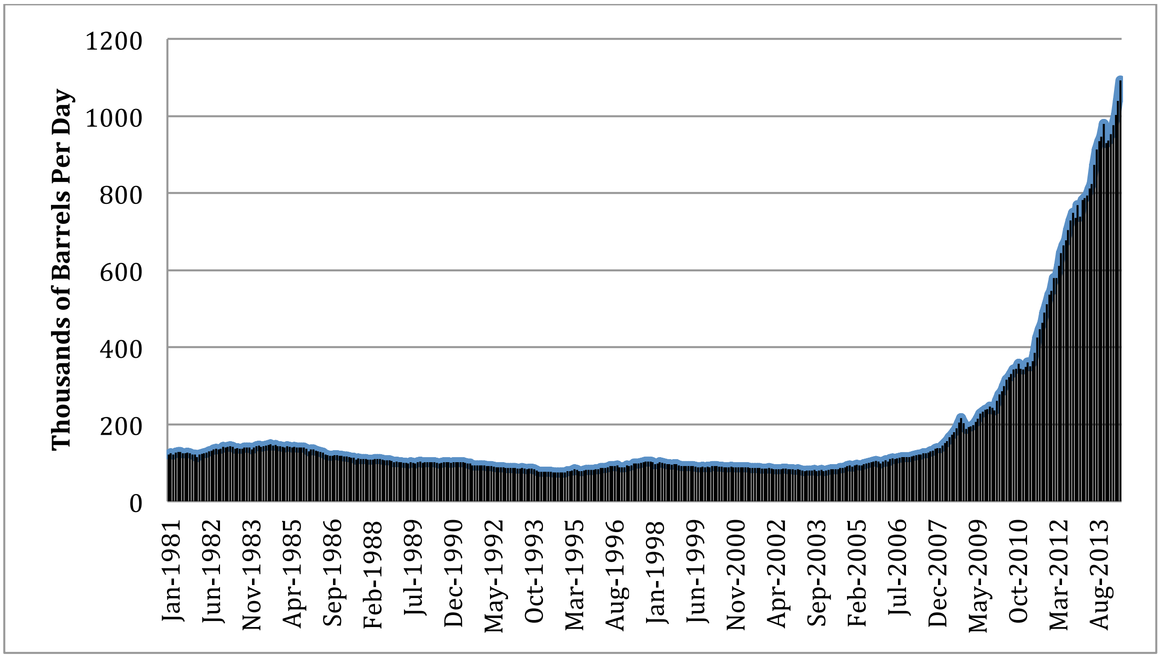

Figure 16. North Dakota Production of Crude Oil, 1981-2014. ***Source: US EIA***

This boom in US energy production has driven the dollar/euro exchange rate toward parity and brought a surplus of oil to global markets, halving the global market price over the last quarter of 2014. Yet given the shorter lifespan of these types of fields (Hughes, 2013), one may fairly doubt the durability of the shale boom. Further, unconventional sources of oil and gas carry larger environmental and climatic burdens. These two factors create uncertainty around such fuels as long-term economic solutions in a climate-constrained world.

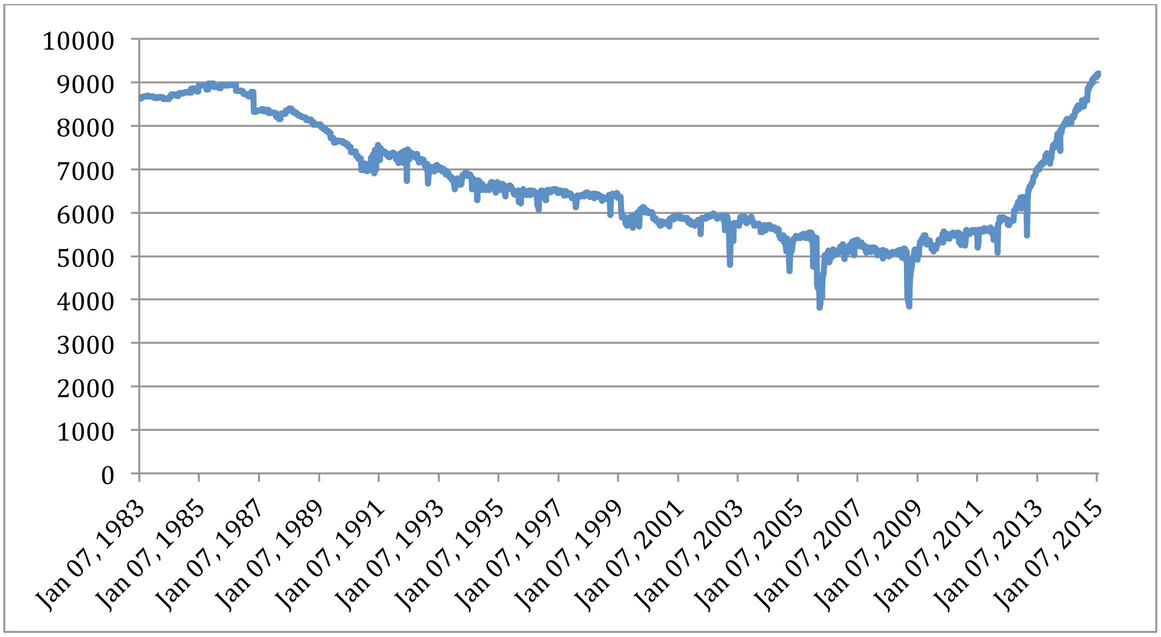

Figure 17. Weekly US Field Production of Crude Oil (Thousands of Barrels Per Day). ***Note: the downward spikes ("icicles") at 2004, 2005, 2008, etc., appear to be large-scale production cuts in response to ongoing or expected price changes (likely influenced in turn by interest-rate movements). Source: US EIA***

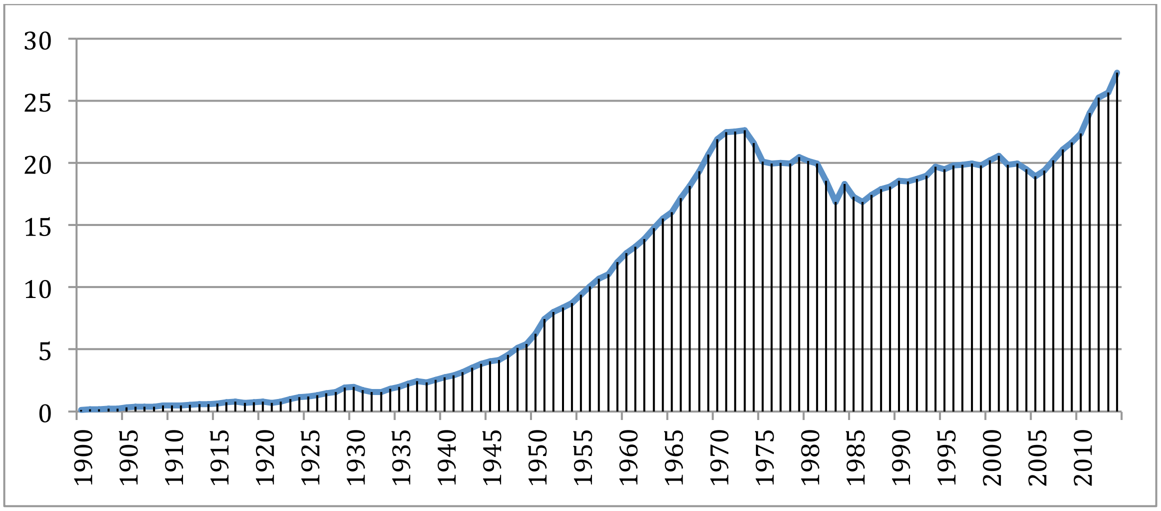

Figure 18. US Natural Gas Production, 1900-2014 (Trillion Cubic Feet). ***Note: in 2013 about 47% of US production came from shale or tight wells. Source: US EIA.***

As a global society we cannot buy our way out of energy constraints, though energy can in many senses transcend financial constraints. One aspect of the economy is imaginary, the other real[19]. One might argue that spending on energy research

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[19] Again, we saw the collision of financial and physical realities in Figures 10-13 on global trade; the global monetary value of traded fuel and minerals rises exponentially, their production only linearly.

allows us to transcend energy constraints. True, advances can help produce more energy yield for less energy expense, increasing our energy return on investment (EROI)[20]. Renewable technologies such as solar and wind do seem to be getting more efficient in this manner, as their costs suggest. Yet the trend for exhaustible sources often works the other way, as Jevons pointed out in *The Coal Question* (1866): as mines and wells run deeper, we continually spend more energy to receive less surplus in return—technology enables us to work harder to get less—or run ever faster to stay in place, as the saying goes[21].

Systemic Causation and an Ecological Approach

Of course, growth is a complex phenomenon. In ecology, from which I draw inspiration for the current study, limiting factors on the growth of species within an ecosystem include energy, water, and various available nutrients. Likewise for species of firms and nations within the global ecosystem, we might imagine that limiting factors include energy, capital, and labor. The claim is not that energy magically produces an economy, but that it underlies other factors, constraining them now to a larger degree than vice versa, leaving it the primary limiting element.

The trajectory of major economies over the past fifty years correlates directly to their energy supply. Linear regressions of gross domestic product (GDP) growth on total energy supply typically produce very high coefficients. Yet what causes what? Does that question even make sense, given systemic causality (Lakoff, 2010)? In the table below, I perform a series of Granger causality tests on differenced monthly US time series data (1959-2010). This provides a first approximation step to determine whether energy production gives us more future information about future economic growth or vice versa. Methods such as artificial neural network (ANN) modeling may be more appropriate to the complex, entwined, and reciprocal macro-, micro-, and physical processes at hand.

What does this mean? Relationships are reciprocal, embedded in a complex system, or nested complex systems. Energy both spurs and constrains economic growth, which in turn stimulates more energy development (toward physical limits). I share Odum's view (1973) that the economic system acts as a positive feedback loop for

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[20] Though Georgescu-Roegen (1971) reminds us that eventually the second law means the economic progression cannot be ever upward. This constraint might bite sooner than later. Until now the global upward trajectory in energy yield and production has mitigated the effects of local peaks, such as those in US oil (1970) and British coal (1913). However, when faced with the problem of "feeding" an economic system that requires enormous amounts of energy to maintain itself, let alone grow, it stands to reason that absent a tremendous new step forward in energy production, society will at some point see a peak in its energy production.

[21] On shale fields this process of keeping production up despite rapid field decline is known as the "Red Queen," named for a character from Lewis Carroll's *Through the Looking-Glass.*

energy production[22]. While industrial production seems central to the analysis, demand in foreign and domestic markets, as we've been reminded by Adam Smith, Keynes, and others, drives much of the cycle. We perform another round of Granger tests on a group of different variables in Chapter 7.

Table 3. Granger Relationships on Key Variables. *Source: OECD, Federal Reserve Bank of St. Louis (ALFRED)*

Lead	Lag	Cor.	Sign	Lag for Peak Strength	Granger direction @ 12 months
GDP	M2	0.65	Positive	-12 months	Both ways, Strongly
Industrial Production	GDP	0.50	Positive at peak around 0	Around 0, slightly leading	Both, strongly for Ind Pro lead
Industrial Production	Oil Imports	0.30	Positive peak around 0, later positive	Around 0, slightly leading	Oil import stronger predictor
Industrial Production	Monetary Base	0.30	Negative Peak around -1 or 2 months, later positive	-2 to 4 months	Strongly both ways

In Figure 19 below we see annual changes in the world's TPES (on a national level, domestic energy production plus net imports) [23]. When plotted against changes in GDP, a linear fit performs as well as nonlinear fits ($r^2 = 0.66$), such as exponential or logistic curves. Here, when comparing GDP and energy in change terms, I prefer to use nominal GDP, unadjusted for inflation, given that the money supply and price inflation are crucial to the understanding of the system, for this application it seems more appropriate not to adjust GDP with the problematic CPI index. Adjustment by such indexes can distort raw data, obscuring the very effects we search for and thus hindering scientific inquiry.

These simple statistical exercises reveal an intricate dance of energy-economy leads and lags. New energy resources spur new industrial activity, which induces monetary growth and further energy development, and so on. Untangling these cycles is difficult, as they feature systemic, rather than linear, causation. Cross-

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[22] These positive feedback loops, modeled in neuroscience and biology as reciprocal Granger causality between two variables, help explain the outsized influence of energy on the economy.

[23] The trend line for the world GDP and TPES data comes much closer to the origin than that of the US, which has an "offset" of about 2% GDP growth (at zero energy growth) versus the rest of the world, which is closer to 0.5% offset. The meaning and importance of this is open to debate. For much of the world energy growth is a hard limit—for individual countries such as the US, it is easier to transcend domestic energy supplies for various reasons. Indeed, this is an important mechanism in the global system, the cause of large-scale disruption in the 1970s and 2000s.

correlation tests at various time scales tend to show dynamic relationships between variables such as oil prices, industrial production, and money supply—correlations negative at one lag, positive at another, which I interpret as the interplay of negative feedback mechanisms and oscillating cycles (Figure 20). Further consideration of these factors will be left to the last part of the dissertation, where we investigate complex relationships between energy and external balances at greater depth.

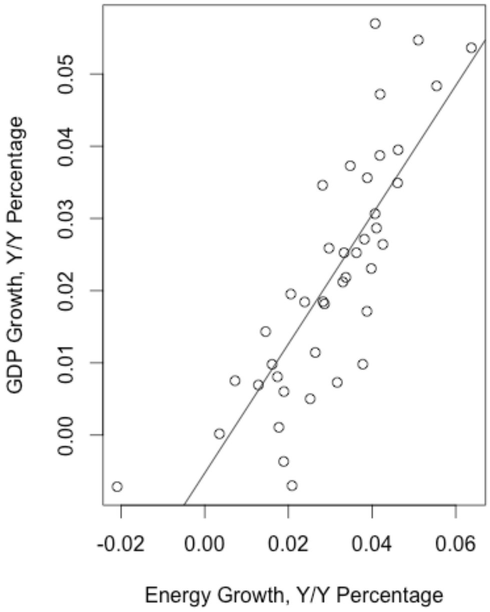

Figure 19. World GDP and TPES Growth Rates, 1972-2013 (Nominal). *Source: Data from IEA global energy balances and IFC International Financial Statistics*

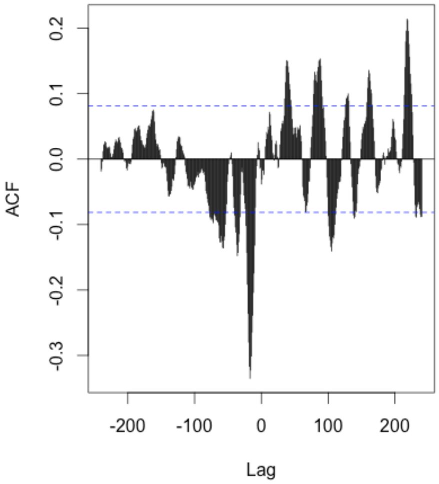

Figure 20. Cross-Correlation of 12-Month Differenced Monthly Time Series: Oil Prices and US Oil Imports, 1964-2013. *Note: Maximum lag is 240 months. Oil price (UK), selected as the lead variable, does lead Imports by a few months in the negative correlation, though at longer periods, oil imports holds significant information about a positive long-term correlation. Source: EIA and International Financial Statistics*

Patterns in National Energy Signatures Over Time

As shown in Figure 14 above, 2009 saw dramatic contraction in global energy production, the largest decline in at least 40 years. This was also overshoot—a reaction to massive disturbance in the financial system, collapse of certainty and fall in expectations, following a recession in the real economy. Yet these events, like the tumultuous monetary events of the 1970s (beginning with the 1971 unilateral dollar float, known abroad as the "Nixon shock"), had energy roots in turn. These lied in the differential growth rates of nations with divergent energy trajectories, the US and China, yoked together in a fragile financial mechanism. The 2009 event thus appears a correction, or feedback effect, of a sustained energy imbalance. Meanwhile, extremely high energy growth rates may represent positive feedback from the monetary system—low rates of interest or easy money can stimulate rapid short-term demand growth, and often does, until correction (see Frankel, 2006).

The 1960s United States and its energy profile provides an excellent example. Energy supplies in the 1960s and early 1970s, during a long expansion, shot far above trend for both the US, and, as we saw in Figures 10-14 above, world mining in general, with oil the major component. The 1970s, beginning with the Nixon Shock and ending with the Volcker Shock, can be read as a readjustment of the US monetary system to deal with the changing global energy situation. I will indeed read it this way, in greater depth, in Chapters 6 and 7.

In short the steep global energy trajectory from 1960 to 1972 was forcibly flattened by massive price adjustments, emerging from the energy contraction of the late 1970s to a completely different growth path from 1982 to 2005. The US added about 35 EJ to its total primary energy supply between 1960 and 1978. China added about 35 EJ from 2001 to 2007. The global energy growth path flattened again in 2006, after four years of spiking oil demand from China.

In both cases the countries went from around 45 to around 80 EJ, though China streaked past 100 EJ by 2010. It is important to note that in the case of China's rise, its growing share of global energy took place against a backdrop of global energy production increases that were on trend, while US and global energy production increases were far above trend in the 1960s and 1970s. This indicates that China's unprecedented energy gain, for all the awe it induces, *merely filled in for decline in other countries during the 2000s*. After both overshoots, crises ensued, though the US 1970s path required two corrections to adjust, with attendant recessions in the 1970s-1980s. Both cases saw a massive energy price adjustment.

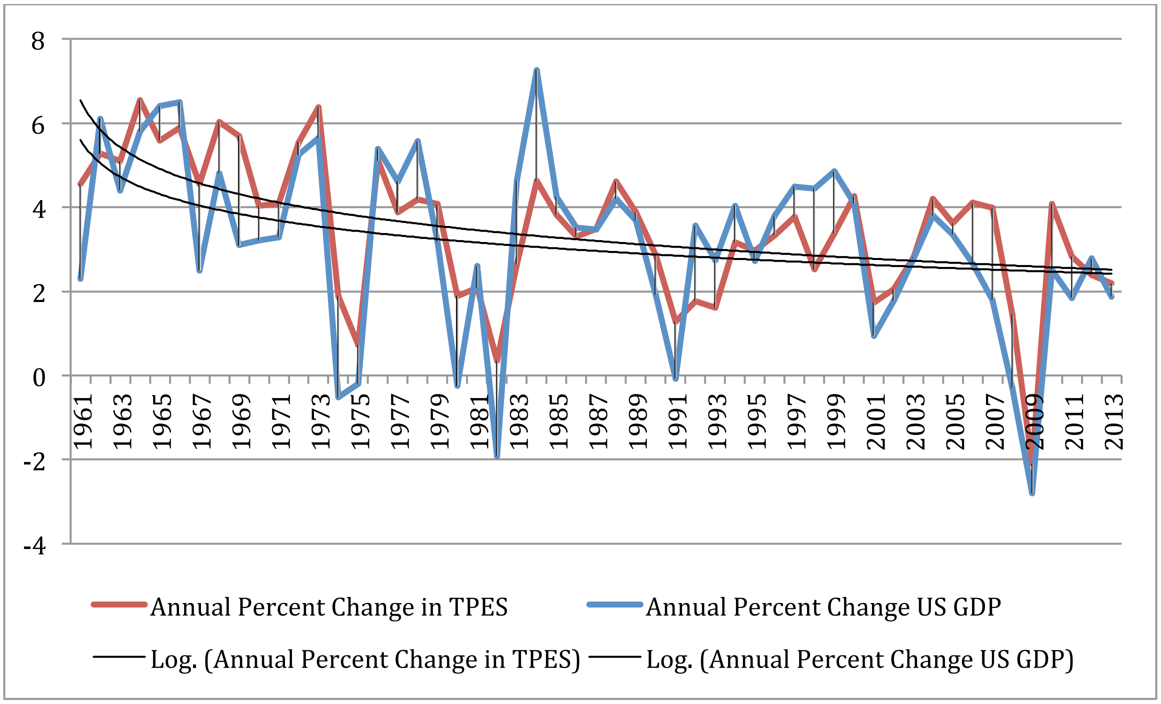

Figure 21. US GDP and TPES Growth Rates, 1961-2012. *Source: IMF International Financial Statistics, IEA.*

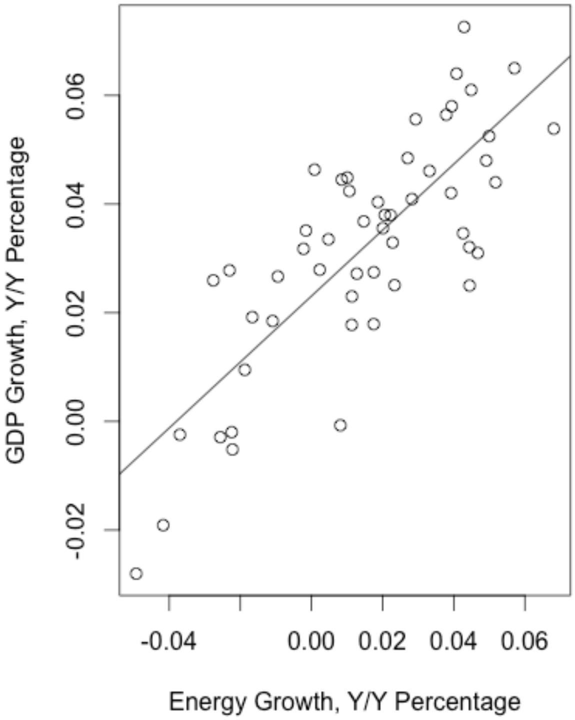

Figure 22. Linear Fit: US GDP and TPES Growth Rates, 1961-2012. *Source: IMF International Financial Statistics, IEA.*

These price adjustments, however, depended not only on supply and demand, but in large part on the changes in—on the correction of—a monetary system *put out of balance by energy differentials and kept there.* This is the root of the "disequilibrium system" of Mundell (1961), as we will see in Chapter 6. Simply put, the artificially expensive dollar's devaluation made an energy price shock inevitable in both cases.

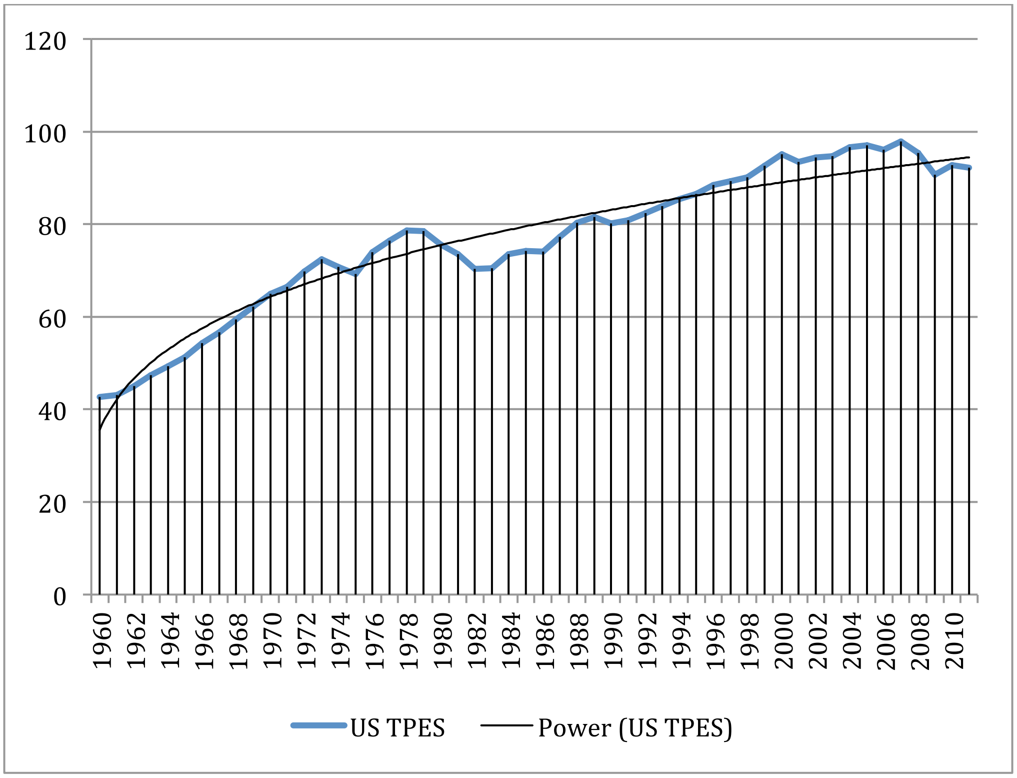

Figure 23. US Total Primary Energy Supply, 1960 – 2012 (Exajoules). ***Source: IEA Energy Balances.***

As the global energy system grows, fairly predictably and linearly, resources are shuffled around with it. The flattening US energy signature above is typical of advanced industrial nations, with Germany and Japan other exemplars of a "rise-and-decline" TPES. These nations in general saw extremely high energy growth in the 1960s and into the 1970s, with Germany and Japan peaking and declining significantly earlier than the US[24].

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[24] Germany and Japan also overshot during the 1960s-1970s, when the great fields of Saudi Arabia and OPEC opened up. Like the US, both nations doubled or tripled their available energy during the golden 1960s.

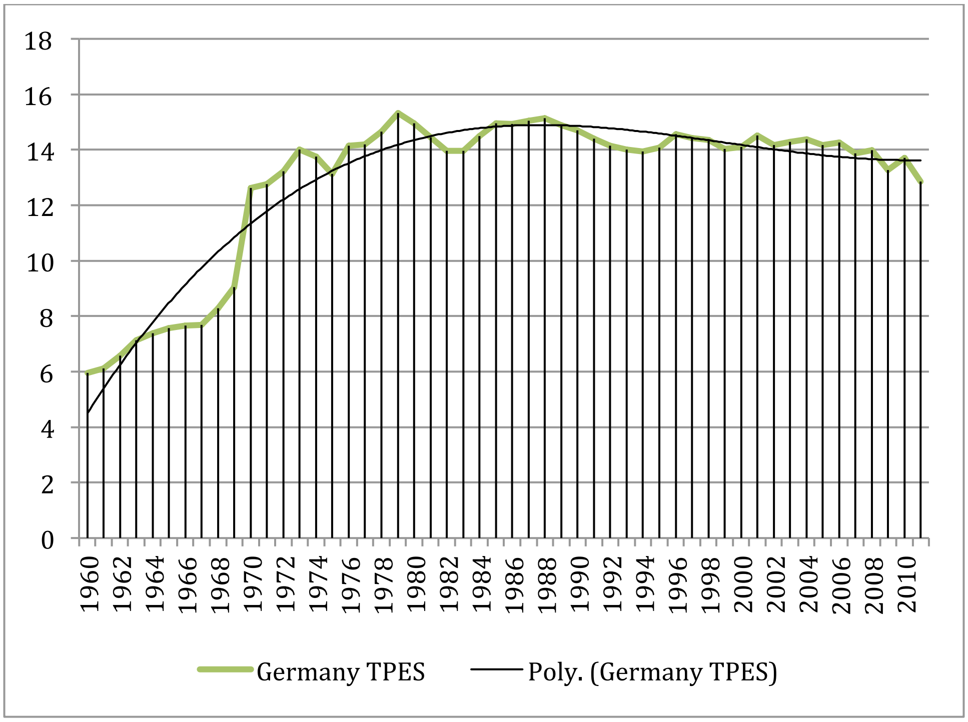

Figure 24. Germany Total Primary Energy Supply, 1960-2012 (EJ). *Source: IEA Energy Balances.*

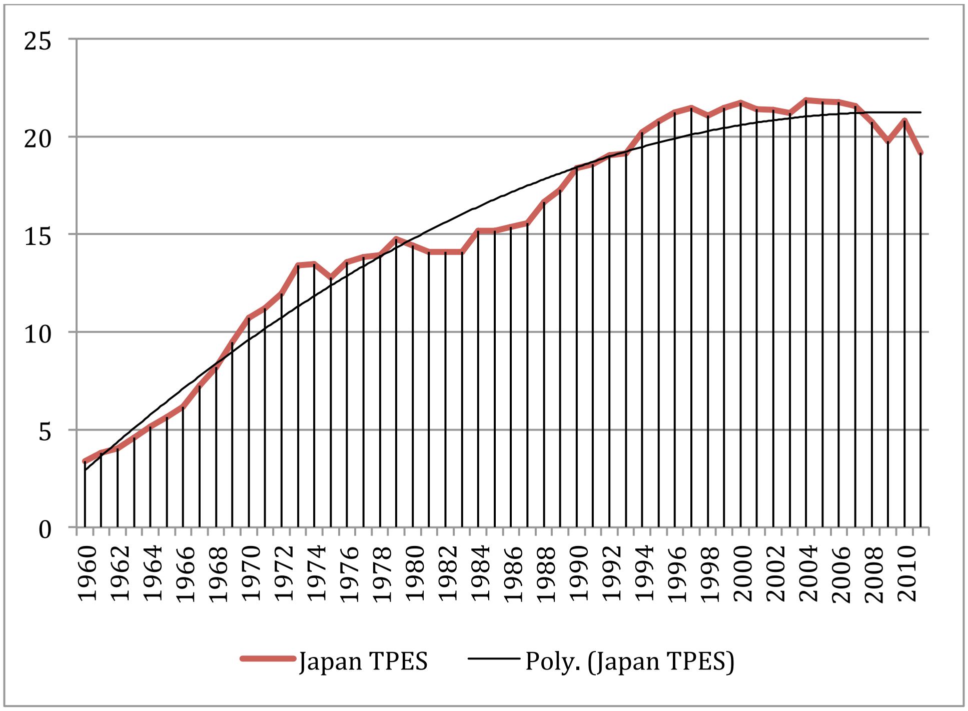

Figure 25. Japan Total Primary Energy Supply, 1960-2012 (EJ). *Source: IEA Energy Balances.*

Not all countries had such gentle plateaus. Cuba's "Special Period" experience in the 1990s and 2000s, after it lost its flow of subsidized oil from the Soviet Union, shows what happens to a nation whose energy supplies disappears overnight. Most Cubans during this time lived on the edge of the minimum sufficient daily caloric intake, while the nation's transport and housing infrastructure deteriorated severely. Meanwhile, sectors with relatively light energy footprints, such as biotech and education, maintained relatively high, even world-class levels (Eckstein, 2004). Here an energy shock produced total economic change. The source of that shock, however, the collapse of the Soviet Union—though perhaps originating in oil markets, according to its former prime minister (Gaidar, 2007)—was a complex political economic event.

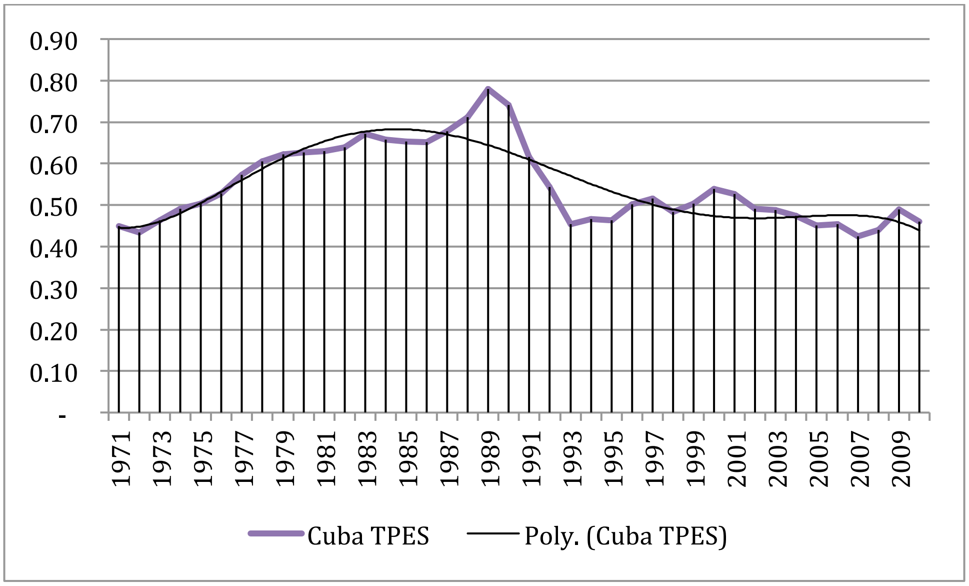

Figure 26. Total Primary Energy Supply, Cuba, 1971-2010 (EJ). *Source: IEA Energy Balances.*

Very few nations have experienced this type of energy signature over the past 45 years. Sustained drops in total energy are rare, and so far in this investigation have turned up only in nations whose supply was connected with the former Soviet Union. One might assume that much of the oil component of that "lost" energy was redirected to the Western world, helping to account, perhaps, for the low oil prices and related economic boom that prevailed across the United States and West through the 1990s.

Not surprisingly, the collapse of the Soviet Union in 1991 also shows this unique, Cuba-like energy signature, with the total primary energy supply (TPES) of its constituent units dropping dramatically. We might say metaphorically that the nation's "binding energy" was released. Yet we do need to pay attention, in this case, to the collinear variables involved, and the reciprocal relationship between the Soviet economy's financial and energetic collapse.

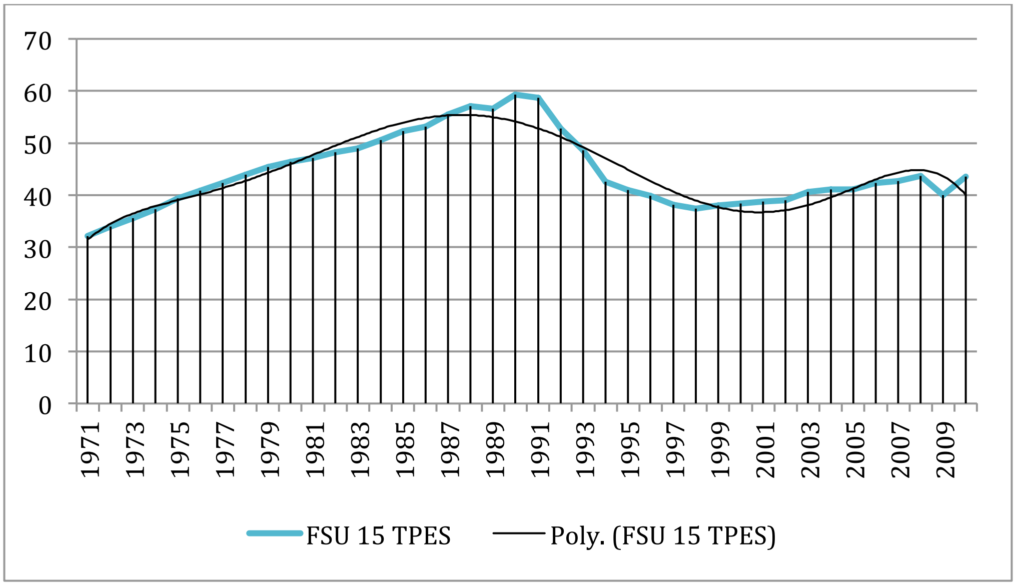

Figure 27. Total Primary Energy Supply, Former Soviet Union States, 1971-2010. (EJ)
Source: IEA Energy Balances.

Meanwhile, as factories closed and former Soviet Union (FSU) nations endured a bitter 1990s, China stood on the verge of the largest energy expansion in world history. Its exponential energy supply path during the second half of the 20th century is reasonably similar to those of other developing nations, but the scope and speed of its burst during the first decade of the 2000s was unparalleled. From 2001 to 2010, China added roughly the energy supply of 1967-era United States, about 60 terajoules (TJ), to its annual use. It accounted for 30-50% of total net global energy supply growth during these years, on average (Table 4, below). This process has recently begun slowing, however, with the Chinese Communist Party announcing it would cap coal production around 2015, at 3.9 billion tons (Bloomberg News, 2012). Chinese coal production levels in 2014 indeed fell for the first time in the 21st century against 2013, with 2015 expected to be lower still (Guardian, 2015).

Table 4. China's share of Global Net Energy Production Increase, 2001-2009. ***Note: Global net energy production contracted in 2009. Source: Author's calculations from IEA World Energy Balances.***

2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
22%	90%	35%	32%	36%	34%	55%	46%	N/A*	30%

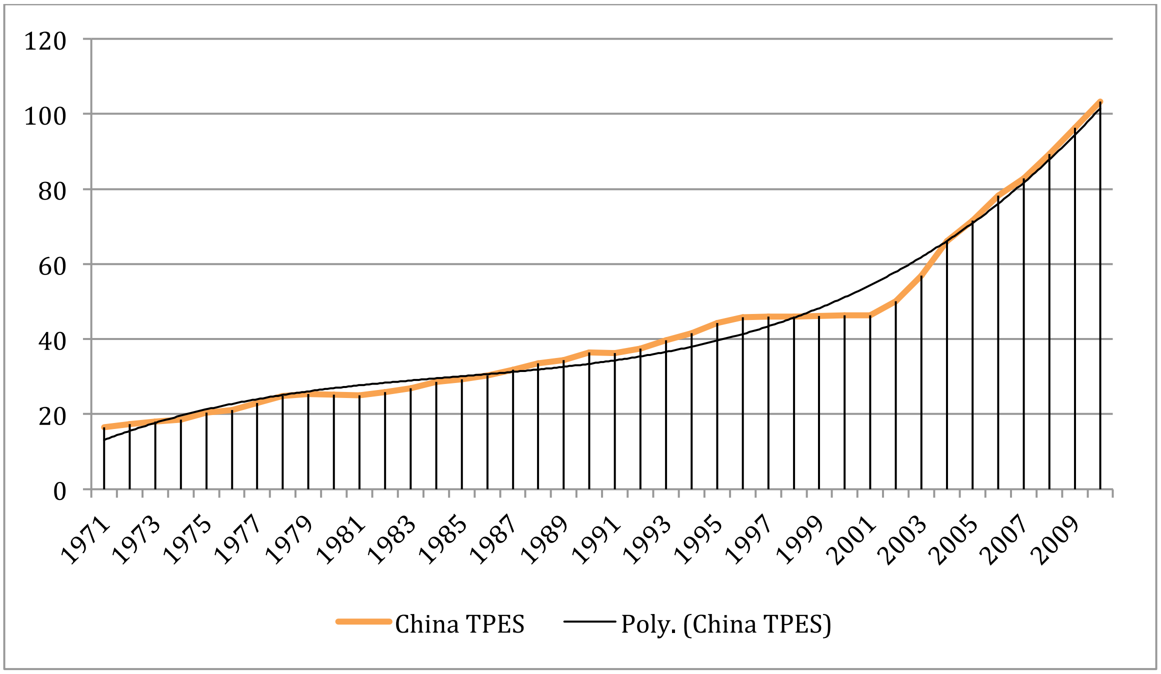

Figure 28. Total Primary Energy Supply, China, 1971-2010 (EJ). *Source: IEA World Energy Balances*

China's energy supply was flat during the period just before its coal-fired takeoff, remaining around 50 TJ per year from 1995 to 2001. The incredible coal drive of the next 10 years began virtually the moment China joined the WTO, in December of 2001. In the year after its accession, China accounted for a startling 90% of new net global energy production. A vast array of new export markets changed the structure of the Chinese economy toward "labor-intensive manufactured goods," while the percentage of population engaged in agriculture dropped dramatically, from 50% in 2001 to 11.2% in 2010 (Boden, 2012, 13).

The global economy had swallowed a whale. China's vast middle class would eventually require a redistribution of global purchasing power. The event that heralded the end of this period, the 2008 financial crisis, stemmed in large part from its accumulated financial imbalances: "an enormous quantity of money flowed into low-income housing in the United States, both from abroad and from government-sponsored mortgage agencies such as Fannie Mae and Freddie Mac….Foreign investors looked for safety. Their money flowed into securities issued by government-sponsored mortgage agencies like Fannie Mae and Freddie Mac, thus furthering the U.S. government's low-income housing goals." (Rajan, 2010, 16). In 2001 China held 10% of global central bank reserves—by 2010, it had accumulated 28%, as shown in Figure 30, below (International Monetary Fund, 2015).

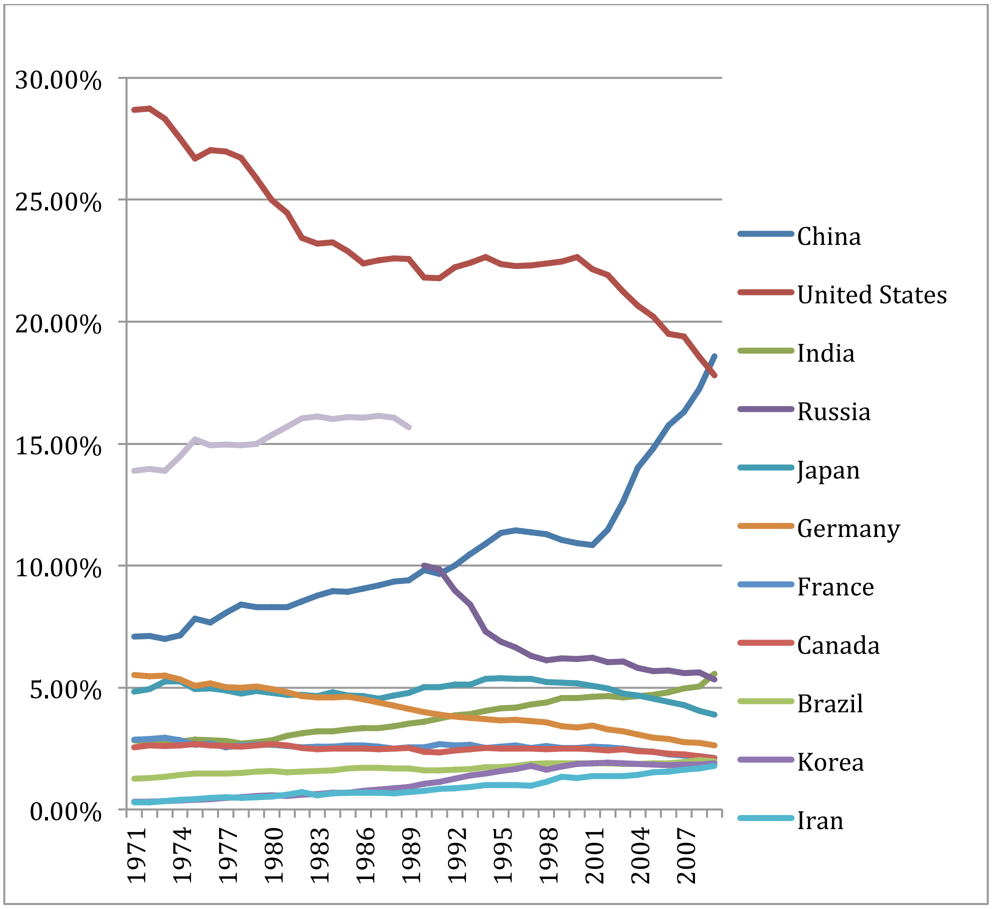

Figure 29. Share of Global TPES, 1971-2009, 12 Nations. *Source: IEA World Energy Balances*

These financial imbalances arose from enormous differentials in energy productivity across the global system—mainly from China's access to enormous amounts of high-yielding coal, complemented by the low-cost energy of hundreds of millions of Chinese laborers. Yet as we will see shortly, the importance of China's labor supply versus its coal supply has perhaps been overstated. By modeling growth with production function improvements made in ecological economics (Ayers and Warr, 2010), it may become clear that lower-cost energy (or higher-yielding energy, similar but separate concepts linked since *The Coal Question*) provided not only a massive boost, but perhaps also the brakes, for China's historic production push.

Table 5. Average Annual Energy Production Growth in China. *Source: Author's calculations from IEA World Energy Balances.*

2001-2003	2004-2006	2007-2009	2010-2012
7.43%	9.07%	4.89%	6.48%

China's energy growth in 2012 was 3.85%--its lowest rate of the boom period. It is not clear what energy source, and thus what region, can substitute for the 2001-

2006 pulse of energy from China, and the impetus it provided the global economic system. Shale oil in the United States, though a contested and potentially short-lived resource, is one near-term answer, with attendant political economic adjustments producing interesting times in the financial and energy worlds as of 2015.

How We Are Stuck: Energy Yields and Global Stagnation

The correlation of total primary energy supply with growth rates is important. This study attributes the current stagnation of the global economic system, dating from the 2008 collapse—and perhaps the 2006-7 slowdown—in large part to falling global energy yields. The collapse itself appears to be in large part an adjustment to differential global energy productivity, given that the Chinese and US central banks prevented the monetary system from adjusting gradually in previous years, mainly through the pegged USD-Yuan and recycling (further discussed in Chapters 6 and 7). Slowing rates of energy production after the Chinese energy burst of 2001-2006 likely exacerbated the effect on a financial system geared toward rapid growth.

Despite what appear to be a large monetary expansion via US central bank policies, global growth seems stuck at levels well below that of the pre-2008 world[25]. The argument here is that global stagnation will remain unless a high-yielding new source of energy growth is identified. The global economic system requires an engine, and excepting the problematic US shale boom, we have not yet identified it.

We can look at secular stagnation in another way—too much savings, too little investment. This is the view of Keynes (1997 [1936]) in the Great Depression, and of Lawrence Summers in the Great Recession (Economist, 2015). Investors can not find enough profitable projects, according to Summers's point of view. For Keynes this makes capital artificially scarce, given liquidity preference under current uncertainty. A true Keynesian response to this problem would involve socialization of investment by the state, which would bridge the gap between expected returns on current projects and the "marginal efficiency of capital"—or, roughly, the going rate of profit—by raising taxes at top income brackets and engaging in a large-scale fiscal investment program. The economy-wide rate of profit would fall toward the going rate of interest (though this is nowhere near the 0% currently being awarded to savers at banks). Previously marginal projects would be matched with readily available capital, increasing investment, then employment and effective demand, and then output.

For marginal projects, energy costs can make the difference between viable and not—given interest rate responses, price shocks often attach what is effectively a private tax across the economy on the order of 5-15%, with direct energy costs often much higher. Notably, in a time when demand for large-scale, low-carbon or

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[25] Due to excess reserves held at the Fed, this monetary expansion may be somewhat illusory. M2 has seen relatively mild growth despite the astounding rise in the US monetary base from the Troubled Asset Recovery Program (TARP) and quantitative easing.

ecologically effective programs seems urgent, what Keynes saw as an unnecessary scarcity of capital keeps many of them on the drawing board. A "Green New Deal" or such would seem to require another "euthanasia of the rentiers" in order to access the capital in the rents they receive as a consequence of artificial scarcity (Keynes, 1997 [1936], 376). Yet rentiers today seem if anything less disposed to go to sleep than they were in the 1930s, evoking deeper questions of state power vis a vis the financial and energy industries in particular, and the corporate sector in general.

In any case, given trajectories of the global and US energy-economic systems, the current global stagnation is no surprise. The same crisis occurs whenever energy production rates begin to peak and decline. The difference now is that the phenomenon has beset the entire world, rather than a single core or hegemonic country. Large debt-based increases to the money supply may cover declining real growth rates and keep incomes at a steady nominal level in a country such as the US, yet this seems impracticable for the whole world. China provided, as mentioned, an enormous boost to the global economy after its December 2001 accession to the WTO. It accounted not only for a large portion of net global energy growth through its coal resources, but also acted as a stabilizer for the US currency, while providing low-cost goods that keep the US cost of living down.

When thinking about energy differentials between nations, it is important to separate total energy production, growth in energy production, and net energy yield (also "energy surplus" or "EROI"). The first term refers to how much energy is being produced, the second to its growth rate, and the third, to what's left over after energy costs of energy production are subtracted. A nation could conceivably produce a large amount of energy—100 exajoules, for instance, about a fifth of global supply—but use 100 exajoules to do so. In that case, net energy would be zero. It is impossible for the global system as a whole to work at zero net energy, given maintenance costs, entropic degradation, and so on. Virgin resources such as coal and oil fields typical had energy surplus ratios of 100 or greater—this means 100 joules would cost their owners one joule or less to produce.

Since the large decreases in net energy yields up to the 1970s, the US has for years been a net consumer, producing less energy than it uses. This requires other nations be net producers; their energy surplus is net of their own energy cost of production. From that surplus they subtract energy used domestically outside the energy industry, while the remainder may be sold abroad to consumers such as the United States. Clearly, there must be a balance between consumers and producers; a world of net consumers is not possible. Long the world's largest energy consumer, the United States has been a net consumer for several decades. Meanwhile, China became in 2007-2008 a net coal consumer, at least, for the first time. While its new energy production averaged around 1/3 of the global total through the 2000s (Table 4), China's new consumption was about half of new global supplies in key years, as it continually increased its share of both global production and consumption.

I argue that the changing role of China, its extraordinary energy growth in the 2000s—lies near the root of the 2008 global financial crisis (see Rajan, 2011). From that point, with China no longer putting out a massive energy surplus onto world markets, the global energy balance looks quite different. As oil prices spiked and China became a net importer of coal for the first time in 2008, it became clear that its growth rate, which propelled global growth and US financial speculation via its capital tsunami, was unsustainable. The system built over it simply fell apart, as the great stream of money produced through the massive conversion of coal slowed. The "too little, too late" 2004-2006 US interest rate rise, and the attendant reduction of demand, was one of many contributors to the system's near collapse.

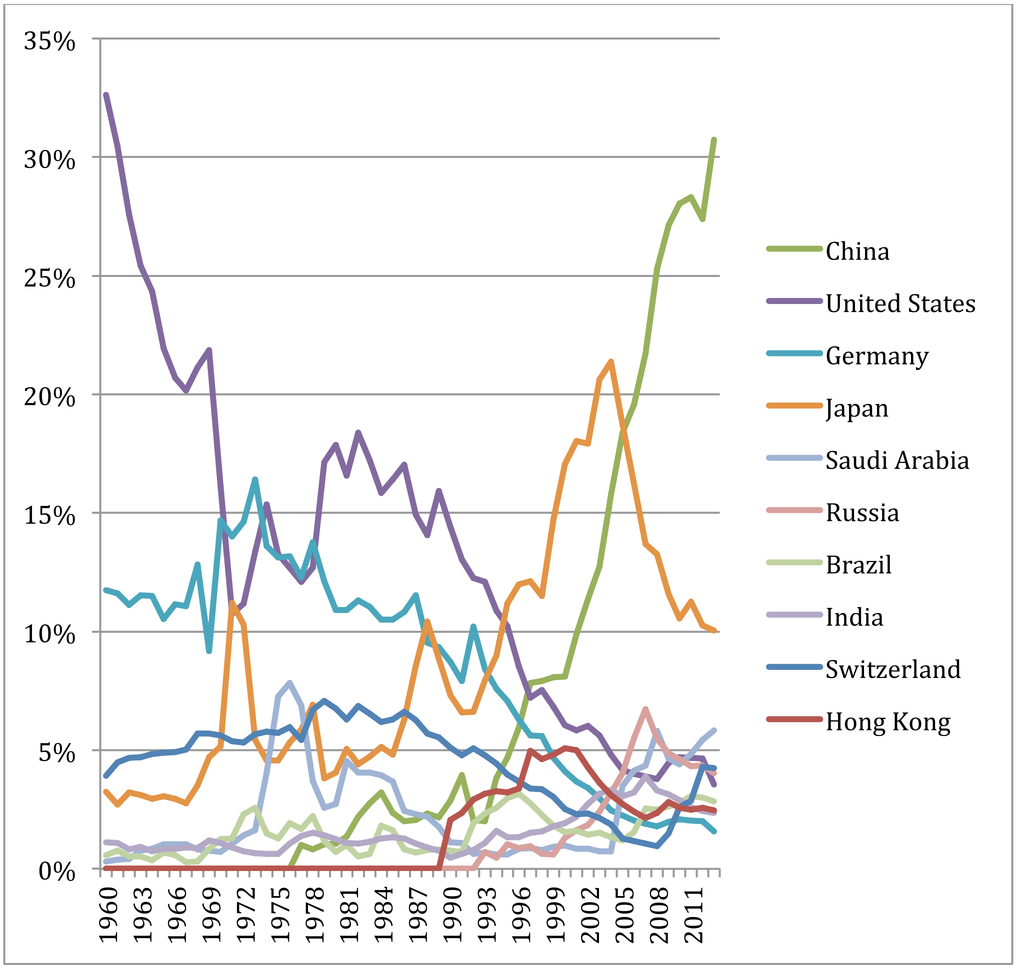

Figure 30. Percentage of Global Monetary Reserves, 10 Nations, 1960-2013. ***Note: Includes monetary gold, special drawing rights, IMF holdings of member nations, and foreign exchange held by the monetary authority. Source: IMF International Financial Statistics.***

GDP growth in the United States has declined with its rate of domestic energy use over time (see Figure 21). The trend appeared in the 1970s, though it was not the first time a global power has seen energy limit its growth and power. England in the early 20th century, as predicted by one of her greatest economists (Jevons, 1866), was the first major global fossil power to peak and decline. As it did so, the role of global monetary hegemon or guarantor began a long migration to the United States, which would not see its prime energy source peak until 1970.

Similar to the global situation of the 2010s, in the 1970s the US struggled to reproduce the growth rates of the previous decade. Insofar as unpegging its currency from the Bretton Woods-era gold regime allowed it, for a time, to import far more energy on the global market than it otherwise would have been able to afford, it succeeded. As we will see in the next few chapters, energy became extremely cheap versus its long term trends at key points leading up to the "energy crises" of the 1970s and 2000s. The key to this apparent contradiction is that the US has devalued the dollar repeatedly over the past fifty years, but, especially in the "posted-price" (non-market) oil regimes of the 1970s, it takes time for energy prices to catch up with the falling value of the dollar, building up tensions in trade that produced enormous overcorrections or "price shocks."

In the next two chapters, I examine these energy price shocks in the United States, with the goal of contributing to current debates on the mechanisms through which they affect the economy.

Chapter 4. The Oil Harvest Cycle (Part 1)

> In particular, Hamilton argues in his more recent work that the correct measure of oil shocks depends very much upon the precise mechanism by which changes in the price of oil are supposed to affect the economy, a question for which many answers have been proposed but on which there is little agreement. *For our purposes, the exact channels through which oil affects the economy are not crucial.* (Bernanke et al. 1997, 100)
>
> A self-organizing system can organize around an available source of pulsing or develop one of its own. (Odum, 1988, 1134)
>
> I would not give a fig for the simplicity on this side of complexity; but for the simplicity on the far side of the complexity I would give my right arm.
>
> --Attributed to Oliver Wendell Holmes, Jr.

Solving "Bernanke's Puzzle": Shift Focus to Oil Investment

Ben Bernanke, former chairman of the Federal Reserve, and his collaborators argue that the effects of oil shocks on the economy are partially endogenous, transmitted through the Fed's monetary tightening in response to rising oil prices, they acknowledge "the long-standing puzzle of the apparently disproportionate effect of oil price increases on the economy" (Bernanke et al., 1997, 94). Oil price spikes have preceded 10 of 11 US recessions since World War II, as most thoroughly documented by Hamilton (2005, 1). The question is why: "In spite of this voluminous literature empirical literature suggesting that oil price shocks have an important effect on economic activity, there is little consensus on the reason why this is so" (Rotemberg and Woodford, 1996, 2).

Three classes of neoclassical explanation are given. The first, and the most intuitive, is that consumer and business expenditure are dampened by the oil price shock (Hamilton, 1983). The second is that loose monetary policy in large part produces oil shocks, and an "exogenous" supply shock is not a necessary (Barsky and Kilian, 2004) part of the explanation. Bernanke et al. (1997) argued, in a version of this, that the Fed tends to tighten interest rates in response to oil shocks, which then constricts growth. A third category of explanation favors some "friction" in the reallocation of labor and capital across sectors (Hamilton, 1988; Davis and Haltiwanger, 2001). There are strong difference in opinion among these authors:

> “We conclude that the potential of monetary policy to avert the contractionary consequences of an oil price shock is not as great as suggested by the analysis of Bernanke, Gertler, and Watson. Oil shocks appear to have a greater effect on the economy than suggested by their VAR, and we are unpersuaded of the feasibility of implementing the monetary policy needed to offset even their small shocks. A key basis for believing that oil shocks have a greater effect than implied by the [sic] Bernanke, Gertler, and Watson’s estimates is that the greatest effects of an oil shock do not appear until three or four quarters after the shock. Investigating the cause of this delay would seem an important topic for research.” (Hamilton and Herrera, 2004, 281)

Researchers tend to be hampered by the fact that oil prices, especially for businesses, do not seem to carry enough weight to disturb the economy—Davis and Haltiwanger (2001, 506), for instance, found “to their considerable surprise” that energy intensities of businesses often go *up* during oil price shocks. Much effort is also expended to explain how the reallocation of labor and capital across industries might be imperfect, and where the “friction” originates.

In this chapter I argue the answer to Bernanke’s puzzle lies in oil’s investment cycle. Using a Keynesian approach, I find that the effect of oil price shocks on consumer and firm expenditure is probably less important than their function as signals for investors to begin shifting investment toward oil and gas. The answer lies in the very large amount of capital shifted into oil and gas during shocks—and in the very small amount of labor that follows. This produces a net downward influence on employment, and thus less effective demand in the economy. In short, friction in reallocating labor is an understatement; in oil shocks *labor often has no place to go*, given the oil and gas industry’s extremely low labor requirements and high capital requirements. Meanwhile, as we will see, falling economy-wide investment in these periods limits reallocation to other sectors as well.

The findings of Davis and Haltiwanger (2001) provide empirical evidence of job destruction during oil price shocks. Their line of thought, however, generally traces consumer expenditure shifts between sectors, leading to costly reallocation of labor. These types of theories often look for energy-intensive industries to do poorly in such settings, but this result rarely appears. The idea advanced in this paper supports sectoral reallocation explanations by removing the total explanatory burden from consumer and firm expenditures. Simply put, the oil and gas industry employs very few people per dollar of investment relative to the economy’s average. Whether necessary or not, rising investment in this sector diverts resources from far more employment-productive industries.

This mechanism also supports foundational work in ecological economics. Odum (1973) wrote that society must devote an increasing portion of its resources to extracting exhaustible fuels, as did Georgescu-Roegen (1971), who urged the consideration of the economy as a one-way, thermodynamic process. Robert Kaufmann and Cutler Cleveland acknowledge "macroeconomic distortions" caused by what they view as an inefficient US oil boom in the 1970s and 1980s, warning of the same cycle again in the 2000s (Cleveland and Kaufmann, 2003, 487). None of these researchers, to my knowledge, connect macroeconomic distortions to shifts in investment that influence labor markets, which then constrain effective demand, then growth, and then further non-oil investment.

As is the case with most researchers who study the question, Cleveland and Kauffman (2003), despite excellent work on this issue over three decades, focus on the shifting expenditure side of the equation. Yet the crux of the issue turns on finance, often difficult for economic researchers—or neoclassical models that treat money crudely or not at all—to cover. It is suggested Keynes handled this side of the economy more competently because he himself was an active and successful speculator in both stocks and currencies[26]. Another aspect beyond the financial that researchers often miss is the cyclical nature of the resource crunch—energy matters in price shock years, but then drops out of sight. Why?

Unlike Saudi Arabia, the US is both a large producer and large consumer of hydrocarbons. During oil price shocks it builds reserves and inventories at a given price, only to deplete them during later periods. In the periods of drawdown, when oil investment is flat and relatively small, the consumer side of the US economy booms. In the oil shock years, the producer side—in particular, the oil producer side—has its turn. As will be explored in the discussion section, this cyclical movement fits neatly into Odum's "pulsing paradigm" of nature (Odum, 1988).

The investment-labor explanation helps clear up an enduring puzzle that has been the subject of debate between leading researchers on the topic: why did we see no massive boost in economic growth after the 1986 price collapse (Hooker, 1996; Hamilton, 1996)? The same problem devils ecological economics researchers, who often silently pass over the inconvenient fact that changes in oil prices often *lag* supposedly connected changes in growth. Researchers have devoted much effort to explaining why the postulated oil price rise–GDP contraction does not work in reverse. The answer is that *the oil price itself doesn't matter, much*. It is a signal.

By 1985-1986 oil prices had been in decline for years, the signal long received by forward-looking investors. A massive investment response came in 1982-3, followed in 1984 by the highest US GDP growth (7.26%) since at least 1955, and possibly even 1950. It has not been matched since. This resulted, I argue, from a

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[26] The story of Keynes's intentionally crashing the value of the Spanish currency is one example (Heilbroner, 2011, 257**),** his alleged habit of doing all his stock trading before getting out of bed in the morning is another.

massive decline in oil and gas investment through 1982-83. As it fell, private domestic investment soared, and resources shifted to sectors with higher labor ratios (full-time equivalent employment/unit of investment), which began hiring. Expectations improved, and people began spending[27].

The investment shift might seem a marginal effect, but likely accounts for millions of jobs during the most intense oil investment periods. This means the difference between growth and no growth in the mature US economy. Oil and gas extraction is one of the largest industries in the US. A doubling or quadrupling of its average historical share of total investment over a period of years might have significant effects on employment, if we can take the first approximation measure of the labor ratio at face value.

The Signal: Oil Prices

Over long periods of rising prices, such as the 1970s and early 80s, then again in the 2000s, increasing investment in oil and gas slowed the real economy, drawing investment from labor-intensive sectors. Expansionary monetary policy may to some extent cover up the problem (whether it helps cause it, as argued in the recent works of Frankel (eg., 2006) is left to answer in Chapter 6 on money, interest rates, and oil shocks). Yet it can't be loosened forever, given inflationary pressures. The inevitable tightening adds to contractionary influences already in play from the diversion of capital to oil and gas.

Here I take the oil price naively as a decent indicator of the supply price or finding cost over the long run. In other words I assume for now that over the long run, the relative price of oil reflects the marginal difficulty in producing it. Supply conditions did not ease until the early 1980s in the US, and then again in the early 2010s—by mid-decade in both cases, oil markets had returned to a more stable long-term trajectory. In both cases, new resources came on—Alaska and offshore in the 1980s, shale oil in the 2000s.

The step characteristics of price and cost rises seem related to the Ricardian rent picture. At certain points new portfolios of new oil and gas sources, with a higher cost, are brought into production. These sources yield lower net energy, in the terms of earlier chapters. The economic dynamics of the process encourage development further up the supply curve than is strictly necessary—a "tulip fever" that generally produces overshoot, a price collapse, industry consolidation, then a long period of flat prices (see Chapter 7). The Hotelling model (Hotelling, 1931) of prices rising with the rate of interest seems to work in punctuated equilibrium, rather than smoothly over time.

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[27] Famously, it was "morning in America."

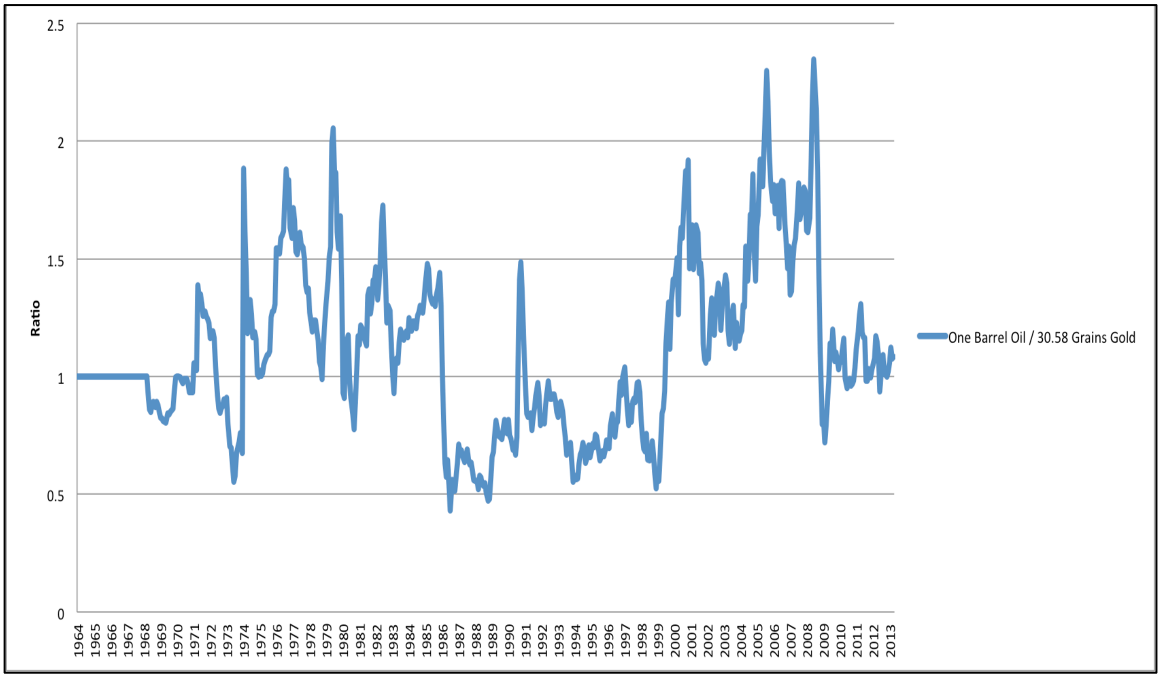

Figure 31. Ratio of Oil Prices to Gold Prices, 1964-2013, Normalized by Series Average. *Note: UK Prices. Source: IMF International Financial Statistics*

Price steps, when sustained and credible, call forth a suite of newer, more expensive resources—Alaskan oil, deep offshore, and shale oil are three examples. Their rate of return, as shown by the Hotelling model, rises quickly during the price shock. Investment moves quickly into these higher-cost sources, whether the exploration of new fields or development of older ones. As it shifts from multiple sectors of the economy to oil and gas (real estate in particular has a negative correlation), conditions in other industries tighten and their employment levels fall or stagnate[28].

Importantly, we leave the intricacies of monopoly pricing and dollar devaluations—important components of oil price spikes from the US perspective (Hammes and Wills, 2005), aside for now. We also aggregate oil and natural gas activities, which need to be pulled apart in future analyses, keeping in mind M.A. Adelman's good, if pugnacious, work on the subject (1988), in which he admonishes not to mix oil and gas costs.

As prices rise, in any case, US investment shifts to oil and gas. As the latter's proportion of total US investment in private fixed assets grows, important economic changes occur. Investment is, of course, something of a zero-sum game; funds, even if the money supply is rising, must come from somewhere[29]. They represent, as

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[28] I leave the effect on wages aside for a moment, though find no immediate reason for wages to increase across the economy as a whole to compensate for this job destruction.

[29] Leaving the question of foreign direct investment flows aside for the moment.

Joseph Schumpeter carefully pointed out in *The Theory of Economic Development*, a claim on real resources.

> The fundamental notion that the essence of economic development consists of a *different* employment of *existing* services of labor and land leads us to the statement that the carrying out of new combinations takes place through the withdrawal of services of labor and land from their previous employments. (Schumpeter, 1934, 95)

While Schumpeter was talking about new industries, the behavior of oil and gas investment, with sudden bursts after years of dormancy, resembles a periodically disruptive industry. This will become apparent below through a study of the growth of oil and gas investment during the 2000s.

Effective Demand

As Keynes (1936) showed many years ago, effective demand drives the economy. Investment increases employment and thus effective demand. Yet not all investments are created equal[30]. Ten billion dollars of investment in the oil industry carries a different employment requirement than the same amount put into manufacturing, retail, or real estate. This becomes apparent from simple comparisons of the ratios of full-time equivalent employees to gross operating surplus in various sectors, the results of which we see below.

Again from Keynes, rising effective demand creates more incentive to invest, and a virtuous cycle begins. What could go wrong? In the 1940s, with the United States and the world brimming with new oil resources and reserves, not much. As oil reserves were drawn down, however, and investment into upstream exploration and development stayed flat or declined in real terms, tension built in the global energy system. Enormous rates of global production increase in the 1960s and early 1970s, far above the long-term trend, were not matched with commensurate US investment in oil and gas, which plateaued in the early 1950s and then declined for 20 years. Not coincidentally, this marked one of the most robust growth periods in American history, an economic golden age.

By the 1970s, however, diminishing returns from US fields, coupled with a long-term decline in domestic exploration and development (E&D) investment, resulted in a US oil production peak. In a series of complex interactions with the balance of payments, overseas producers and the devaluation of the dollar, this produced a

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[30] Nor are all government monetary and fiscal program. The above brings to mind Keynes's idea about the Bank of England burying bank notes in disused coal mines, then allowing private entities to dig them up. The real blind spot revealed by this tongue-in-cheek idea, the necessary augmentation to Keynes's thought, is the energy question. At root, the economy must produce energy to support itself, or perish.

sharply rising oil price in 1973-1974 (see Chapter 6 and 7). Once the trend's durability became obvious, oil and gas investment followed suit, in 1974 rising substantially for the first time in more than 20 years as a fraction of US gross investment in private fixed capital assets.

This view depends on the allocation of investment, fundamental claims on economic resources, as an essential timer of the economy as a whole. The mining industry's investment is often a countercyclical indicator, peaking in times of distress and stagnation in the larger economy. This firmly supports the view of Howard Odum (1971), Nicholas Georgescu-Roegen (1971), and their students and successors in ecological economics (for example, Kauffman and Cleveland (1991) and Daly (1980). The increasing resources needed to coax fossil fuels from more difficult deposits tends to be a limiting factor for the economy. The argument here—that we can measure this through investment shifts in the larger economy and their effects on labor markets—is an extension of this intuition. Using the rig count, a physical measure of production, rather than dollars, helps us focus on the biophysical aspect of the issue.

A Word on Methods

How does this differ from previous explanations? The explanation developed here integrates Keynesian macroeconomic concepts with the idea of a biophysical supply constraint. It sets aside the neoclassical model and assumptions in favor of an "ecosystem" approach to investment in the economy, taking each industry as an entity with an average flow of resources (investment or capital) available to it.

Despite some light statistical work, this approach is resolutely historical. It is the process of working through previous biophysical explanations of business cycles—Jevons's agricultural pulse, but also Keynes's *General Theory* translation of that pulse to effects on current investment. This line of thought dovetails nicely with Joseph Schumpeter's (1934) account of credit and capital as a zero-sum game across the economy. It may seem strange to turn to such aged sources in the information era, but in some cases we might do well to go even further back, to the roots of the current system, to Sir Thomas Petty's statecraft and Isaac Newton's management of the British mint. The former, "that keen student of human affairs who insisted that labor is the father and nature the mother of wealth," has been given some credit for a proto-biophysical approach (Georgescu-Roegen, 1975, 350).

In evolutionary and systems perspectives, newer mechanisms and functions often layer over older ones, rather than replacing them. Earlier explanations of such obscured mechanisms sometimes proves superior to newer work that focuses narrowly on the present, often explaining more and more about less and less. As we develop increasingly sophisticated and accurate views of what happens inside parts of the economy, ignoring the work of those who studied its modern foundations seems an error.

I proceed by examining the US industrial matrix as an "ecosystem," each industry with an average allotted portion of the precious capital resource. Seen this way, the picture becomes clearer. We see some industries born, such as sub-sectors of the "Information" sector, which increase more or less monotonically through the postwar era. Other industries, such as agriculture, *decrease* monotonically in terms of their portion of total US fixed investment. I argument that the change in the relative portion of investment accruing to various industries is an excellent guide to what is happening to a nation's economic structure. We see even more when we compare the ratio of current investment in an industry to its historical norm.

We dare not venture too far yet into models or abstract mathematics representing how the economy works under various assumption, but focus on a simple mechanism, keeping our subject in clear sight for a while longer before it turns into a Greek letter. Keynes, an able mathematician, had great reservations on "symbolic pseudo-mathematical methods" that "allow the author to lose sight of the complexities and interdependencies of the real world in a maze of pretentious and unhelpful symbols" (Keynes, 1936, 297-298). Schools of economic thought deeply opposed to pure Keynesian theory may dislike the investment-labor mechanism here, but one hopes the interest in a clear solution to existing puzzles—ways oil prices effect the economy, whether oil shocks cause recessions, why oil price collapses do not produce commensurate booms, and perhaps even Dutch disease, the resource curse, and "jobless growth"—will overwhelm more esoteric disputes.

For this application it seems best to begin with simple measures and add dynamic or second-order effects as the situation warrants. The main idea, that increasing investment in oil and gas tends to sequester scarce societal resources in a labor-light (capital-intensive) corner of the economy, can for now be stated without benefit of a formalized model. It seems at least a qualitatively elegant in that it parsimoniously answers a number of existing puzzles.

This investment-centered approach appears unique in current economic debates on oil and the economy. Why? While a crucial part of the Keynesian program, investment from the investor's perspective can be difficult to see in neoclassical models that treat finance lightly or not at all. Changes in financial trends, such as a rise in oil and gas investment, may be hidden further by the inevitable adjustment for inflation, with the deflator generally higher during oil price shocks. At the very least the consumer price index and GDP deflators muddle the picture. Changes in money figures, or dollars, can be a slippery handle; value changes with the evolving system and in different proportion across all commodities. In short, mechanisms discussed in this paper may often hide in the economic dislocations of which they are an essential part.

There is a strong focus in economics—perhaps too much—on production functions. Ecological economists spend much time critiquing neoclassicists for the two-factor, labor-and-capital Cobb-Douglas production function (now nearly a straw man). Yet such functions still assume, when energy *is* added as an explicit factor, that its weighting in the function should be equivalent to its cost-share of GDP, which trivializes the role of energy in the economy. As shown in Chapter 2, ecological economists have derived "improved" production functions that sacrifice the Cobb-Douglas elegance for a better fit to energy realities (ie., Ayres and Warr, 2010).

Yet these functions, heavily stylized in the best of cases, seem to miss a great deal of what's actually happening across the economy. If oil and gas investment must rise in order to mine increasingly difficult deposits, a production function that translates Liebig's Law of the Minimum into economic terms, with energy as one of several limiting factors (capital and labor also come to mind), could be a useful approach to modeling macroeconomic production. China's aggregate function in 2001, for instance, would reflect the relaxing of the capital constraint on production, as it received perhaps a saturating amount after its accession to the WTO.

Rig Count and Recessions: The Oil Harvest Cycle and Investment "Ecosystem"

> "The replacement investment process is vital to any extractive firm that wishes to remain in its traditional line of business." (Scarfe, 1985, 403)

A reasonable first approximation measure for exploration and development activity in the oil and gas industry is the rig count, the number of rotary rigs drilling in the US at any given time. Keeping in mind the dangers of mistaking correlation for causation, the Jevons sunspot story, and countless other countless tales of naiveté, this appears a tantalizing piece of evidence. Figure 32 below suggests a reasonable, yet remarkable solution to the puzzle of how the oil price shocks affects the economy: they don't, much. Oil prices matter more as signal than as burdens on expenditure. What matters is the channeling of limited societal resources, or surplus, into a *deep and narrow, almost sequestered pool of capital*, where it tends to employ far fewer people than equivalent investment in other sectors. The rest of the impact on growth, effective demand, and the macroeconomy follows from the Keynesian principles.

To interpret these results, we should return to Jevons and Keynes for a moment and try to imagine a new harvest cycle—one with longer return periods and a different farmer. This is the "oil harvest cycle," or more generally, the energy harvest cycle[31]. The former helps explain the relationship between oil prices and recessions (see figure 33, below, for a lovely illustration of this cycle).

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[31] It likely works for any limiting, exhaustible resource.

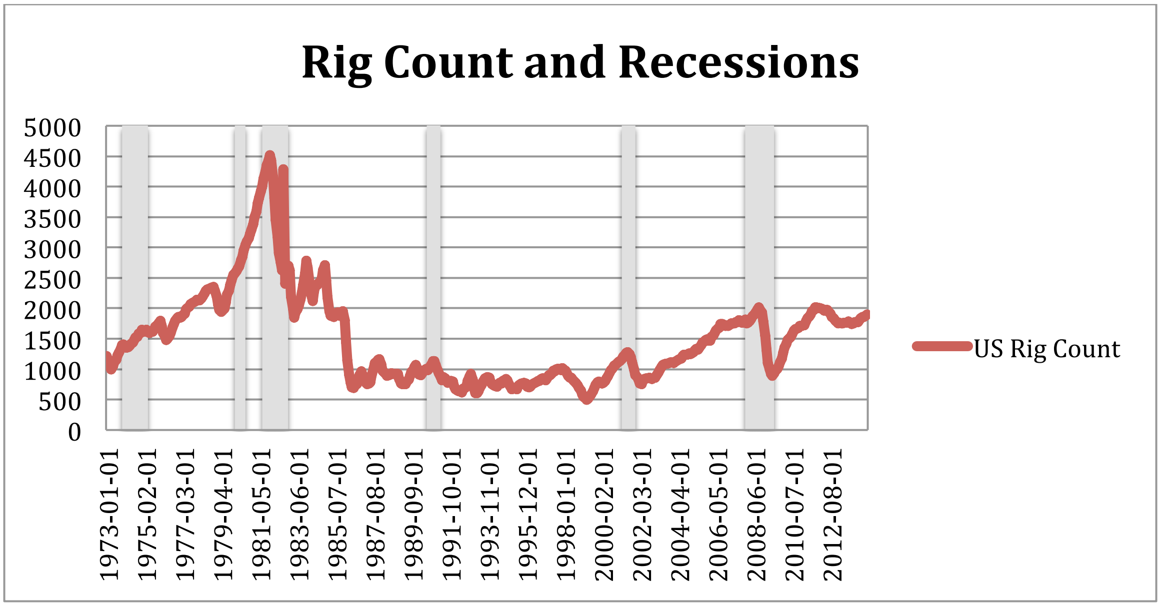

Figure 32. Monthly Rig Count (Rotary) , 1973-2014, With Recession Bars. *Source: US Energy Information Agency, Board of Governors of the Federal Reserve System (US)*

Table 6. Largest Components Of Private Fixed Investment, 1947-2013. *Note: L-T = long-term. Source: US Bureau of Economic Analysis*

Industry (Level 1)	**Average**	**Range**	**L-T Trend**
Real estate and rental and leasing	30%	22-44%	Cyclical
Manufacturing	17%	12-23%	Cyclical
Information	9%	5-12%	Increasing
Finance and insurance	6%	1-7%	Increasing
Mining	4%	3-12%	Cyclical
Health care and social assistance	4%	1-6%	Increasing
Utilities	4%	3-7%	Cyclical
Professional, scientific, and technical services	4%	1-5%	Increasing
Transportation and warehousing	4%	2-9%	Decreasing
Retail trade	3%	1-4%	Cyclical
Wholesale trade	3%	1-4%	Cyclical
Agriculture, forestry, fishing, and hunting	2%	1-8%	Decreasing
Industry (Levels 2 & 3)	**Average**	**Range**	**L-T Trend**
Real estate	28%	19-43%	Cyclical
Durable goods	10%	6-14%	Cyclical
Nondurable goods	7%	5-10%	Cyclical
Broadcasting and telecommunications	6%	3-8%	Increasing
Credit intermediation and related activities	4%	1-5%	Increasing
Computer and electronic products	3%	1-5%	Increasing
Oil and gas extraction	3%	2-9%	Cyclical
Chemical products	3%	1-5%	Cyclical
Miscellaneous professional, scientific, technical services	3%	0-4%	Increasing
Hospitals	2%	1-4%	Increasing
Rental and leasing services, lessors of intangible assets	2%	0-4%	Increasing
All Private fixed assets	**100%**		

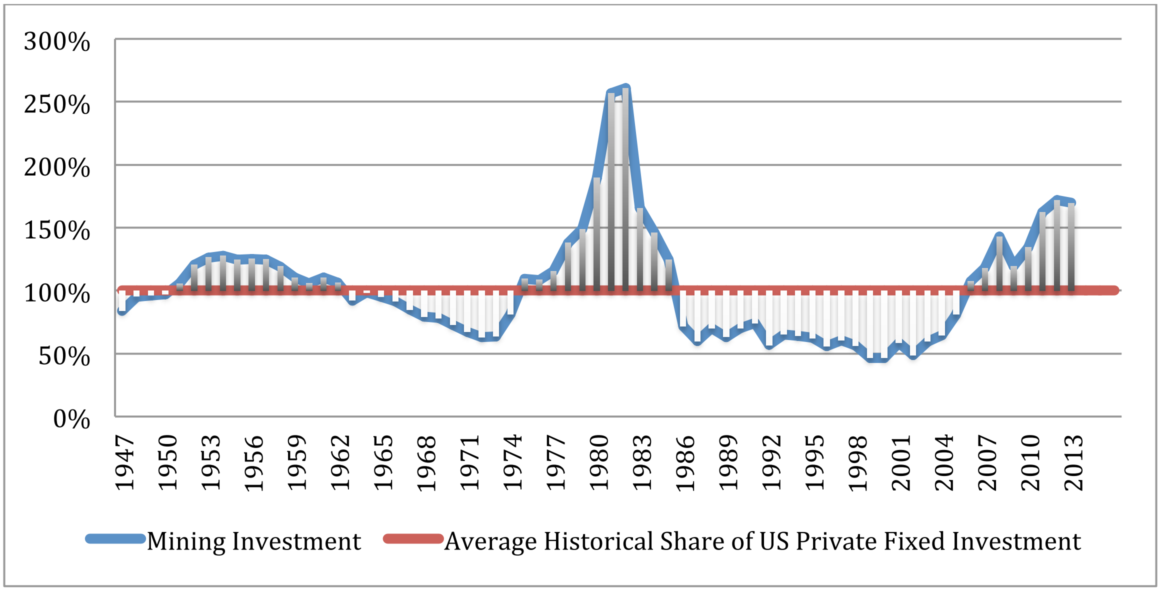

Figure 33. Mining Sector, 1947-2013, As Percentage of Its Average Historical Share of US Private Fixed Asset Investment. ***Source: US Bureau of Economic Analysis***

This shifting pattern in investment has been with us for a long time, across various types of resource extraction, including oil and gas, coal[32], perhaps agriculture and even precious metals according to Mill (1848), as mentioned above. Even more importantly, the foundational fossil fuel inputs to agriculture must be analyzed within this framework—the simple observation that food prices spiked along with oil prices in 2008, adding to sociopolitical turmoil and causing pain in many countries, is a place to start (the 1970s and early 1980s saw similar dynamics)[33].

A careful rereading of Keynes's ideas on current investment and "carryover" as essential determinates of the business cycle support this work (Keynes,1936, 329-331). In place of good harvests we have periods following large bursts of capital expenditures (drilling) on oil. In place of bad ones, years in which returns from previous bursts of drilling effort has diminished to the point that increasing

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[32] The question arises of how to treat global coal—a fundamental energy source with its own pattern of diminishing returns over time, as shown by Jevons. The coal cycle seems to be slower and less intense than oil, but subject to some of the same effects. Here we do not differentiate between various extractive or fossil fuels. More work is needed on previous fossil cycles in England, and on current ones in China.

[33] David Pimentel (1973) and his collaborators broke important ground here**,** giving one of the earliest and most comprehensive analyses of the fossil-fuel-centered agricultural methods being exported from the US. Another question is whether investment in food trades off with investment in oil and gas.

investment must be diverted to the oil and gas industry. This is less productive of effective demand for the community.

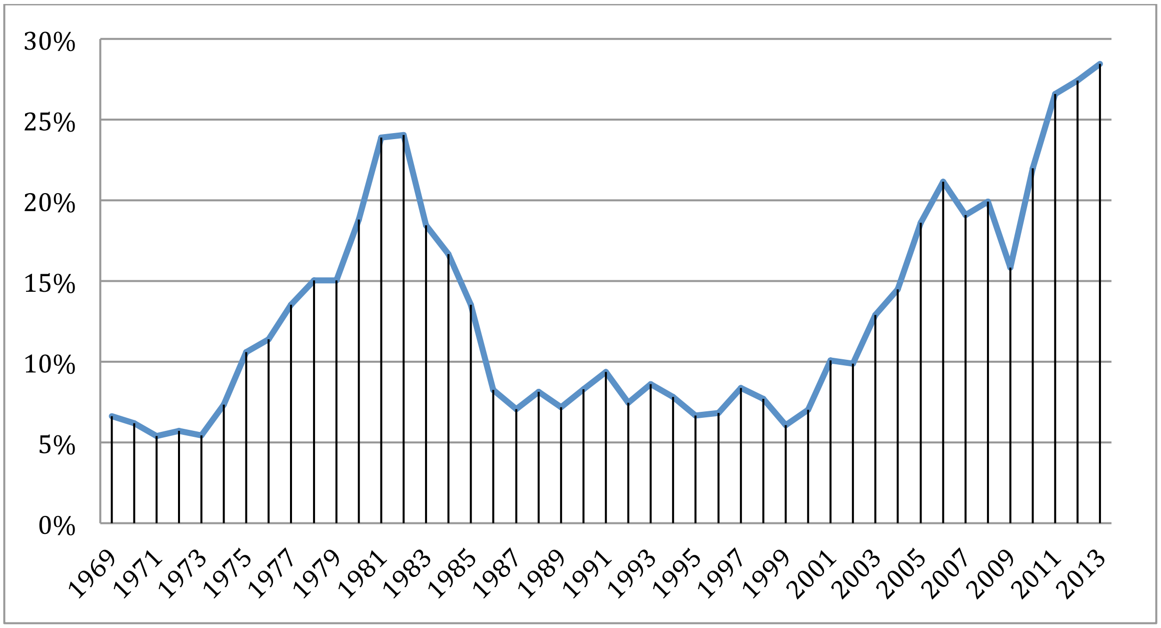

Figure 34. Oil and Gas as Percentage of US Investment in Non-Residential Structures, 1969-2013. *Note: Includes both "oil and gas extraction" and "petroleum and coal products" (coal is a very small component). Source: US Bureau of Economic Analysis*

This cycle likely interacts with other harvest cycles. The agricultural cycle, though largely driven by fossil fuels, still exists. Climate change has an increasingly disruptive effect, as mentioned above, and thus perhaps more influence on the global economy than currently acknowledged. Also notably, US large-scale agriculture now functions like an extractive industry, with a very low labor ratio**.**

In Keynes (1936), grain surpluses are bought in fat (high-yielding) years as an investment, financed from savings, but not consumed. In subsequent lean years, when prices are higher, those grains will yield a return *at higher price*, adding not to the income of farmers, but to that of investors. This is a double squeeze—prices for staples rise, while a leaner harvest provides the consumers, with their higher propensity to spend, with less income. Demand falls in this case, squeezed by rising prices and falling income. Crucially, this mechanism revolves around who produces society's energy—the consuming class, as in the case of farmers and to a lesser extent coal miners in the past, or the investing class, as with the increasingly capital-intensive oil and gas industry. (Mitchell, 2009, traces the political effects of this shift.) To sum up, fat years for the consuming class generally translate to high effective demand, fat years for the investing class, at extremes, do not.

We might relate the return period of oil harvest cycles to a field or well's productive lifetime (see Naccache, 2001, on cycles of oil investment). The effort put into exploration and development during the lean years, or investment pulse, produces a large number of new wells. The 1960s saw the peak of giant field discovery; these follow an exponential decline curve. By 20 years of age, fields yield far less than before (Höök et al., 2009). Shale oil wells have much shorter lifespans, going through the same order-of-magnitude decline, in 3-5 years of production or less (Hughes, 2013). At this point a new pulse of mining investment is needed—bad news for the larger economy, especially since continuous high drilling effort tends to contract the economy.

Durable price declines in oil and gas signal the end of an investment pulse—and the beginning of an energy pulse. The decline in the second half of 2014 likely marks the end of the energy investment cycle that began 10 years earlier, in 2004[34]. Still, we can expect an overshoot signal from this decline, with some near-term recovery in prices, toward a long-term equilibrium[35]. We may also expect a shorter return period for future oil price shocks, given the productive lifetime of shale fields. One might also ask whether *investment pulses* are getting longer as *energy pulses* get shorter, which follows from the argument that returns on oil and gas resources are diminishing.

Meanwhile, long periods of low oil prices, with minimal levels of US oil and gas investment relative to the historical average, seem good for the economy. These conditions prevailed during the late 1950s to mid 1970s and 1986-2000. This negative case, the correlation between decreasing or flat oil investment oil investment and consistent growth, is as strong as the positive case. The early 2010s did see periods of decreasing or stable unemployment with increasing oil investment, which calls for further investigation, but few observers would call the US economy especially robust during the periods between the 2001 and 2008 recessions and after—the 2008 collapse revealed a significant portion of US growth in the 2000s to be chimerical. In late 2014, when the US experienced its highest growth rates in decades, investment in oil and gas had already began to plateau. The price signal received through the second half of 2014 is perhaps a lagging indicator of what many in the oil and banking industries knew earlier[36].

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[34] Over that time, global exploration and development investment rose dramatically, in step with US investment. International effects and dynamics, however, must be largely left aside until Chapters 6 and 7.

[35] The effects of the US dollar exchange rate on the oil price should not be taken lightly (see for example Frankel, 2014, or Wills and Hammes, 2005). It is not coincidental that the peak and decline of the Euro and Yen against the dollar coincides with the oil price drop. This effect will also be considered further in following chapters. Notably, as of this writing in mid-2015, the oil price and EUR/USD ratio have recovered in step.

[36] As mentioned, the important currency and balance of payments issues, and their reciprocal influences on the oil price, will be kept offstage until Chapters 6 and 7 in order to focus on the internal US mechanisms. European, Japanese, and Chinese monetary expansions, needless to say, appear important. The Euro/USD rate, for instance, has dropped dramatically, from around 1.40 in July 2014 to 1.10 in May 2015.

This part of the cycle—the boom following the return of investment to the rest of the economy, the non-energy sectors, brings up an important point. The periodic expansion of investment in exhaustible resources sectors seems not the plot of evil people in a small room, but a necessary condition of fossil fuel economies. The process may be managed more smoothly and equitably, but we cannot have one side of the modern economic equation without the other. The economy builds up and runs down its fuel reserves in a sort of energy-economic respiration. Investment pulses by any name will be key to low-carbon energy transitions, with different cycles of resources necessary to build out renewable sources such as solar and wind.

I use Odum's "pulsing paradigm" (1988) as a heuristic for these oil harvest cycles. The economy, after a high-growth period, must pause and refresh its fundamental nutrients and fuels. Investment shifting to resource extraction constrains the rest of the economy, mainly through labor markets. The diminishing returns aspect of exhaustible fuels necessitates this periodic pulse of investment.

This mechanism produces a number of predictions. One, the period of low oil prices should more or less correspond to the productive lifetime of the new marginal sources that resulted in the previous price rise. Two, the global economy should recover in a more robust fashion from 2015 forward, with investment leeching out of the fossil industries for a period, though political economic and technical disruptions always have the potential to surprise.

Oil and gas supplies tighten as the diminishing harvest falls out of step with the rate of economic expansion. This supply, as noted, increased to an enormous degree during the 1960s, the peak discovery period of the world's giant oil fields (Höök et al., 2009). Yet this was matched step by step by a global generalization of the US-style auto culture: a "power-maximizing" economy to match this flood of energy (Odum, 1988)[37]. As supply tightens, rising oil and gas prices gradually attract investment—it takes months to years for investors to become convinced of a durable rise. The investment then tends to come in large pulses, as do oil shocks. Especially in the 1970s, this was a step function more than a slowly rising price. The 2000s oil rise seemed smoother than the 1970s and 1980s, perhaps due to the increased importance of the market mechanism in determining price.

These cycles, occurring in periodic bursts, challenge ecological economics researchers (eg., Hall et al., 2008), who pose implausible, endless linear growth of energy costs and investments until there is no economy left—neglecting some of the

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[37] The idea that there is some kind of natural, independent demand path for oil or almost anything else seems untenable—demand seems jointly determined with supply, a function of many cultural and technical factors. In other words, high-energy lifestyles were partly a function of, and partly created to absorb, the oil supply gushing online in the postwar world.

economy’s natural dynamics and making this line of biophysical economics easier to dismiss. Their story of endlessly rising linear production costs may be dismissed at the completion of every cycle, when prices crash.

Chapter 5. The Oil Harvest Cycle (Part 2)

Investment Shifts

Keynes's work on interest rates and investment is central to my thesis. Societal resources diverted to one sector must be drawn from another, as Schumpeter (1934) and others showed. This should also be true of large relative shifts among industries with very different combinations of labor and capital. Rising interest rates tend to concentrate investment in the highest-returning industries—oil and gas during sustained price increases provides a good example. (The "normal" rate of profit in oil and gas seems merely a long-term average of boom and bust periods, with barriers to entry one reason its level remains higher than that of other sectors.) Meanwhile, marginal, lower-yielding projects are cancelled or delayed; investments suitable to the economic climate and it high liquidity preference become scarce in many industries.

The fact that energy-intensive industries are no more likely to see problems in oil shocks than the rest of the economy puzzles researchers such as Davis and Haltiwanger (2001). The oil-harvest idea suggests capital-intensive industries in competition with oil and gas for investment would be more likely to contract. This rationalization according to profits, the "marginal efficiency of capital" in Keynesian terms, hinders economy-wide investment during later stages of price shocks as the increasing profitability of the oil industry soaks up capital, the required return on investment moving upward with the interest rate and liquidity preference[38].

Energy prices largely do not of themselves cause recessionary disruptions and economic problems—results here indicate it is the increasing cost of replacing these reserves, and the channeling of the necessary investment into a labor-light (low-employment) section of the economy, where it is increasingly sequestered during oil shocks. In short, major resources are put into *unusually self-funding,* capital-intensive industries (including oil and gas, refining, and oil services), leaving less surplus for other industries and inducing contraction. The resulting prediction is that after the 2004-2014 investment wave, which appears to be receding, other industries, culled and restructured, will begin to recover. The investment period is over, and the energy harvest pulse, however long- or short-lived, may begin.

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[38] There is an interesting connection here to Hotelling (1931) and his views on interest rates and oil price rises. Yet under Greenspan and Bernanke in 2004-2006, the Fed first increased interest rates with the oil price as it had historically, but the link between interest rates and oil prices was cut from around 2007, though both declined at similar rates during the peak of the 2008 crisis. This also brings up the effect of excess reserves held at the Fed since then, or how lending and monetary growth can be limited at zero percent—these questions must be dealt with further in Chapter 6.

Oil production is highly capital-intensive. When prices start to rise, often in the middle of economic expansion, investment flows to an industry with one of the highest capital to labor ratios—it may, like real estate, be fairly thought of as a rentier industry. Capital flows (assuming here a closed system, which the US is not) are to some extent zero-sum games. Assuming regular growth in GDP and money supply over the long term, a short-term doubling or tripling of capital flows to one industry must necessarily shift investment from other industries. There is no question here of growth accounting for the additional investment, as the periods in question mostly feature low growth and flat to declining investment.

As we learned from Keynes, effective demand is a key to economic growth. Yet as capital shifts to energy industries, new workers in other sectors are not hired and existing workers are released. This can be shown through growth rates of worker numbers and total wages in various industries.

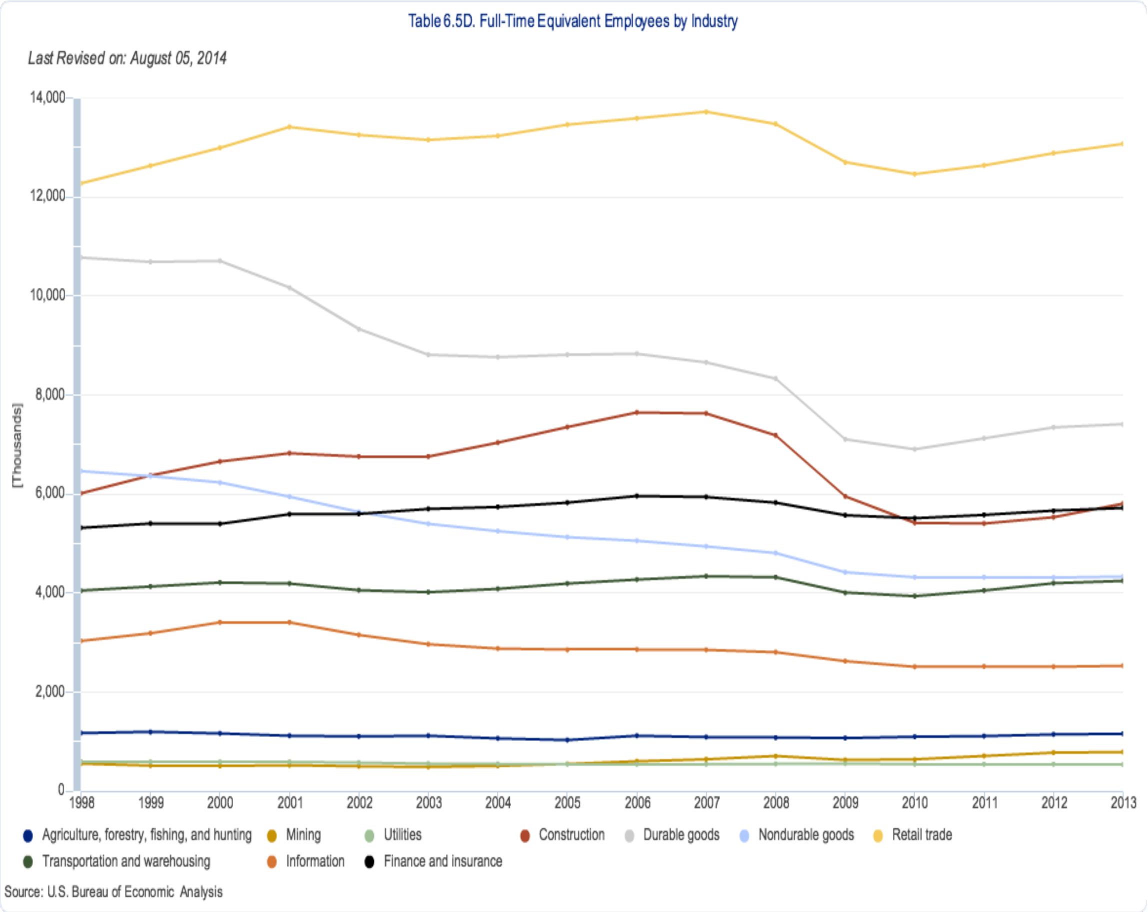

Figure 35. Full-Time Equivalent Employees, Various Industries, 1998-2013. ***Note: Mining is the industry near the bottom of the graph, intertwined with utilities; both have less than a million domestic full-time equivalent employees. Source: US Bureau of Economic Analysis***

The trend may be more evident in countries with mature industrial sectors. I suggest that much of the phenomenon known as Dutch disease, and perhaps the "resource curse" as well, both of which both refer to the ill effects resource extraction can have on a national political economy, may be traced to the shifting between capital and labor-intensive industries. The rise of information technology and financial sectors complicate, but do not change, the basic picture.

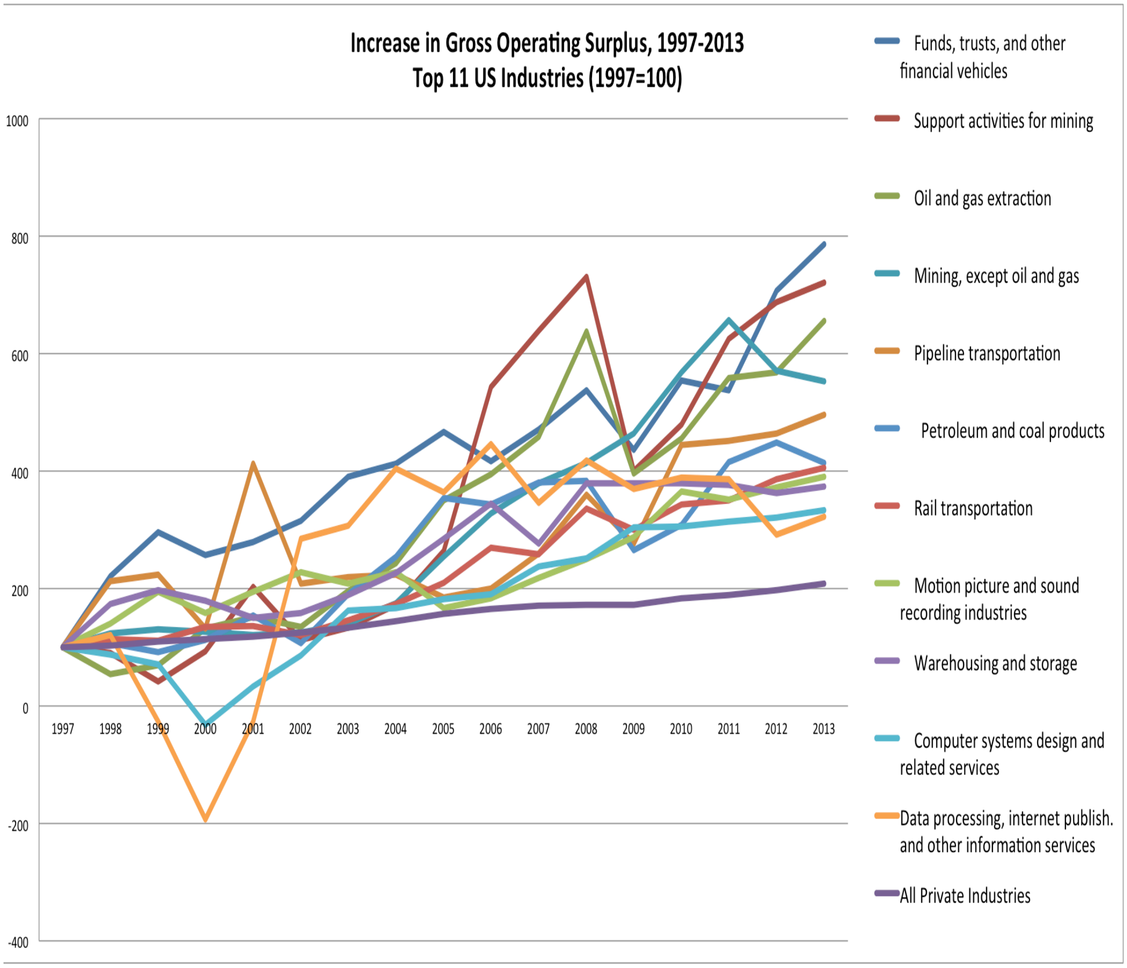

Figure 36. US Industries with Highest Gross Operating Surplus Gains, 1997-2013.
Source: US Bureau of Economic Analysis

The key mechanism—a nation and world running on diminishing returns from its oil supply until induced to make a large investment—helps explain the oil price-shock to recession phenomenon. In addition to cost-push inflation that shifts consumer expenditure to fuel industries, oil industry resources are recycled in a capital-intensive manner that tends to put fewer people to work per dollar. The oil and gas industry sequesters an increasing amount of societal resources during its periodic bursts of exploration and development (drilling). Until the price signal eases, this circuit tightens economic conditions elsewhere in the economy. Amplified by "animal spirits" and expectations, this can have a much larger effect on the whole than one might guess by simply looking at the average GDP share of oil—as economists often do (see Ayres and Warr, 2010).

Table 7. US Industries with Largest Increases in Gross Operating Surplus (GOS), 1997-2013. *Note: *Support activities for mining, rail, pipeline, and warehousing all have large oil and gas components. Source: US Bureau of Economic Analysis*

	GOS, Billions USD (Nominal)		
Industry	**1997**	**2013**	**1997-2013**
Oil and gas extraction	$34	$223	$1,889
Petroleum and coal products	$36	$148	$1,586
Motion picture and sound recording industries	$20	$79	$811
Mining, except oil and gas	$10	$54	$513
Data processing, internet publishing, other information services	$5	$30	$400
Funds, trusts, and other financial vehicles	$10	$38	$345
Computer systems design and related services	$9	$32	$302
Support activities for mining*	$4	$28	$235
Rail transportation*	$5	$21	$203
Warehousing and storage*	$3	$13	$154
Pipeline transportation*	$3	$12	$122
Oil & Gas Extraction + Petroleum and Coal Products	**$70**	**$371**	**$3,475**
All Other Industries Above	**$49**	**$307**	**$3,084**

Recessionary tendencies play out as investment and building reserves begin to resolve the energy price issue. We leave the longstanding monopolistic aspect of oil markets aside for now, assuming only that such rentier aspects further reduce the flow of cash through public hands. The worse the energy situation, or, from another perspective, the greater the expansionary impulse to the global energy industry, the longer this situation takes to resolve itself. We can view the United States in the 1970s and much of the world in the 2000s as examples of this cycle.

We typically see a drop in gross private investment a year or so before recessions, as forward-looking investors delay in response to rising oil prices and interest rates, which signal a tapering of demand (for the relationships among expectations, uncertainty, and investment, see Bernanke, 1983). For most of the economy, rising rates transmit a signal to slow. Oil and gas, however, sees rising interest rates as a signal to increase investment and drill. Meanwhile, the oil price tends to overshoot, growth rising while the larger economy slows or even contracts. Returns in oil and gas look increasingly good by comparison, further redirecting investment and intensifying the last stage of the investment pulse. Few other consumer staples—one thinks of toothpaste or cooking oil—have this dynamic.

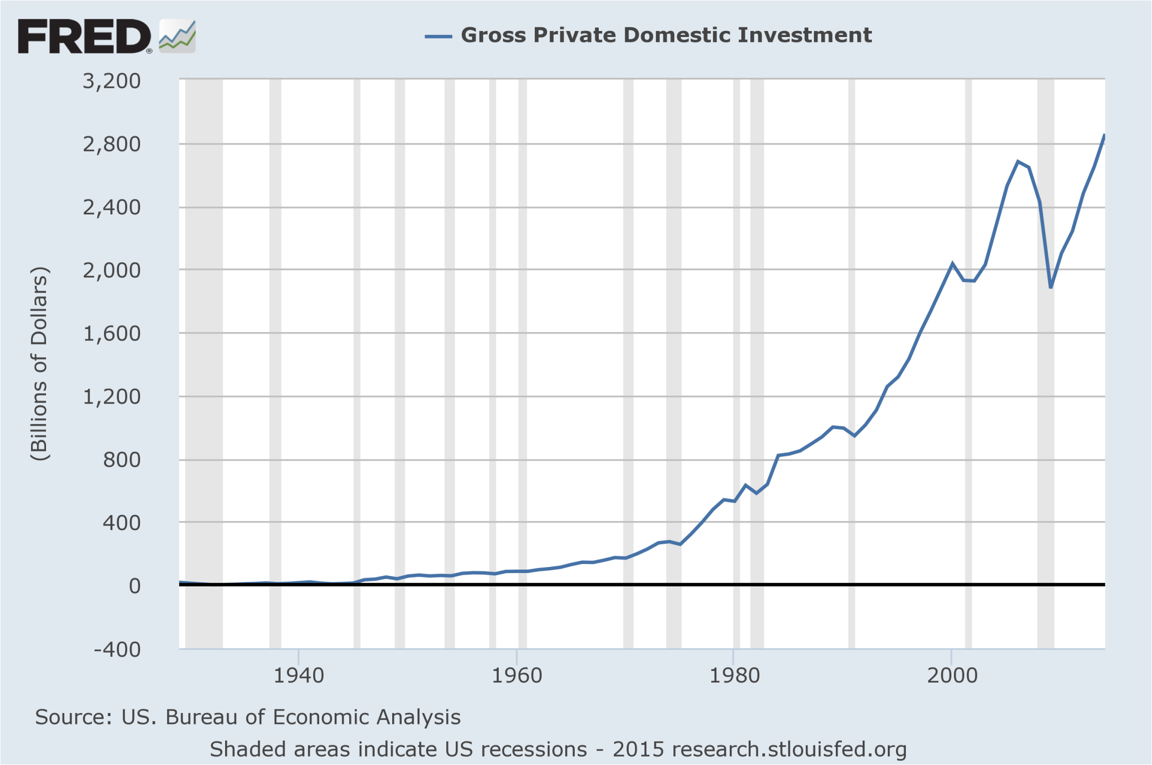

Figure 37. ***Gross Private Domestic Investment, US, 1929-2013***

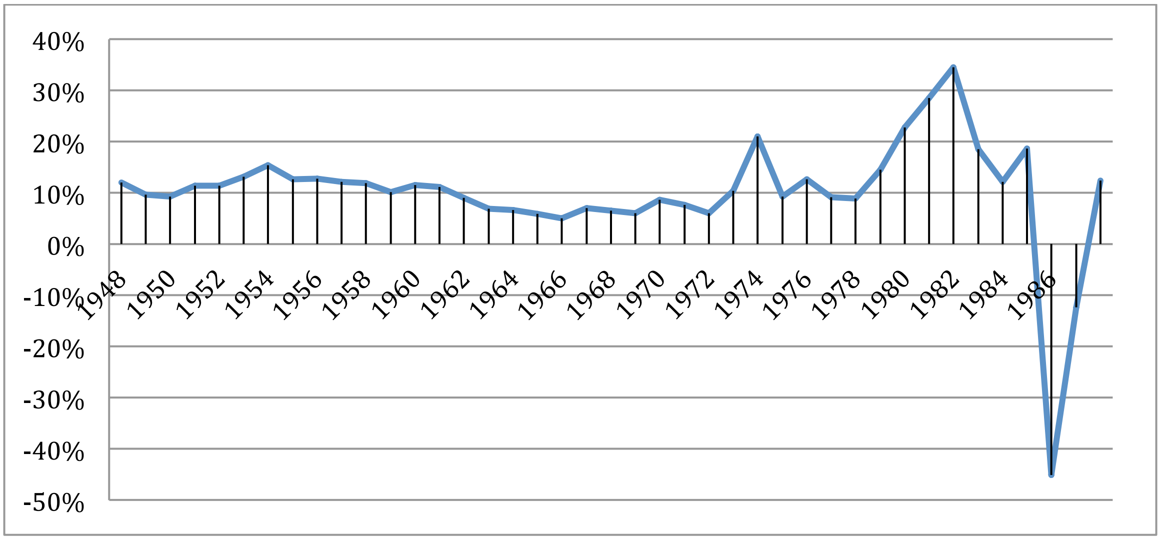

Figure 38. "Petroleum and Coal Products," Percentage of Undistributed Corporate Profits, 1948-1988. *Note: The coal component of this sector is very small, even trivial, compared to petroleum. Source: US Bureau of Economic Analysis*

Much energy investment also flows overseas. The 1970s and 2000s saw enormous expansion in foreign oil development (the Middle East in the 1970s, deepwater and unconventional sources in the 2000s). Some of this capital comes from US sources, of course, further tightening conditions in the United States, given the uniquely self-funding—mainly through consumer expenditure—nature of oil and gas investment.

At the center of this model, the supply side constrains production and growth. Innovation pushes supply limits out, entailing large bursts of investments signaled through prices and interest rates. I examine long-period cycles in the economy, focusing on the 1970s and 2000s. The 1970s serve as an example of the effects of peak conventional oil production in the United States, while the 2000s provide an example of the same on a global scale. While alternative sources such as shale, oil sands, and natural gas liquids grow the global supply of hydrocarbon liquids, the expansion comes at a high cost.

Nevertheless, the investment expansion of the 2000s should result in a "harvest period" of lower oil prices, similar to the one that prevailed in the global economy from roughly 1986-2004, though likely not as extended, given the shorter lifetime of shale wells (and the lack of an oil pulse from a fracturing USSR). The oil price drop in 2014, like the one in 1986, followed a decade of high and rising energy prices, a "price step" that brought on new supply.

This price step is important for the energy harvest cycle, as it induces investment in a new round of energy sources. For the 1970s this included Alaska and offshore, primarily, while in the 2000s it includes deeper offshore and shale oil. The "cost-push" of oil prices help produce inflation and stagnation, but so does the need to reroute capital into the probabilistic endeavor of exploration and development[39]. Drilling is a gamble, and "dry holes" seem particularly unproductive.

Enormous growth in global E&D during the 2000s, especially in the United States, provided the unconventional and natural gas liquids that help fill the "crude oil gap" created by the slowing or peaking production of conventional oil. This increase in investment, on the order of 10% per year, had to come from somewhere during a time when the US economy was only growing at 1-2% a year. How did such a relatively labor-light sector drawing so much investment affect demand in the US? There is an opportunity cost to investing so much in such a light employer: the diversion of resources from high-employment industries.

The oil and gas investment circuit runs through consumers (Engler, 1977). Rising energy prices for consumers also reduce the amount of surplus channeled to other sectors. In the extreme case, in the late 1970s and early 1980s, the "petroleum and coal products" industry designation, of which oil is nearly the entirety, took in more than 30% of all US after-tax corporate profits and 40% of undistributed corporate profits, squeezing profits from many smaller industries and shifting its surplus back into upstream investment (see Figure 38, above). Some percentage surely flowed

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[39] It is commonly noted that exploiting shale wells is less probabilistic, with a more controllable output, more akin to manufacturing.

into other high-return sectors, such as finance, as well—oil and gas's investment in other industries is an intriguing topic for further research.

Particularly upstream, in exploration and development, oil and gas companies fund themselves to a degree unusual in other industries (Scarfe, 1985). Resilient (versus short-lived) oil price shocks signal new investment and historically induce the Fed to allow interest rates to rise (Bernanke, 1997). Investment flows away from other industries, into oil and gas; meanwhile, consumers find less cash to spend on other items. The economy tends toward recession. Rising prices in effect vacuum an increasing amount of money from consumer pockets into the corporate stratosphere. This effect is large in the oil industry due to the near-necessity of automotive transportation in the US. I argue, along with other authors, that this functions much like a periodic private tax (Engler, 1977).

The marginal change in non-fuel consumer spending this entails dampens consumer and investor expectations in a vicious cycle, another Keynesian concept. This is characteristic of oil investment pulses, any time E&D and the rig count rise in a substantial and sustained manner. The worsening situation in the labor market and rising fuel prices slow investment in other sectors and further reduce demand as consumers prepare for, then endure, a downturn.

Table 8. Full-Time Equivalent Employees, Industries with Fastest GOS Growth 1998-2013. *Source: US Bureau of Economic Analysis*

	Full-Time Equivalent Employment (1000s)		
Industry	**1998**	**2013**	**% of 2013 API**
Oil And Gas Extraction	138	194	0.18%
Petroleum And Coal Products	121	110	0.10%
Motion Picture, Sound Recording Industries	309	333	0.31%
Mining, Except Oil And Gas	241	207	0.19%
Funds, Trusts, And Other Financial Vehicles	14	3	0.00%
Computer Systems Design, Related Services	N/A	N/A	N/A
Information And Data Processing Services	399	335	0.31%
Support Activities For Mining	180	395	0.37%
Rail Transportation	212	189	0.18%
Warehousing And Storage	456	670	0.63%
Pipeline Transportation	48	41	0.04%
2013 Totals		2,477	2.32%
All Private Industries (API)	99458	106911	100.00%

The shifting of investment into an extraordinarily labor-light industry is the key to this cycle. Surplus in oil and gas tends to accumulate in the pockets of shareholders or is reinvested, in both cases dodging the pockets of most middle- and working-class consumers, who may be expected to spend it on investment-stimulating consumption (their propensity to consume being higher than that of wealthy individuals by necessity). We get another view of the "labor-light" oil and gas industry by looking at the full-time employment of the industries with the fastest-growing gross operating surpluses from 1998-2013 (Table 8).

Energy investments may be seen as the system maintaining itself. When prices rise, signaling for our purposes, naively, that resources are running low, investment is diverted to the energy sector. This puts a higher premium on capital; high-return projects are necessary in such periods, when energy prices are rising with the interest rate. (This accords with the Hotelling (1931) model of exhaustible resource extraction.) Our central prediction, that oil and gas investment would be much higher during (oil shock) recessionary times, turns out to be validated by the data (eg, Reiss, 1989). Investment comes mainly in exploration and development capital expenditures from the industry, though a small portion is for leasing of new territory for exploration. Meanwhile, this "pulse" of energy exploration, which diverts other investment and related consumption, bears fruit after 5-10 years as these wells begin producing, easing supply conditions (and overwhelming storage).

Recent research (Jakobsson, 2014; Höök et al., 2009) shows that conventional wells have a productive period, roughly 20 years, that fits the observed investment cycle in the oil industry. After a period of high prices that induce increasing investment, there is some lag as wells come online, perhaps 4-6 years, then a period of "high supply," where the price tends toward its pre-shock price, adjusted for inflation. This seems to have happened in 1986 and again in 2014.

The results of regressions do not support a strong, direct statistical negative correlation between oil and gas investment and other sectors, with the exception of real estate. A non-linear relationship seems likely. It seems that oil and gas investment tends to rise with the rest of the economy to a point, but excess—when it rises 100% or more from its previous share of private fixed investment—seems to draw investment from the rest of the economy. This signature is most prevalent in the years 1980-82 and 2005-9, notably, the deepest recessionary periods in the postwar era. There seems a threshold effect for oil and gas investment, a point beyond which it no longer benefits the economy as a whole.

A conceivable alternative argument is that oil and gas is a more recession-proof industry, and remains strong as the rest of the economy contracts around it, thereby accounting for a larger portion of investment during downturns. There is some support for this idea in the fact that oil and gas investment does normally decline at some point during recessions, but after general investment. Yet this lagging factor seems to intensify downturns as it overshoots and constricts the rest of the investment ecosystem. In other words, a slowdown attributable to rising fuel prices often becomes a recession once processes to replace those fuels kick in.

This mosaic of facts begins to explain the high-oil-prices-cause-recession story. Oil prices rise as reserves decline, new supplies become more difficult to develop. As older, cheaper fields deplete; newer, more expensive ones take their place. After the 1960s fewer and fewer giant fields exist to be found. At the same time, the Fed usually allows interest rates to rise with oil prices (until 2006-2007). This restricts total investment, cutting off projects at the margin and, shortly after, slowing employment, consumption, demand, and growth. Oil (energy) takes in a far larger share of investment than its historical baseline during this period. The resultant pulse of oil exploration and development shifts investment away from the larger economy, but produces, less than a decade later, a new pulse of oil. The economy picks up where the last expansion left off.

Crucially, we see this process resulting in a shifting of investment as a whole region peaks. The US in the 1970s took enormous infusions of capital into the oil industry, directing them around the world. This was generalized globally in the periods before and after the 2008 crisis. Along with telecommunications, energy was the top sector for investment during that time, but as of this writing, in 2015, the expected oil pulse has arrived, easing global supply conditions and prices. But how long can it last?

Labor Intensity

> Many industry analysts argue that the government should provide financial incentives to stimulate large scale drilling programs. If society helps sponsor such an effort it should consider the opportunity costs associated with such a program.
>
> --Cleveland (1991, 185)

Table 9. Labor Intensities of Fastest-Growing GOS Industries, 1998-2013. *Source: US Bureau of Economic Analysis*

Employees/$10 Billion Dollars of Gross Operating Surplus			
Industry	**1998**	**2013**	**% of 2013 API Average**
Oil and gas extraction	75,000	8,700	5%
Petroleum and coal products	31,759	7,417	4%
Motion picture and sound recording industries	109,964	42,420	25%
Mining, except oil and gas	199,174	38,192	23%
Funds, trusts, and other financial vehicles	13,208	796	0%
Computer systems design and related services	N/A	N/A	N/A
Data processing, internet publish., information services	356,250	112,040	66%
Support activities for mining	514,286	140,569	83%
Rail transportation	359,322	89,573	53%
Warehousing and storage	772,881	527,559	313%
Pipeline transportation	90,566	33,065	20%
All Private Industry (API Average)	317,544	168,752	100%

In labor lies the key part of the process for the economy. Oil and gas extraction is one of the least labor-intensive big industries in the economy, though real estate surpasses it. One difference is that real estate typically sees no undistributed corporate profits at all—ie., its investment appears not to temporarily sequester resources in the same way that oil and gas does. This characteristic, along with its large investment fluctuation range relative to other industries, accounts for the oil industry's outsized effect on the economy.

Imagine a dense, heavy weight that slides back and forth across the length of a cargo ship, now raising the bow from the water, now the stern. The non-oil and gas economy may be thought of as cargo better stowed and balanced—it shifts less, its weight more distributed. Various cargoes can disrupt the boat's balance by appearing, by growing rapidly in size, or by shrinking, but these normally account for smaller parts of the economy at first and become distributed over time. The implied policy question is what the captain might do to counterbalance or secure that weight, were she so inclined.

Table 10. Ratio of Gross Operating Surplus to Employee Compensation. *Source: US Bureau of Economic Analysis*

Gross Operating Surplus / Employee Compensation

Industry	1997	2013
Housing	7602%	10088%
Funds, trusts, and other financial vehicles	600%	6283%
Real estate	1856%	1910%
Real estate and rental and leasing	1410%	1532%
Petroleum and coal products	338%	828%
Oil and gas extraction	276%	619%
Farms	426%	535%
Rental and leasing services and lessors of intangible assets	422%	448%
Other real estate	346%	374%
Agriculture, forestry, fishing, and hunting	313%	348%
Mining	136%	329%
Finance, insurance, real estate, rental, and leasing	293%	307%
Mining, except oil and gas	71%	293%
Motion picture and sound recording industries	107%	263%
Chemical products	165%	258%
Broadcasting and telecommunications	158%	211%
Pipeline transportation	71%	203%
Average, All Private Industries	80%	89%

New hiring in oil and gas is increasingly trivial on an economy-wide scale. The ancillary effect of feeder industries does not seem strong enough to counter this effect[40]. The US seems to sacrifice employment for new domestic energy resources. Whether this is correct, necessary, or efficient policy, I do not address. In the case as

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[40] In any case we must first identify, in the globalized world, in which regions of the world such industries are located.

it is, the Keynesian mechanisms come into play. Falling employment reduces effective demand, lowers expectations and the inducement to invest, and begins a contractionary cycle (Bernanke, 1983, on expectations and investment uncertainty is again useful).

What Does This Model Do? What Does It Solve?

> Cost increases would be a sonar "ping" warning us we were getting closer to the end, when it would no longer pay to find and develop.
> (Adelman, 1988, 40)

The oil harvest cycle 1) answers longstanding questions in mainstream economics on the channels through which oil affects the economy ("Bernanke's Puzzle"), and 2) lends empirical support to the theories of those who helped launch ecological economics in the 70s and 80s. In particular, it lends a specific economic mechanism to diminishing marginal returns on exhaustible resources—analogous to the economic influence of declining net energy yield or EROI. Simply put, it illustrates what Jevons described in the *Coal Question*—as mines get deeper, or wells more difficult to produce, an increasing amount of society's resources must go into maintaining their flow. In our case resources are drawn from more labor-intensive, growth-stimulating parts of the economy.

This framework helps explains why the mining sector is the largest source of fluctuation in US investment, relating back to the harvest cycle of Jevons and Keynes. In the fat years between *investment pulses*, about 15-18 years for conventional oil, the economy receives an *energy pulse* from previous major bursts of exploration and development drilling[41]. The latter coincides with the lean years of heavy energy investment, when reserves are built back up and a price step brings new, more expensive sources of supply online.

This cycle obscures aspects of both the ultimately rising costs of exhaustible resources and the potential for energy prices to decline over long periods. This in turn leads more Malthusian ecological economics researchers and more cornucopian neoclassicists to overemphasize their arguments. In lean years, energy-focused arguments—such as those made in ecological economics during the 1970s and early 1980s—draw more attention than they do in fat years, such as 1986-2001, when they are often forgotten. In fact, we seem to have a cycle oscillating around a rising trend of fossil depletion and costs. To make this clearer, I have used the average share of annual investment in each industry as a baseline (see Table 6 and Figure 33). During the fat harvest years, mining's share of investment typically drops to around half of its average level, leaving it important in the mix, but not disruptive. In the lean years, it can rise to nearly 250% of its long-run average,

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[41] I imagine the case can be generalized to any extractive resource the economy might base itself around, in past or future. Individual rare earth metals come to mind, though substitution possibilities seem much greater.

choking off investment in other sectors, with the concomitant effect on employment and growth.

Some tests of a good theory, perhaps, are whether it is elegant, simple, concrete, and answers many questions reasonably neatly. The oil harvest cycle tells us where to look in the data and what to look for—the questions it answers in a straightforward manner seem to outweigh the questions that nag it. So what can this model do?

The oil harvest cycle adds to the "energy as business cycle trigger," literature, bringing a pure Keynesian focus on investment, employment and effective demand to what had mainly been a consumer cost-push explanation (Hamilton, 2005; Sexton and Zilberman, 2011) grounded in microeconomics. It also helps adjudicate the argument between supply and monetary causes for oil price shocks and resultant downturns. Monetary effects seem to arise partially as a need to adjust the domestic supply of credit to accommodate and manage energy exploration and development—the resultant movements of the dollar and interest rates then feed back into the energy system. The effects of oil price shocks and investment shifts on the dollar, devaluation, petrodollar recycling, and the global trade-monetary system will be discussed in more depth in Chapters 6 and 7.

This model may also help explain both Dutch disease and the resource curse, national afflictions often discussed in political economic literature. Through mechanisms discussed here, it becomes clear that sectors such as manufacturing and construction suffer when oil and gas exploration rise, due to the effects of the investment shift. This accords with Dutch disease. Over longer periods the effect could become more or less structural, though it fluctuates in the US.

As for the resource curse, heavy long-term investment into oil and gas—or any extractive sector with labor-light requirements—could easily produce a more stratified and unequal society. Political power in this case becomes as concentrated as capital, perhaps bringing with it all the attendant governance problems—cronyism, lack of effective democracy, etc. This theory would then predict less effective democracies, generally, in nations with heavy deposits of hydrocarbons or any capital-intensive, high-value resource—confounding effects and Norway aside.

The theory also gives a better sense of where the trouble lies in restarting the global economy. Massive investment into the US and global oil and gas sector from 2004-2014 here is a large contributing factor to the slow recovery from the 2008 global economic crisis—and a precipitating factor. Put simply, the world awaits its energy pulse after long years of floundering, and with the recent drop in oil prices and the related European and Japanese devaluations, 2015 may begin this cycle.

The oil harvest cycle lends credence to the biophysical view of the economy as essentially founded upon, and paced by, energy and resource inputs. The exhaustible, diminishing nature of the key energy resources are important one-way downward influences on economic growth. More precisely, they bias the system against infinite continuation of the massive growth rates *they themselves engendered in their virgin, high-yielding form*. While there is a constant technological push back, this idea, with its focus on dislocations caused by necessary but uneven investment in expanding fossil fuels, casts doubt on the view that the economy will seamlessly generate technology and new resources that produce infinite growth, as argued classically by Barnett and Morse (1963)[42].

Finally, the oil harvest cycle provides insight into what changes in industrial structure necessary for climate change policy might mean for economic growth. It could thus illuminate the potential investment and distributional impacts of climate mitigation. For instance, many of the low-carbon technologies currently in vogue—such as solar and wind power—are more manufactured than mined energy technologies. This could make heavy investment into these technologies less of a drag on the economy, or even a boost—in line with "Green New Deal" ideas. Yet any burst of manufacturing activity will require a concomitant burst of energy and materials mining, which could displace new investment in existing industries.

This point is crucial: manufactured renewable energy sources still depend on extracted ores and energy resources, which create constraints. Until now the former have depended at least partly on higher energy yields or surpluses from oil, gas, and coal—energetic subsidies. The oil harvest theory brings up two important questions. At what point will those surpluses from fossils no longer be worth the effort in investment, given their economic effects? And when will they no longer be necessary to support the manufacture of renewables? How to include the rising environmental cost is key here.

Due to the scale of investment needed to replace fossil fuels with renewables, the economy could perhaps slow for much longer—ie., downturns, or energy investment periods, could take longer without a fossil boost. Yet this partly depends on the higher labor intensity of the renewables industry versus the fossil fuel industry. Widespread renewables substitution could also create an opening for a new labor movement and better economic conditions across the global economy.

One argument for renewables is that their "harvest" is more predictable—their replacement based more on mass production than extraction—and thus more constant, given a 20-25 year lifetime, than a burst of oil production. Biomass could also, given a steady stream of solar and wind products, conceivably provide a pulsing cycle in a low-carbon world. Nevertheless, such a switch to mainly manufactured rather than mined energy could regularize and reduce the severity of

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[42] The question of whether a completely rational depletion schedule for oil and gas—for instance, using the world's cheapest supplies completely before moving up the supply curve—would mitigate these dislocations is an interesting one, but due to national and regional competition, one that will likely remain academic for some time. It may be argued, however, that the global oil cartel, in its varying forms since the early 20th century, accomplishes some measure of this.

recessions. The question of what other extracted materials could provide a pulsing signal remains. Rare earth cycles? Meanwhile, shale oil and gas may also act more like a manufactured energy source than a mined one, able to be "dialed up" when needed, rather than drilled for in the probabilistic manner of conventional oil.

Political Economic Effects

It would come as no surprise, under this set of dynamics, if economic inequality were to rise during energy investment periods. In fact, the theory would predict it. Nor would it come as a surprise if strong political coalitions, "floated to victory on a sea of petroleum" and the resultant cash, gained the upper hand on the electoral battlefield during these same period. We find both effects in the 1970s and 2000s.

We might also fairly predict increasing oil investment might come partly at the expense of government revenue and investment (or that increasing or flat levels of government expenditure might increasingly require debt funding). With a lowering of marginal income tax rates, notably in 1981, revenue that once flowed to the government—the fruit, in some ways, of Keynes's argument that it should enact "a somewhat comprehensive socialization of investment" (Keynes, 1936, 378)—could more easily be invested back into oil and gas[43]. This may also divert investment into narrower and deeper channels during price spikes. Notably, the new US chief executives in 1980 and 2000 both worked with the opposing party to lower taxes dramatically after their elections.

This zero-sum relationship with government revenue could be argued to hold true for any industry, of course. Yet sales tax revenue, which falls disproportionately on the middle- and working classes, can be expected to plateau during contractions and generally does. As do income taxes. Meanwhile, oil and gas investors, subject to lower capital gains tax rates, might be expected to contribute less to government resources during their boom periods than what is lost from the income- and sales-tax decline of the energy investment period—marked, in the last two cycles, by steep reductions in top marginal tax brackets and other sources of government revenue that affect mainly the investor class.

The relationship between resource constraints and political philosophy provides an interesting path of exploration, stretching from Marx to Leslie White and beyond. To what extent do dominant social philosophies take root in material circumstance?

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[43] The 1981 Republican tax bill and oil revenues were not unrelated, as suggested by Democratic congressman Richard Gephardt: "I felt it [pro-oil legislation] was not only good energy policy but would also allow us to show domestic drillers that we were not down on everything they were for—which was their impression. If you look at the 1980 campaign, you'll find incredible amounts of oil money going into Republican campaigns. The drillers had become increasingly Republican and aggressively Republican. I felt if we were going to try to hold our party together for the tax bill—to hold the 'boll weevils' and win—we had to do something about independent oil" (Drew, 1983, 50). Needless to say, the "boll weevils" were not held.

Is there a connection between energy constraints and market liberalism, for example? Does the magnitude of social surplus affect social thinking, or at least the political operating system? One thinks of the Keynesian social democratic model, conceived and deployed during the time of oil's greatest peaks, only to wither in the United States as it lost its oil surplus. The question revolved around the degree of determinism appropriate to the story. Yet the alternative, a random dispersal of more or less redistributive governments, the degree of which depends on many factors, cultural and historical prime among them, may also be too strong.

Interest Rates

The main mainstream economic debates on the oil price–recession phenomenon focus on supply versus monetary influences on the economy. Yet this is a linked system. Oil accounts for by far the large fraction of global trade in terms of both value and volume (UN Comtrade, 2015). Global trade and the resulting balances have monetary effects, of course, and have been thought traditionally to determine relative interest rates (Whale, 1937). The rig count seems to have a positive relationship to the interest rate as well.

It remains to be seen to what extent this is a function of the Fed's tightening during periods of rising oil prices; of changes in the economic conditions, including investment and debt; or a function of global imbalances. Suffice to say, oil prices and production have a heavy influence on the balance of payments and the money supply, a point that may help tie together supply and monetary shock stories. The brief comments on interest rates, global trade, and energy prices to follow mainly serve as an introduction to the US external adjustment story of Chapter 6 and 7.

Interest rates typically rise during oil investment periods. There is a strong correlation between the commercial banking prime rate and the rig count—as mentioned, a good proxy for oil and gas capital expenditure. In the severe 2008-2009 crisis, however, the Fed cut the Federal Funds rate quickly to its zero lower bound. This results in a different "signature" for the event, as the 1970s-80s event culminated in very high rates. The mid-2000s US could not bear even the far less dramatic increases of 2004-2006, which helped push an unbalanced global economy into crisis. This, along with related issues, such as the relationship of Fed policy to energy prices, will be set aside for discussion in Chapters 6 and 7. Rising interest rates, suffice to say, help channel scarce resources into the high-return phases of the oil and gas industry, marked by sharp and rapid price rises for their commodities. Notably, other extractive commodities also take part in this cycle (Frankel, 2006).

To what extent is the interest rate independent of the price and disposition of oil resources? Interest rates, along with relative currency or metals values, are partially controlled by the hegemonic global monetary power—Britain for many years and then the United States. Capital markets and liquidity preference also matter, of course. Some nations have more control over their interest rate than others. How far can the Fed control this "natural" mechanism in the economy? Not completely, according to Fama (2013) and Hamilton and Herrera (2004), as we explore in the next two chapters.

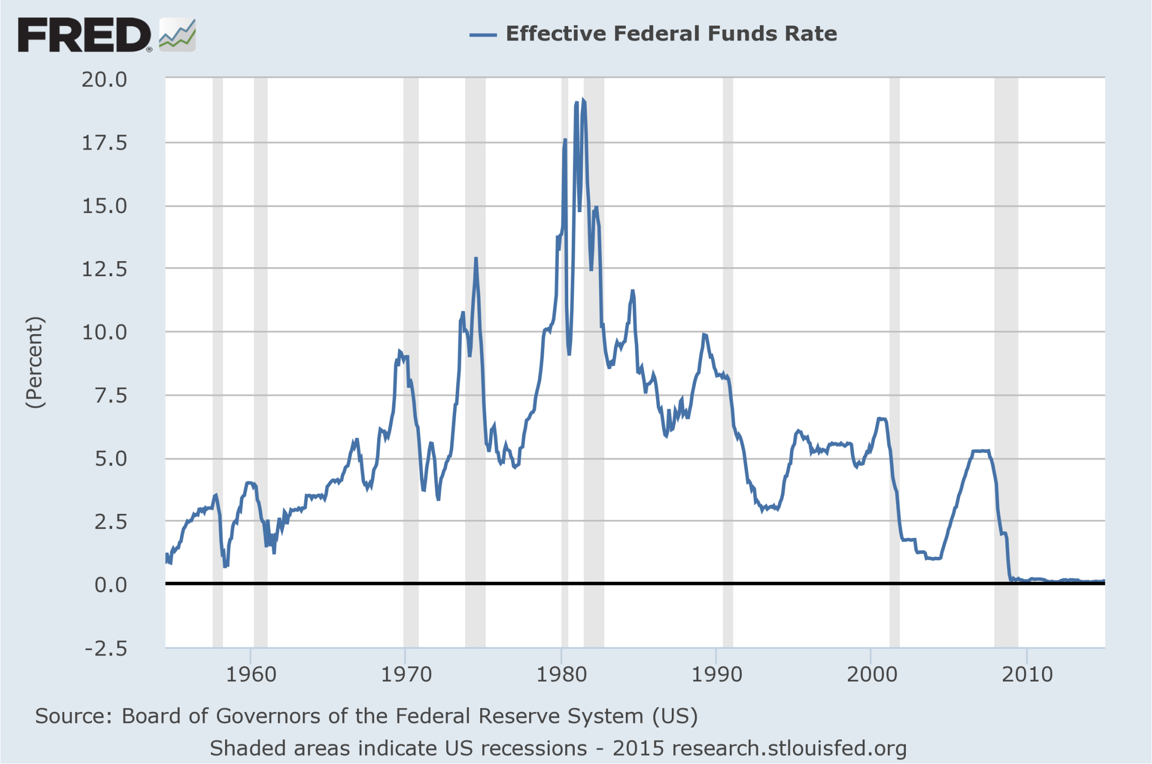

Figure 39. The Fed Funds Rate, 1955-2015. *Source: US Bureau of Economic Analysis*

The interest rate and Hotelling rule mechanism, whereby oil producers pull their oil from the ground to convert to currency when rising interest rates outpace price rises, governs all extractive commodities to some extent, oil to coal to copper to timber (Frankel, 2006). This explains something of the pulsing pattern, an energy and resource phenomenon, with oil merely the most important factor. Prior to the devaluation, in the late 1960s, when it became clear the US dollar needed to fall, (Gilbert, 1997 [1968]), one did not have to be clairvoyant to see that producing oil as the dollar rapidly lost value would be a losing proposition. It is preferable to sell resources exactly when the dollar begins to appreciate and prices to fall. At this point one expects feedback and pile-on effects, as perhaps occurred from July 2014.

Interest rates, of course, help control global trade flows. It seems that for many years policy makers in the United States allowed interest rates to rise in response to rising energy prices (Bernanke et al., 1997), thereby cutting off some increment of projects and investment. Yet this strategy was abandoned in 2007 as US investment banks stood on the edge of bankruptcy; rate increases had stopped in 2006, a few months into Ben Bernanke's tenure, at signs of a global industrial slowdown. In fact, falling interest rates in the US from 2007-2008, before the oil investment cycle ran its course, likely played a part in the period's oil price spikes. Investment by then was well into its massive shift to oil and gas, both in the United States and globally.

The basic Hotelling idea, that producers increasingly take oil out of the ground at higher interest rates, may be more historically correct than given credit for by economists who look purely at price. Oil investment seems negatively correlated with the economy in general, but positively correlated with the interest rate.

We can relate this to the Hotelling rule. Under this model prices should rise at the competitive interest rate, but there was little sign of this until 2004. The rule seems to work in fits and starts. The posted-price regime, which governed oil sales through previous shocks, may be a reason the Hotelling model performed poorly, as oil sold mainly under long-term contracts, with very little in spot markets governed by short-term supply and demand. Yet the investment pulse is signaled by a price rise; this marks a declining return from existing resources and perhaps rising marginal cost. In the subsequent energy pulse, producers typically start with very high margins, which erode over a period of flat to declining real prices, until a new cycle of E&D—another investment pulse—begins.

A real issue now is the zero interest rate, which has persisted at least from 2009 to this writing in mid-2015. This is a new situation. In theory the schedule of marginal capital efficiency or profitability should be full, with very low thresholds for investment. Yet the interest paid on reserves at the Fed, and reports from insiders, shows that zero interest rates are not the only story. Lending in the US, despite the low interest rate, has been sluggish, suggesting little appetite for risk among banks and project developers. Yet bank loans for capital expenditures are a key element of monetary growth and a central indicator for the economy[44].

Changes in the interest rate, unsurprisingly, are strongly correlated with domestic private investment, *which in turn influences growth a year late*r. For instance, in 1982-83 interest rates were cut enormously, while 1983 saw an equally enormous rise in private domestic investment. This in turn helped produce in 1984 the highest growth rate the US had seen since the early to mid-1950s. Throughout this process the rig count, our central measure of oil and gas investment, plummeted.

Oil and gas exploration is not an isolated system—money will "trickle down" to other sectors and there will be an increase in employment in some of the primary and intermediate industries involved. What's important, however, is the net effect across the entire economy. More work on the feeder industries for oil and gas, versus those of other important sectors, must be done, most likely through input-output or related methods.

The point here is that exhaustible resources are depleted over time, and require large new capital injections at various periods to expand reserves. Rising prices

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[44] A self-funding industry, as it grows, may increase the money supply by less than an industry using a higher degree of debt funding. It is an expansion of credit that often marks a rise in the money supply.

over time signal the onset of such periods. As capital shifts from labor-intensive areas of the economy to capital-intensive ones, jobs are lost or deferred while interest rates tend to rise, squeezing the economy both from the investment and effective demand side. Meanwhile, rising prices mean less surplus directed back into labor-intensive industries and, importantly, falling confidence and expectations. Diversion of capital to energy-rich countries, and cheap resultant imports from them, can also foster monetary imbalances that create global economic instability.

The question remains, does oil and gas investment remain the best “timer” for our economy? How might we manage this cycle better? Why do these periodic disruptions in the international system occur? In Chapters 6 and 7, the concluding pieces in this dissertation, I examine external US balances and the global economy.

Chapter 6. The Oil Standard: Energy and US External Balances

> "The dollar has spiked 22 percent against a basket of currencies since the Fed published its December forecast, continuing a trend since last summer. Oil prices have fallen about 25 percent in that time."
>
> (*Reuters*, 2015)

> "The majority of the impact of an oil price shock on the real economy is attributable to the central bank's response to the inflationary pressures engendered by the shock."
>
> (Bernanke et al., 1997, 122)

> "For every action, there is an equal and opposite reaction."
>
> --Newton's Third Law

The Oil Price as Adjustment Signal

Two events stand at the center of the next two chapter. One, the severing of the gold link to the dollar by the United States, the effective end of the Bretton Woods era, in August 1971. Two, the accession to the WTO of China in December, 2001. These two events instigated the two largest oil price rises in modern history. Both involved the rewiring of global capital circuits. Both spawned continuous disequilibrium in global trade balances. Both eventually resulted in wrenching macroeconomic dislocations.

Why do major oil price movements in the United States move so precisely in sync with other macroeconomic indicators? Given the relatively small percentage of US national product devoted to the oil industry, why do the magnitudes of macroeconomic fluctuations often mirror those in the dollar price of oil? Is it a coincidence that the two most significant US macroeconomic disturbances of the last 75 years, the recessions of the 1970s-80s and the 2007-8 financial collapse, both turned on spiking oil prices? We have examined oil's role in the US internal balances, working through investment and employment. Now we turn to the international system to complete the answer.

In previous chapters I argued that very high levels of oil investment limit the US economy through a constrictive effect on the labor market, in particular the quantity of employment. International causes and effects of the oil "signal," however, which produce this investment response, I left largely unexplored, presenting a standard oil price explanation based on rising long-term global supply costs.

In this chapter I take into account another important determinant of the oil price, along with supply-demand. This is monetary policy in general, and the exchange rate in particular. One factor left aside is market power. Over the past 130 years or so, since the time of John D. Rockefeller, oil has rarely been a competitive market in the neoclassical sense.[45] This story is known in detail, from Cleveland to Achnacarry to the Texas Railroad Commission and OPEC. Nevertheless, while market power can determine margins or consumer surplus (in the economics jargon) lost, I find it ultimately more an enabling mechanism than instigating factor in oil price spikes. While market power may be a necessary condition for the manner in which oil shocks often lag their predominate causes, I find supply and monetary forces bearing on relatively stable oligopoly arrangements more likely to be those causes[46].

Much of the confusion in the literature over oil prices and the economy comes from differences in perspective. There are exogenous supply explanations (summarized in Hamilton, 2005). There are also monetary explanations (Frankel, 2006; Wills-Hammes, 2005). The missing link: the oil supply is a determinant of trade balances: at 15% of global trade by value in 2013 (UN Comtrade, 2015), it has been in the post-Bretton Woods era by far the largest component of international trade. Thus relative supply conditions of oil in various nations affect the monetary system, especially the value of the dollar—and vice-versa.

Here we find a positive feedback loop. If the US reaches the peak of its oil supply at some global price and begins to import more, as in the 1960s and 1970s, without increasing its general exports in equal measure, it will develop a trade deficit. Without compensatory capital flows, this leads to a worsening balance of payments position, which in the classical (Hume, 1997 [1752]) price-specie model produces price deflation. In the Keynesian income-specie model**,** it produces falling output.

> "…in the Keynesian case of price and wage rigidity, the decreased money supply results in *higher interest rates* and therefore an inflow of capital and a reduction in the rate of investment and output (because of the multiplier), a process which is eventually reversed as the gold inflow (due to the inflow of capital and the reduction in imports) supplements bank reserves and permits a monetary expansion; this is the *income*-specie-flow mechanism of Keynes." (Mundell, 1961, 159)

In a flexible system of exchange rates, rising deficits put pressure on the dollar to depreciate against foreign currencies. This depreciation, however, often produces a concomitant *rise* in oil prices given inelastic global demand. Whether we call the

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[45] In late 2014 and early 2015 we witnessed the strange spectacle of commentators in the United States lamenting that Saudi Arabia appeared *unwilling to exercise its market power* to keep oil prices high—this underscores how accustomed we have become to the control of oil by integrated majors and international cartels (for more see Blair, 1976; Yergin, 1991).

[46] Putting it even more crudely, though consumers surely can get a raw deal from the oil industry's market power, I find it a fairly static, "baked in" raw deal. Correcting this would, of course, likely benefit a large majority of people in the US.

mechanism "market forces" or "a rise in posted price" or "producer power," it matters less than the result. This higher price further worsens the balance of trade, and so on, until some countervailing force slows and then reverses the cycle.

This force is a contraction in the United States. *The rising oil price signals the mechanisms that produce this contraction*. The primary response—an investment shift in the Unites States and a sharp decline in the multiplier—plays a large role. We saw this process play out in detail in the previous two chapters.

At some point, all else being equal, diminishing returns from the "secret coinage" of domestic oil wells eventually puts pressure on the money supply. This would be obvious for nations that cannot print reserve currencies at will, but is true to an extent even for a monetary hegemon that wants to preserve some global price stability and credibility in international markets. Following Mundell and Keynes, declining wells must then reduce output.

In short, after August 1971 and the end of the Keynesian Bretton Woods era, the oil price became the fulcrum of US external balances, the dollar its proxy. It seems to have replaced, or at least complemented, gold as the global economy's primary physical anchor. How? It provides the ultimate constraint on the extent to which the US, administrator of the global reserve currency, can expand the money supply in a floating regime. This mechanism helps explain the lockstep of gold and oil prices since 1971, a phenomenon difficult to attribute to production factors alone. I assume here that gold still functions as an unofficial global benchmark of value[47]. The oil mechanism challenges Mundell's claim (2000, 7) that the disequilibrium system, due to sterilization practices, has no adjustment mechanism. Oil (energy or resource) constraints are simply weaker, with longer lags and thus a more violent adjustment, than a gold standard.

US Trade Imbalances Since the End of Bretton Woods

The above cycle helps explain the tight synchronicity between oil and macroeconomic indicators such as interest rates and national income growth. One may look at the periods in the United States following oil spikes as *normal recessionary periods* that historically correct global trade imbalances. The oil price triggers these periods, which proceed as sketched in the previous two chapters. This price depends on the US trade balance but also partially determines it, given

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[47] Evidence for this would lie in, for instance, unwritten or explicit institutional agreement among oligopolistic oil producers that long-term oil prices should remain in a fixed ratio with gold, which would exert some pressure on the United States to formulate a credible monetary policy. The 1) extraordinarily tight relationship between oil and gold prices from the late 1960s, unique among unrelated commodities (versus, say, hardwood and softwood); 2) sequence of the 1970s-1980s political events; and 3) statements by the nations involved (see Hammes and Wills, 2005) are suggestive of such a benchmark.

the scale of US consumption and production, as well as oil's eclipse of other commodities by an order of magnitude in trade value.

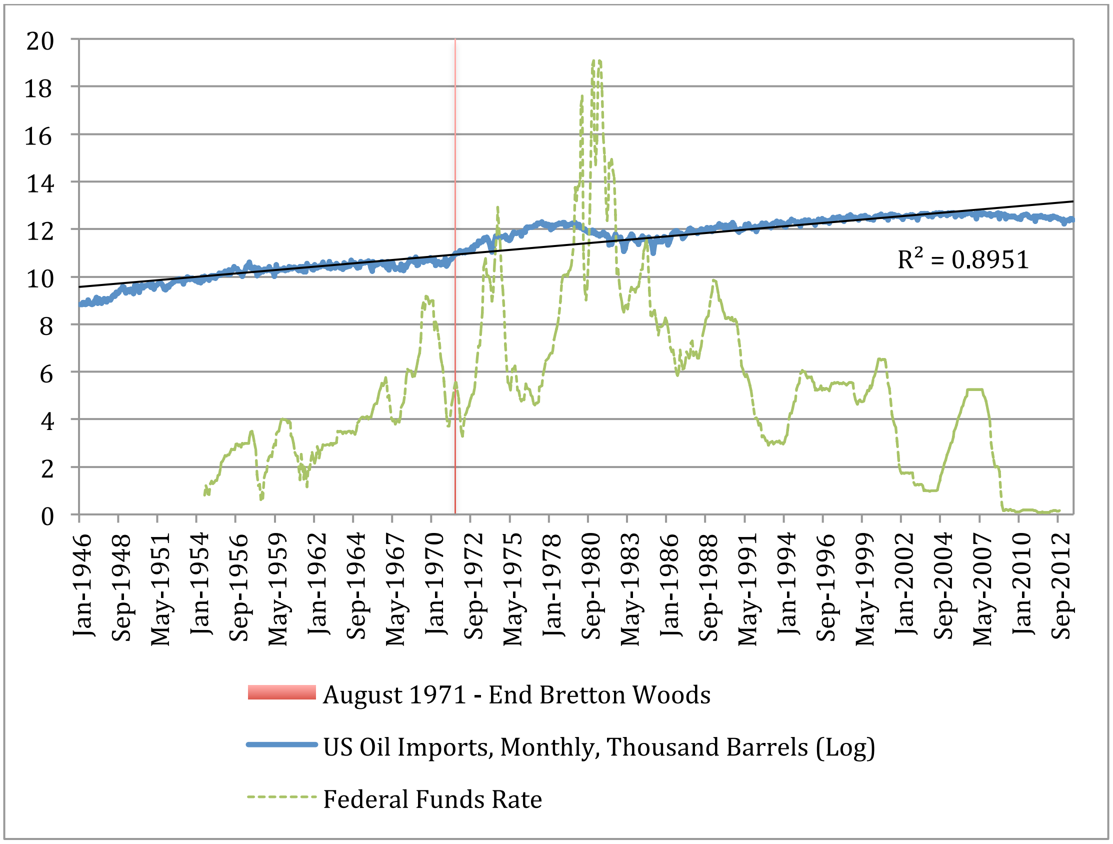

Figure 40. The "Bump": Oil Import & Interest Rate Overshoot After Dollar Float.
Source: Federal Reserve Bank of St. Louis (FRED), Energy Information Agency (EIA)

In essence, excess demand for oil in particular, and primary commodities in general, fostered by an unbounded money supply in the US, produces 1) a rising and uncorrected trade deficit; 2) reserve outflow[48], 3) sterilization by the US central bank, which expands credit to prevent the contractive effects on the money supply that would otherwise result; 4) downward pressure on the currency and upward pressure on interest rates; and 6) a rising oil price, via dollar devaluation and the increasing marginal cost of supplying the excess demand. This is a positive feedback loop that ends in a US recession and occasionally a financial crisis.

With the gold restraint removed, oil thus becomes the biting physical constraint on the economy. Correction in the US comes as the rising oil price signals producers to begin exploration and development. As new wells come online, the US trade balance improves, with demand for imports falling, especially in the contractions of 1973-

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[48] This was an outflow of gold in the 1960s, then dollars after 1971. It was the former outflow that induced the US to float its currency, which removed the disciplining influence of gold redemptions from US monetary policy.

1975, 1980-82, 1990-1, and 2007-2009. Interest rates, having risen during the expansion with the rising oil price and falling effective money supply, constrict new investment. The recessionary investment shift induces job destruction in the US as outlined in the previous chapter. During recession the US balance of payments trend in a positive direction, moving from positive to negative in the 1970s, 80s, and 1990s events (though within sight of a trillion dollars by 2008, it was nevertheless cut in half in half after the crisis). As the US remains the global hegemon, oil is thus the most important homeostatic mechanism in the global macroeconomy, seeming to work more or less in tandem with gold via arbitrage.

The latest cycle in this saga has just played out. In the aftermath of the global financial crisis of 2008, the US outpaced the European and Japanese recoveries by dramatically increasing its energy production—via widespread drilling for oil and gas. It alone possessed the new hydrocarbon resources (and perhaps the deficits) for such dramatic improvement in its balance of payments. This dynamic finally helped produce a devaluation of Euro and Yen against the dollar beginning in the summer of 2014, as noted by Frankel (2014). This helped in turn reduce the price of oil dramatically from the American perspective, but left it largely unchanged from European and Japanese perspectives. This decline marked the end of a US adjustment cycle begun in the mid-2000s by the tightening, perhaps peaking (Höök et al., 2009), of global conventional oil supplies at the price prevailing from the mid-1980s, at the end of the last investment pulse.

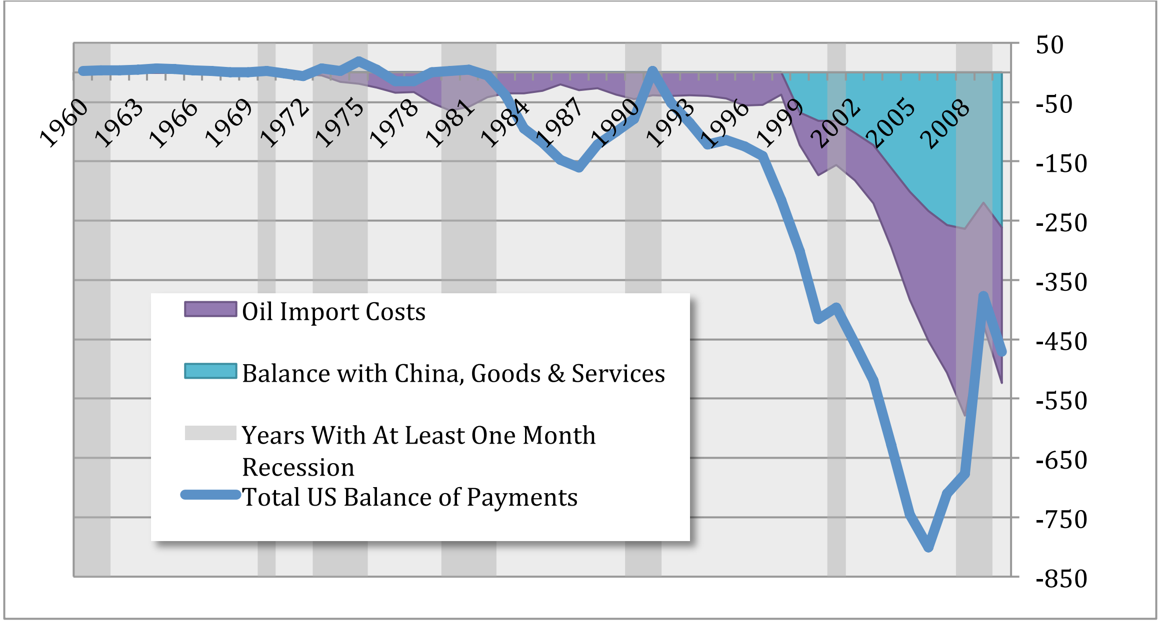

Figure 41. BOP, China Trade, and Oil Import Costs, 1960-2010 (Billions). *Source: US Bureau of Economic Analysis (BEA), FRED, EIA*

This is a new answer to an old problem. Under a strict gold standard system, such as prevailed intermittently in the global system until the 1930s, price deflation in the deficit country could theoretically resolve imbalance. Lower prices and wages encouraged exports, discouraged imports. In the Bretton Woods regime that replaced it, nations could adjust their currency to correct fundamental changes in the terms of trade in emergencies, yet normally remained fixed to the dollar, which in turn had a fixed gold price. Currency devaluation had balancing effects, under most conditions, similar to price deflation—ultimately increasing exports (production) and decreasing imports (consumption). Yet devaluation, by avoiding the spiraling effects of price deflation on investment and social conditions, became the preferred method of adjustment. A system of currencies pegged to gold, however, restrained nations' ability to devalue (Mundell, 2000, 7).

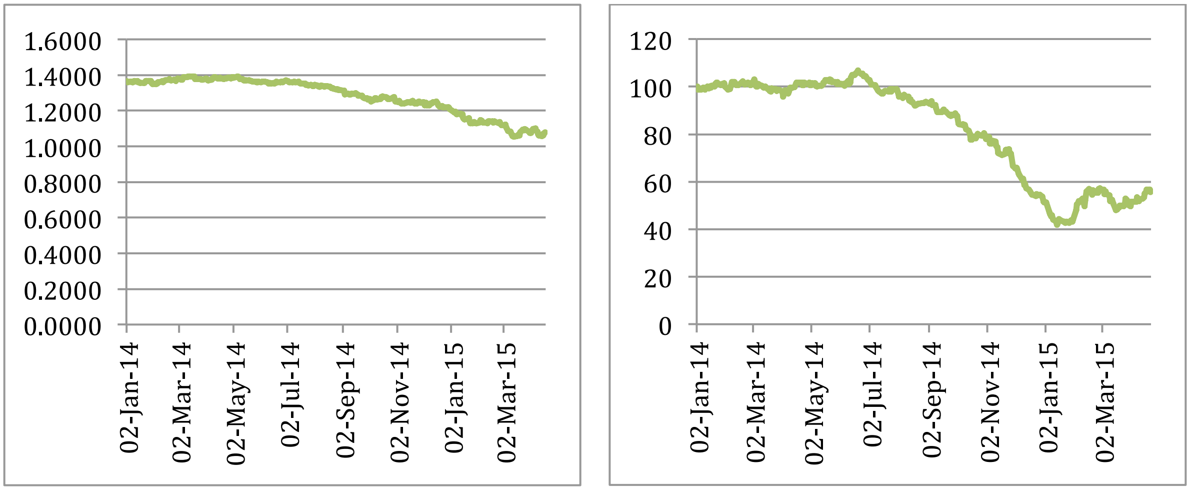

Figure 42. Oil Price Overshoot on USD Appreciation, 1/2014-4/2015. ***Note: (a) USD/EU Exchange Rate, Daily; (b) Brent Crude Price, Daily, Indexed (1/2/2014=100). Sources: FRED, EIA***

By abruptly severing the link between the dollar—the major global reserve currency—and gold in August, 1971, the Nixon Administration began the floating regime that replaced Bretton Woods. Nations once again could pursue competitive devaluation in competition for export markets. The US devaluation that began in the late 1960s and early 1970s was special—not only would it conceivably assist its export sector, but it also meant the nation could print money to buy oil nearly at will, continuing the dramatic rise in oil imports begun in the 1960s (see the "bump," Figure 40). This caused problems for foreign oil producers, however, who received less and less in exchange for the fixed dollar amount (a fraction of the inflexible "posted price") they received for their oil—which accordingly became worth much less in terms of German Marks, Japanese Yen, or gold. Oil almost always gets very cheap before it gets expensive, due to this devaluation-price rise mechanism.

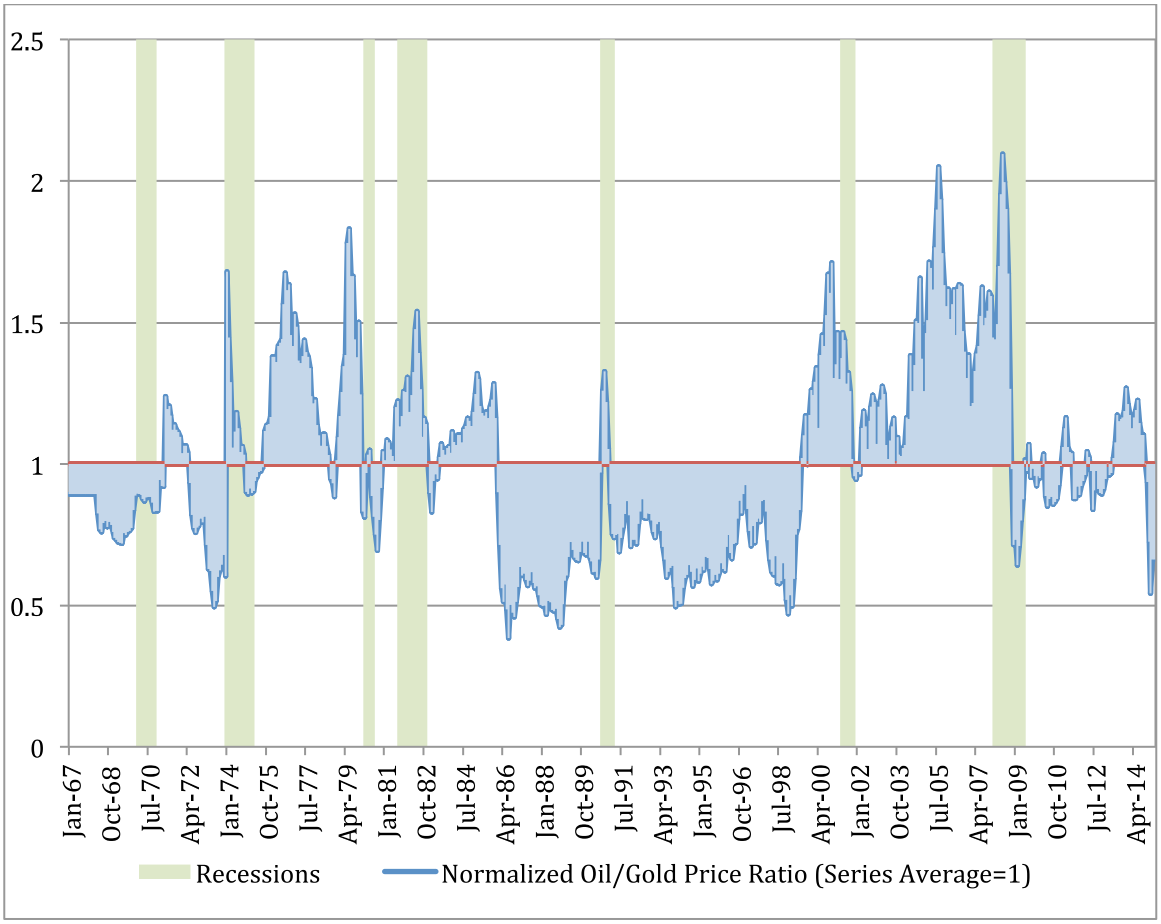

Figure 43. Oil/Gold Price Ratio, 1967-2015 (Normalized). ***Source: FRED, IFS***

The dramatic oil price rise in 1973-1974 resulted from the monetary conditions described above and ended the tremendous US boom dating from the mid-1950s. This occurred, again, via expenditure shifts, lowered expectations, the reversal of relative disinvestment in US oil seen from the 1950s on, and concomitant effects on US labor markets. A similar process occurred in 1980-82, 1991, 2006-2008.

The US central bank, meanwhile, took a stronger stand against inflation after the dislocations of the 1970s. Yet this management of "core inflation" (perhaps a better name for precisely what it excludes, food and energy) does not focus on, and has limited power to constrain, the oil price. The threads of US, Euro, and Japanese currency all run through the world's largest oil producers, of which the US is again at the top. Oil, and its most salient indicator for US consumers, gasoline prices, present early signals of a growing then easing real trade balance for the United States. I do not argue perfect correlation between trade balances and oil prices—which have, of course, a strong degree of reciprocity and form a positive feedback loop—but only that peaks in negative trade balances for the United States tend to be marked by oil price spikes. Further, net US oil import costs in the 1970s, as the world adjusted to its new monetary regime (or lack thereof), were very large, in some cases equal to multiples of the total US payments balance.

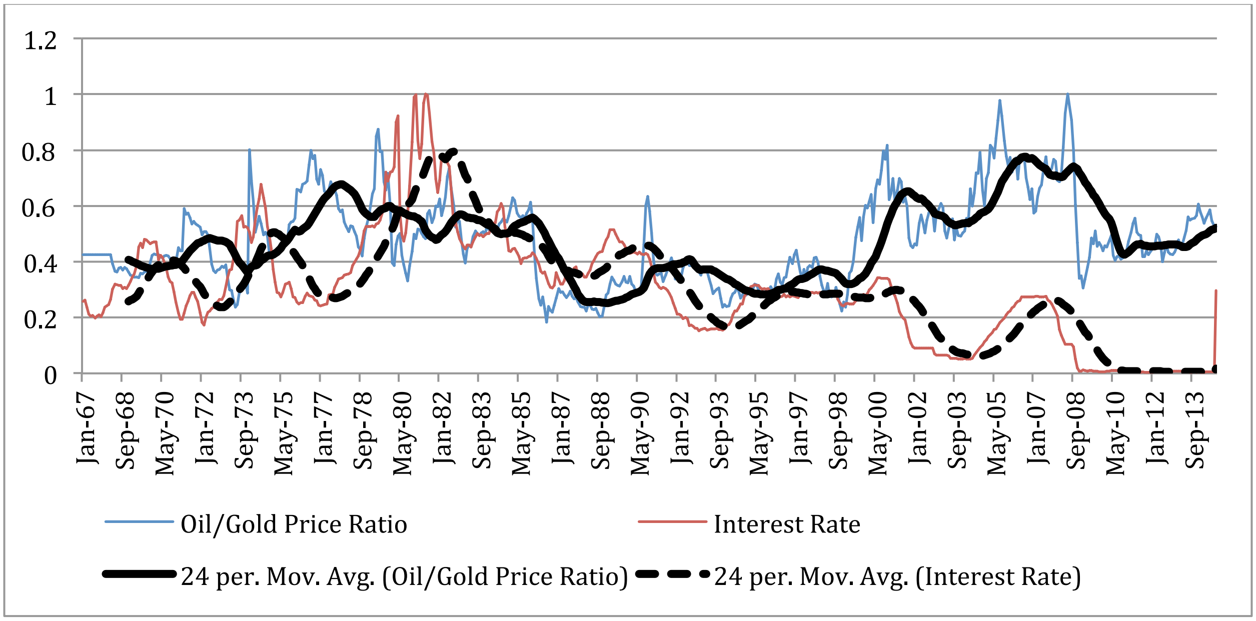

Figure 44. Interest Rates and the Oil/Gold Ratio, 24-Month Moving Averages. *Note: Fed Funds and UK prices, normalized at long-term average and scaled from 0-1. Source: FRED, IFS*

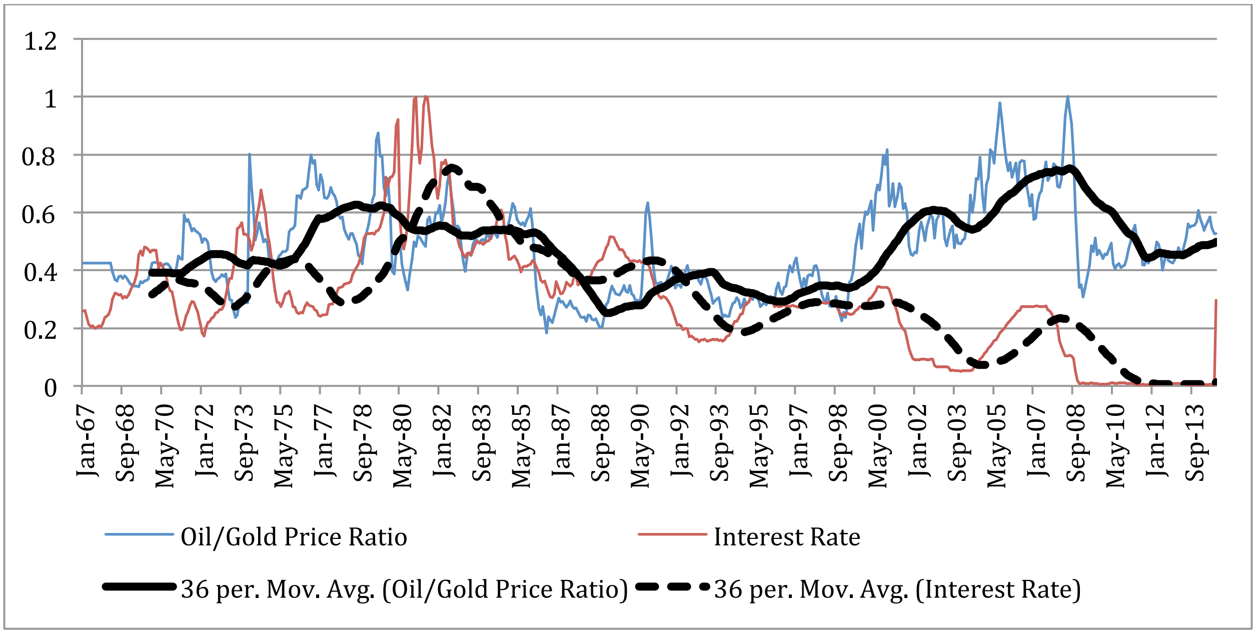

Figure 45. Interest Rates and the Oil/Gold Ratio, 36-Month Moving Averages. *Note: Fed Funds and UK prices, normalized at long-term average and scaled from 0-1. Source: FRED, IFS*

Oil now comes into focus as the primary physical limiting factor for the US economy in the 1970s, binding before capital and labor. It also became a central mechanism for adjustment. No other nation could adjust its money supply as the United States could after 1971, as printer of the reserve currency, so none relied on oil prices for adjustment in quite the same manner. As we shall see, however, another conventional oil peak, or perhaps a plateau, this time an international one dating from around 2005, acted as a *global* limiting factor, helping produce a collapse in a financial system swollen by the US-China debt loop, the latter built on a foundation of cheap coal, as we saw in Chapter 2 and 3. China's entry to the WTO in December, 2001, its currency peg to the US dollar, and the mismatched monetary and energy positions of the US in the global system provide the starting points for this analysis.

China and the Evolution of Energy's Disequilibrium System

The above argument revolves around the general idea that differentials in net energy yields between nations—the relative limits of energy expansion within them given current economic conditions—puts constraints on their various rates of expansion, given ample capital and labor. Lower rates of growth often produce devaluation, or debasement of the currency, the latter an ancient method for nation-states to manage declining surpluses and the subsequent deficits in their budgets. As mentioned in the first few chapters, this dynamic has been identified in energy empires of old, such as the Roman, which, faced with declining returns from conquest in terms of agricultural revenue, embarked on a steady devaluation that lasted centuries (Tainter, 1990, 133-151).

To mark today's declining energy yields, we might use the terms developed by energy analysts in ecological economics, such as "surplus energy" (Odum, 1971); "energy return on energy investment" (EROI) (Cleveland et al. 1984); or "net energy" (Carbajales et al., 2014). Crudely, these terms all refer to the ratio of energy provided by a given source to the energy required to extract and produce it. For instance, the oil from a gushing well in East Texas around the turn of the 20th Century might provide 100 units of usable energy out—100 joules, for instance—for every 1 unit (joule) spent extracting it (see Table 1).

By the 1970s the EROI of oil and gas in the US had dropped to around 30:1, while in Saudi Arabia and other low-cost producing nations, it remained near or above the 1930s US mark of 100:1 or greater (Murphy and Hall, 2010). This produced a vastly different cost structure, of course; net energy yield is closely related to the Jevons idea that harder-to-retrieve fuel deposits are more expensive and thus lower the competitiveness of a given nation. In his case, the fuel was coal and the nation was England. As mentioned in earlier chapters, Jevons worried, correctly, that depleting coal mines in England, forced ever deeper, would undermine its manufacturing competitiveness in the global system, especially vis-à-vis the United States, where surface coal was being mined "in the light of day" (Jevons, 1865, IV.30).

Ecological economists have long argued that the productivity metric of mainstream economics is essentially a proxy for the amount of energy applied to given activities (Cleveland et al., 1984; Kummel, 1989; Ayres and Warr, 2010). Assuming this is true allows us to make a neat conversion from neoclassical economics theorems such as the following: "The Balassa-Samuelson theory predicts that the country with a higher rate of productivity growth will experience trend real appreciation" (Dornbush, 1988, 209). A country with cheap energy access and domestic industrial applications for it, with ample supplies of labor and capital, would normally see currency appreciation, which would eventually dampen the advantages of the energy imbalance via the normal adjustment mechanisms.

Thus under a different political economic regime, perhaps the imaginary one of neoclassical economics, the gap between US and rest-of-world energy production costs, and the resulting imbalances, would be smoothed by gradual shifts in the currency and terms of trade over time. In the world as it exists, it was addressed abruptly, by a massive devaluation of the dollar in the 1970s, and a subsequent reengineering of the world's capital flows throughout that decade (Spiro, 1999).

China in the 2000s provides the other major case where energy yield differentials have contributed to enormous trade imbalances, which require reengineering of global capital circuits to persist. Once China joined the WTO in 2001, a massive influx of foreign direct investment relaxed its capital constraint, which, along with other factors, such as state policy, had previously moderated its growth path. This influx allowed China to harness its massive deposits of high-EROI coal on an astonishing scale. This gave it an enormous manufacturing edge over most of the world, including the United States. Its lack of effective environmental laws and willingness to tolerate an enormous burden of air pollution added to this.

Once again, an energy differential helped create a massive trade imbalance[49]. Extremely low-cost Chinese goods appeared in the US market. Wal-Mart became the symbol of the Chinese "how did they do it?" pricing from the early 2000s. It was done through *exploitation of a domestic energy resource* on a tremendous scale, via the same mechanisms Jevons outlined in the *Coal Question,* published 150 years ago. Yet it required one other mechanism to make it an enduring process: the virtual fusing of Chinese and American currencies.

This mechanism built upon the "petrodollar recycling" of the 1970s, in which capital flows passed out to oil producers and then back into the US via arms purchases, direct investment, and the purchase of securities, especially US Treasury bills. The Chinese "Wal-Mart dollar" recycling program involved a peg to the US currency (a peg allowed to "crawl," or adjust very slowly, in recent years). This peg disabled the traditional mechanism theorized to correct trade imbalances—a strengthening of the Chinese Yuan against the US dollar, which, had it been allowed to function, would eventually disappoint US consumers at Wal-Mart and nearly every other US

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[49] We leave aside here lower Chinese labor costs, the massive resource obviously an important omission, but one that I think does not change the essential fact of the energy differential—and which may, upon further examination, partially depend on the latter.

retail outlet by raising prices. China instead accumulated a massive surplus of dollars, while recycling a significant portion back into US Treasuries[50].

Figure 46. US-China Foreign Exchange Rate, 1980-2015

As with the 1970s, the huge 2000s US-China trade imbalance reflected what Mundell dubbed the "disequilibrium system" (1961), in which certain nations in the global system exist far from balance in their payments. This can persist as long as deficit and surplus nations are willing to sterilize the effects of the constant one-way flow of reserves on their monetary supplies. China accomplished this by investing gains from trade in large part back into the United States, especially in Treasury securities, thus preventing large increases in its money supply. The US, for its part, also sterilized through the purchase of Treasury securities by its central bank, increasing its reserves and allowing commercial banks to expand credit and increase its money supply at a normal rate. This temporarily stabilized the situation, despite the constant loss of reserves to China and other creditors via negative bilateral balances of payments.

Meanwhile, low-cost goods mass produced in China helped keep core inflation in the US, as measured by the consumer price index, low. Yet unlike these consumer staples, energy (and later food) prices, excluded from "core" inflation, saw massive inflation during the 2000s. As did health and education services, as well as real

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[50] As the cycle progressed, China diversified into land, equity stakes in global corporations, and other currencies and securities beyond those of the US.

estate prices[51]. The "Wal-Mart dollar" recycling mechanisms help us understand this phenomenon; it kept Chinese consumer goods cheap, in relation to an overvalued dollar, with the latter then flooding into asset markets and inflating prices.

Here we see the development of the "fault lines" to which former IMF chief economist Raghuram Rajan (2010), now the governor of India's central bank, attributed the global financial crisis of 2008. It echoes, in many ways, the summary of US economist and Treasury Secretary Lawrence Summers, who has famously and repeatedly blamed the crisis on "too much money sloshing around"—or a surfeit of savings and not enough investment outlets (Porter, 2014). Yet this surplus of money, of dollars, came from twinned US-China monetary policy.

From that date we also see an enormous rise in corporate profits and bank credit in the US—an overshoot signal discussed in the next section. This dramatic overshoot seems clearly related to China's accession to the WTO and the subsequent lowering of costs for corporate America through offshoring (as well as to their new markets). The rise in bank credit, at least, would be predictable given the rising trade deficit, from Mundell's (1961) observation that nations must expand bank credits to cover or sterilize growing trade deficits. December 2001 also, not coincidentally, marks precisely the beginning of the 2000s oil price takeoff (Figure 50, below).

Examining US corporate profits over time (log scale, Figure 48), we can identify a long 1960-1979 rise, the kink in which relates to the balance of payments problem the United States solved through the Nixon administration's severing of the gold-dollar link in 1971. The proximate cause of the first energy price shock, in 1973-1974, was the unceremonious end of Bretton Woods, and this accounts for another bump in the road for corporate profits. Yet it takes the second oil price and interest rate shock of the late 1970s for the pressures of the energy disequilibrium system to correct the US corporate growth path.

Despite China's tremendous influx of global capital and its associated export boom, its peg to the dollar prevented the US currency from the bilateral devaluation it otherwise would have undergone given the pressure building on its current account. We may fairly call this imbalance the effect of an energy differential: the majority of the US balance of payments deficit was due to trade either for oil or for Chinese goods manufactured with extremely cheap coal energy (see Figure 41). Sterilization—preventing the domestic monetary supply mechanism from easing trade imbalances—created excess demand for both.

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[51] It may be an exaggeration, but perhaps not an enormous one, to say the 2000s saw inflation in everything that *couldn't* be produced in China.

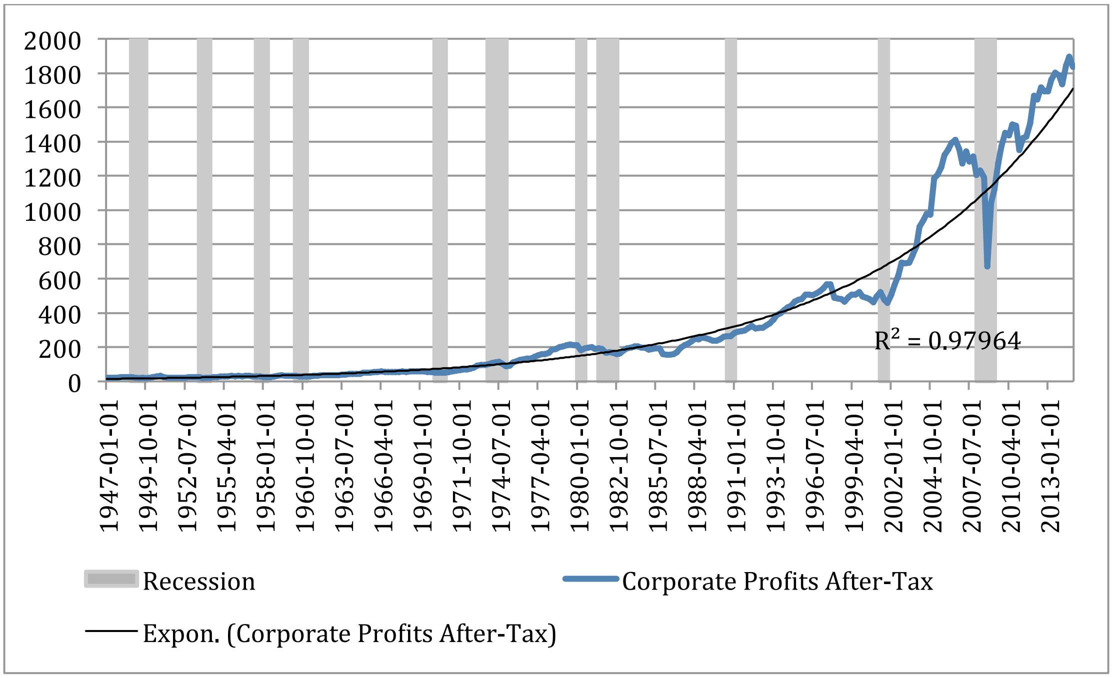

Figure 47. Corporate Profits After Tax (Billions). *Source: FRED*

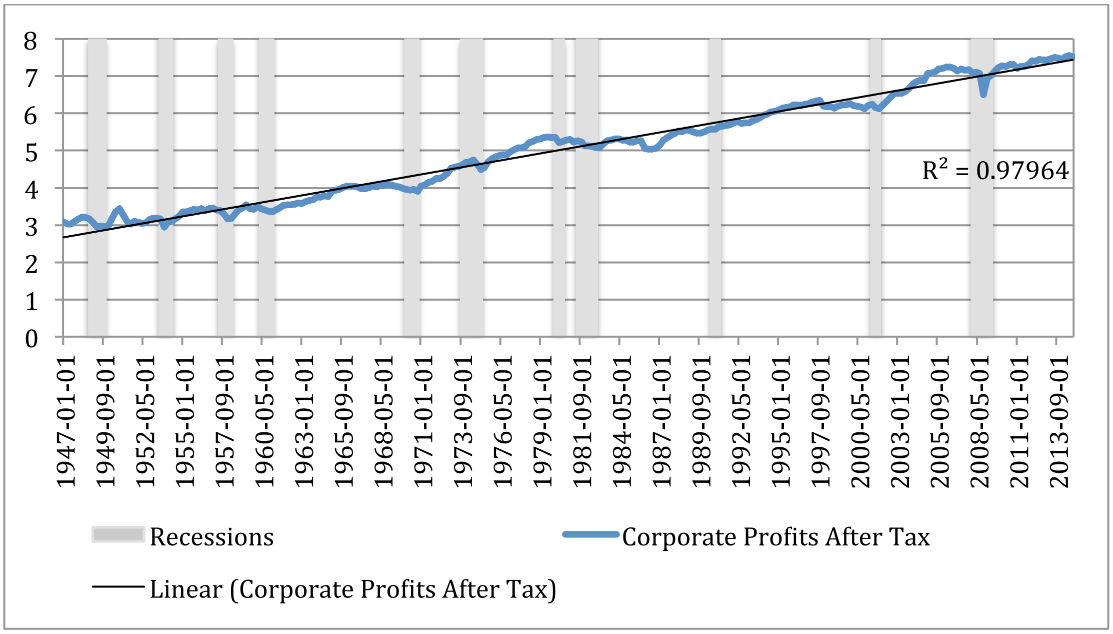

Figure 48. Corporate Profits After Tax (Billions), Log Scale. *Source: FRED*

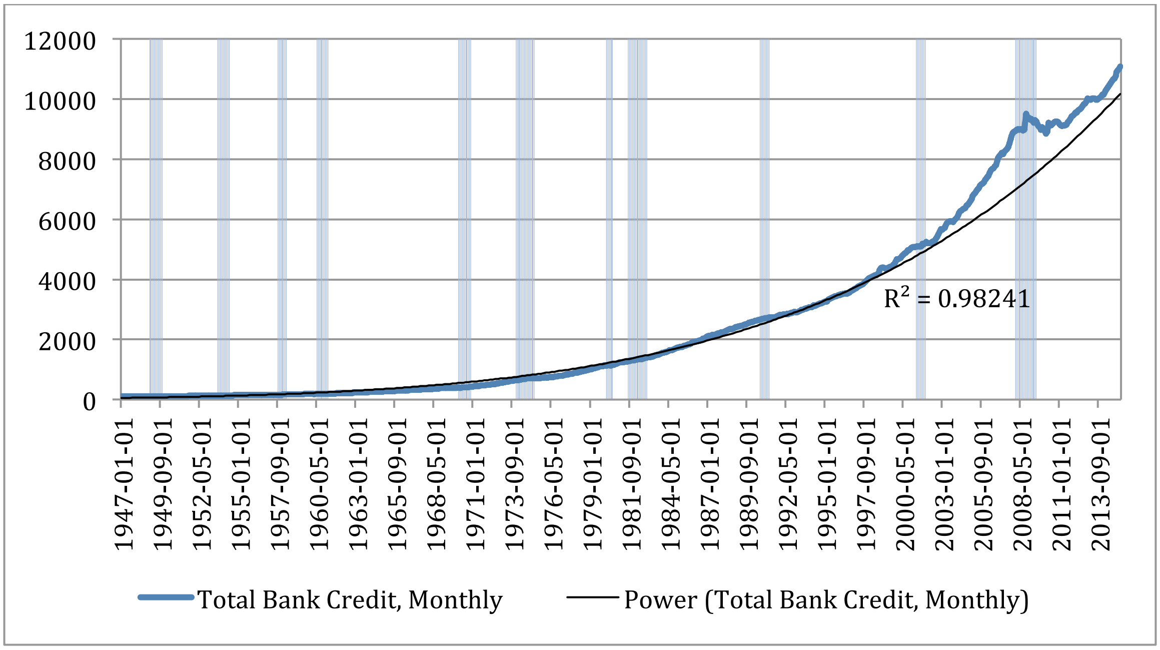

Figure 49. Total US Bank Credit, (Billions). ***Source: FRED***

This new coal-based energy differential, activated by China's WTO accession, built up pressure on the oil system through excess demand—and the prevention of currency adjustment, as in the 1970s—to help produce a dramatic 600% rise in the price of oil from the month China joined the WTO, December 2001, to July 2008 (Figure 50, below). The resulting investment shift and job destruction in the United States eventually produced a collapse in expectations and thus in inflated asset prices, following the Keynesian mechanisms—this produced financial crisis on a grand scale[52]. Artificially stimulated housing investment and high levels of speculation across many types of asset classes exacerbated this dislocation, characterized by excess demand and in some cases simple speculative channels for recycled capital where fundamentals justified no further investment (Rajan, 2011).

We find here another result of the disequilibrium system and the instabilities created by its imbalances—especially its tendency to correct all at once. The disequilibrium system, at bottom, results from the severed link between a nation's balance of payments and its money supply (Mundell, 1961). This system is enabled by power positions in the global monetary system that no longer correlate to resource endowments across nations. If monetary hegemony is not co-located with high-yielding energy supplies (and thus the locus of short-term revenue and capital flows) , financial engineering for recycling becomes necessary, as with petro- and coal (Wal-Mart) dollars. The United States developed hegemonic monetary position as the world's undisputed energy power after World War II, but lost that position with the decline of its energy yields through the later 20th century. Britain

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[52] Oil here played the primary negative feedback role, the key limiting factor in this ecosystem. Coal in China, which became a net importer in 2007, was also likely important.

underwent similar relative decline in the late 1800s and early 1900s, which, as Jevons foresaw, eventually resulted in the loss of manufacturing supremacy, and then monetary hegemony, to the United States.

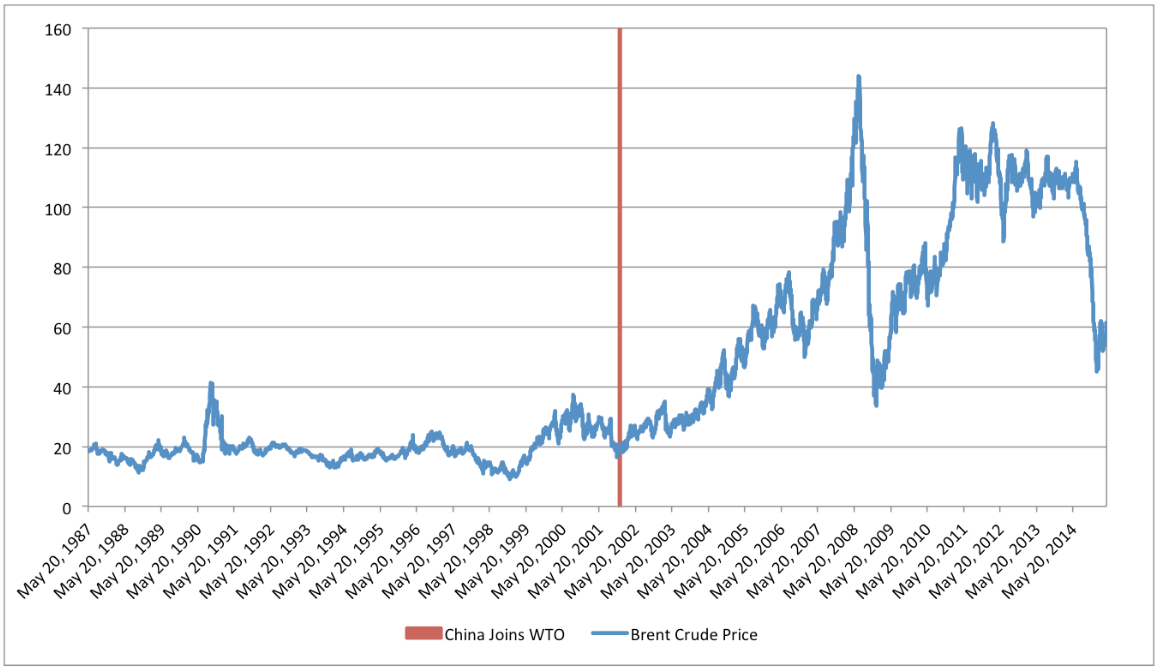

Figure 50. Weekly Oil Prices, 1987-2015 (Nominal). *Source: EIA*

Notably, the latter transition, mainly occurring from 1913-1945[53], coincided with one of the most turbulent periods in recent history. We saw another turbulent period in the 1970s, as the linked energy-monetary system reflected a shift in the US position to what some researchers call illegitimate hegemony (Spiro, 1999). The events of the late 2000s reflect yet another major shift, the post-2001, WTO-led internalization of China into the global capitalist economy, which produced the rise of a hegemonic challenger with high-yielding energy resources. The attendant shift in global production and linked financial mechanisms upset key balances in the global monetary system. The capitalist world, again, had swallowed a whale.

In short, hegemonic monetary privilege, when not backed with the necessary resources, often seems to prevent smooth adjustment of the global trade system. On the other hand, some economists view an enduring deficit position for the global hegemon as necessary, as it allows other nations to run surpluses, a situation desirable for a number of reasons, chief among them that it prevents debilitating trade wars, as most nations normally wish to run small surpluses to accommodate growth (Gilbert, 1997 [1968], 306). The question, then, may be how deep a deficit is appropriate.

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[53] According to Galpern (2009), Britain did not lose its monetary status completely until it lost control of Middle Eastern oil fields and flows in the 1950s and 1960s.

This surplus argument seems to founder slightly on the fact that the US ran a surplus during most of the Bretton Woods era, from 1945-1971, with no obvious deleterious effects on the global system. Yet capital controls then in place, and the need of industrial nations to finance postwar reconstruction, perhaps produced narrower buffering requirements and surplus/deficit distributions. Today, however, a global system largely without capital controls, run on floating currencies, sees a recurring energy-monetary overshoot pattern described in the last chapter.

Chapter 7. Overshoot and The Monetary Impulse

> "Apparently, all systems on all scales pulse. Gradual accumulation of one storage is followed by a short period of frenzied consumer use and development, which disperses materials, setting up the next growth period."
>
> --(Odum, 1998)

> "A self-organizing system can organize around an available source of pulsing or develop one of its own…Pulsed consumption keeps production and consumption from interfering with each other…To smaller units, sustained pulses can seem like catastrophes…."
>
> --(Odum, 1988, *1134-35)*

Economist Jeffrey Frankel bases a recent argument around the idea that "high commodity prices can be a signal that monetary policy is loose" (Frankel 2006, 292). Yet Frankel expresses surprise that oil and gold are uncorrelated with interest rates while a number of other commodities have significant negative correlations. I believe this is because high oil and gold instead often signal that monetary policy *was recently* loose. The massive commodity price rises in the 1970s were triggered and amplified—if not ultimately caused—by the monetary shock of 1971. It took the tightening of the early 1980s to ultimately dampen them. In fact, as can be seen in Figure 51, five years in the 1970s saw M2 growth above normal, about 10-14% per year, while five years saw rates in the 5-8% range. The former were not oil shock years, however, but the periods (1971-1972; 1975-1977) that *preceded them*.

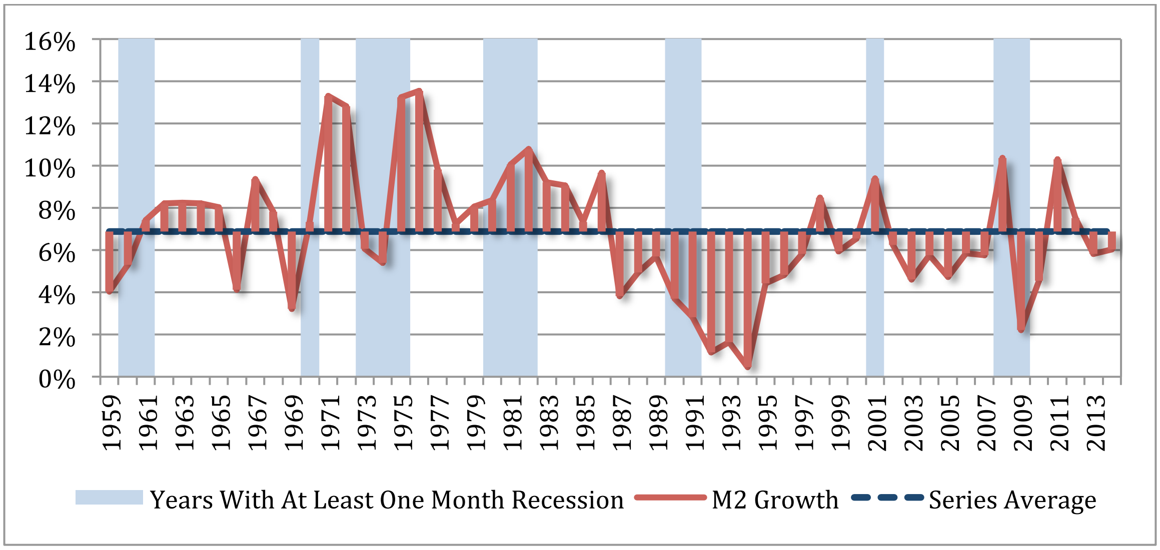

Figure 51. Annual M2 Growth 1959-2015. ***Source: FRED***

Likewise, I argued above that the resource commodity price spike of the 2000s followed excess global demand made possible by a highly accommodating US-China monetary cycle. Exuberant activity spurred by loose monetary policies—especially with regards to bank credit, a good complement to interest rates for gauging monetary conditions—often overshoots the tightening period, so that rising oil prices often occur simultaneously with rising interest rates, as in the late 1970s and the mid-2000s. The rapid oil and commodity price rise of early 1973-1974 was a lagging reaction to the end of the gold-dollar link and the devaluation from 1971. Meanwhile, very loose monetary policy from 2001 to near the end of Alan Greenspan's Fed tenure preceded the sharp oil spike of 2004-2006, a period of rising rate (Figure 54). Yet much of the 2007-2008 spike did coincide with falling interest rates, when the Fed possibly felt it had no alterative.

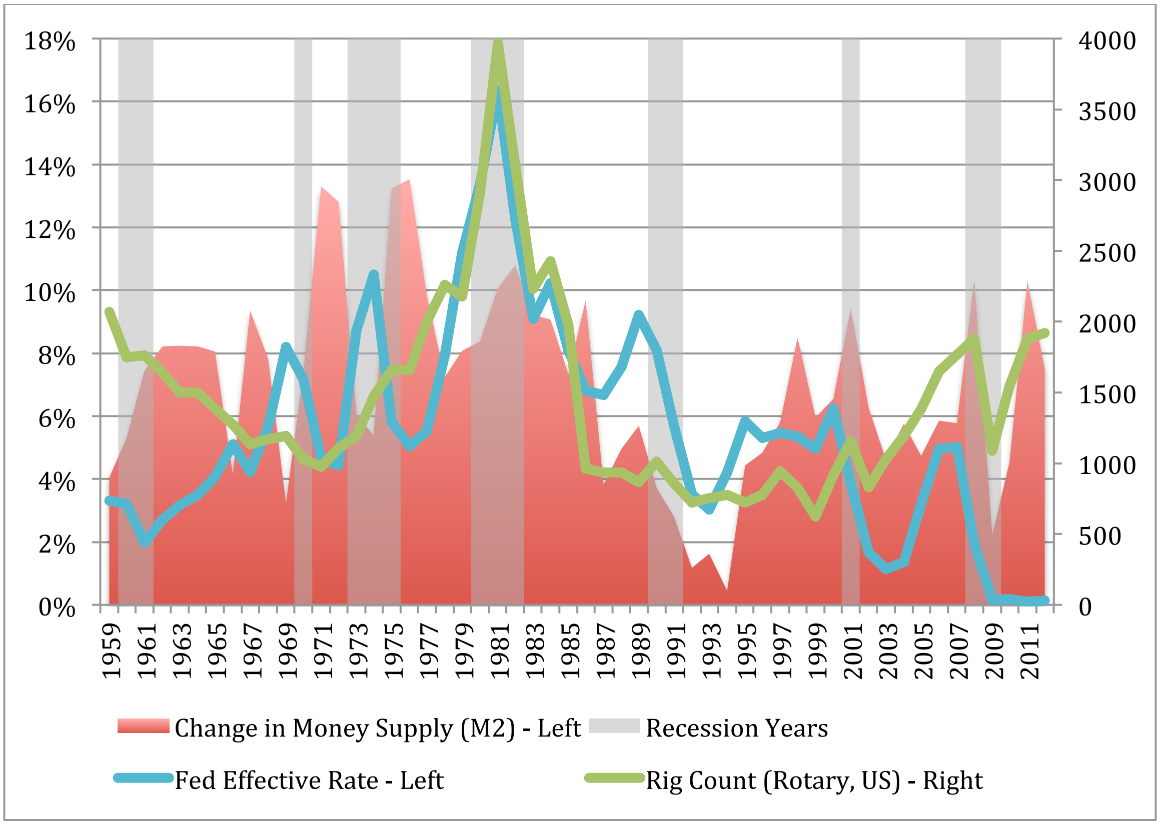

Figure 52. US Money Supply, Interest Rates, and the Rig Count. *Source: FRED, EIA*

This lag helps explain why oil and gold are the worst-performing commodities in Frankel's regression of real interest rates and commodity prices: oil and gold prices tend to lag and then overshoot the monetary or currency cycle[54]. In fact, oil prices

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[54] The cycle is slightly reminiscent of current and voltage in a circuit; the angular phase shift, or lead and lag, of two sinusoidal waves is an intriguing heuristic for study of some

and oil investment are positively correlated, unlike other commodities, with *high interest rates.* This result is bound to confound researchers who do not grant oil its proper due as the fundamental global commodity and the ultimate limiter, according to the ideas in Chapter 6, on the US-centered global monetary system. Friedman and Schwartz, for instance, conclude in their *Monetary History of the United States, 1867-1960*, that there is a "mutual interaction [between money and business activity] but with money rather clearly the senior partner in longer-run movements and in major cyclical movements, and more nearly an equal partner with money income and prices in shorter-run and milder movements" (Friedman and Schwartz, 1963, 695). Yet findings here suggest that *whatever ultimately limits money* has the ultimate influence over growth. Changes in relative oil and energy positions of various nations may be seen as primary limiting factors, working through trade balances and interest rates to constrain their money supplies.

If the expansion of the US money supply in times of continual reserve outflow depends on the issuance of bank credit, as in the Mundell disequilibrium system, then the overextension and resulting fragility of the financial sector in the US may be partly attributed to its sole management of the reserve currency while no longer the center of the world's energy production. Why? Most of the outflow is excess demand for energy or energy-intensive items produced in countries with higher energy yields. The US, when Bretton Woods took shape, truly was the energy center of the world, with massive oil, coal, and hydropower resources. Yet a monetary hegemon without equivalent control of resources—the global production system's primary limiting factor—faces chronic instability due to the increasing financial engineering necessary to preserve its artificial position.

We might say that at essence, the interest rate responds to resource availability, with oil in a class by itself. This makes sense when we view the discount rate as governing the tradeoff between present and future consumption (Norgaard & Howarth, 1991, Arrow et al., 2013). A very high interest rate, and thus tight money, is not a discouragement but a signal to oil producers to extract and monetize reserves (Hotelling, 1931)—in the early 1980s especially this incentivized a great deal of oil exploration and development. *This produces more money.* Alternately, a very low discount rate signals producers to keep reserves in the ground and produce in future periods. The other variable is the expectation of future prices, thought to rise toward the ultimate substitution point, in the Hotelling model, of a backstop technology. Yet if the price of oil is expected to decline over the long term, even a zero interest rate could be consistent with high extraction and investment. This might occur after an investment pulse, for instance, or in expectation of a carbon price, for instance, that will make a significant part of oil reserves redundant.

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macroeconomic indicators. The first challenge may lie in determining which factors lead and which lag—or if the question is answerable in a circular system.

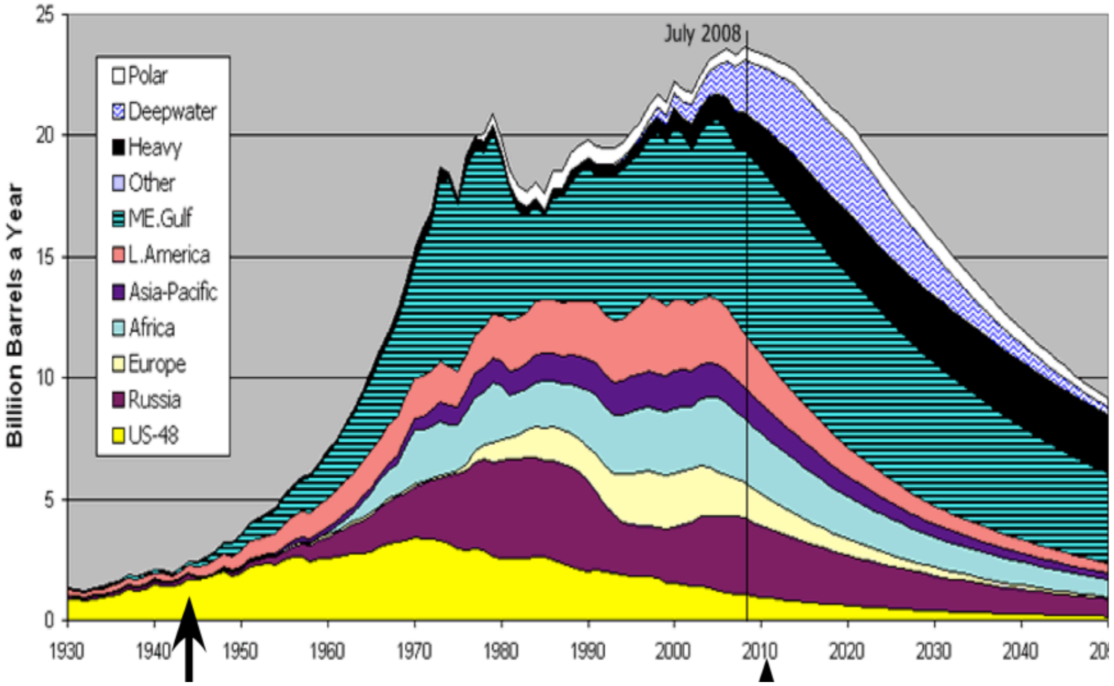

Figure 53. Global Oil Production by Region, 1930-2010. *Source: Reproduced from "Energy and Society" lecture, Professor Daniel Kammen, UC-Berkeley, Fall 2014*

Gold and prices oil move through two different long-term regimes, depending on where the world stands in its oil harvest cycle[55] (Figure 43). Meanwhile, global oil producers receive a signal to expand supply, or their reserves, through a credible, long-term relative price movement. In the oil harvest cycle gold is cheap (compared to oil) in investment pulses and expensive in oil pulses that follow. The investment phase of the cycle both corrects excesses of the previous boom and prepares for the next one. Similar signals may be found in regards to other resources, but we focus on oil, the most important global commodity from an economic standpoint.

I assume, with Fama (2013) and Hamilton and Herrera (2004), that the Fed doesn't control interest rates completely, but has incremental influence at the margin. If we understand the interest rate as set primarily by the market, with the Fed exerting some influence—but not complete control—through expectations and the target rate, many oil and interest rate questions become easier to interpret. Recessions correlate to spiking investment in high-return, capital-intensive industries with tiny labor intensities, such as oil—and with high interest rates[56]. While we typically

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[55] I give primacy to oil rather than gold in the cycle because of oil's utility—this assumption should be verified in future work.

[56] The extent to which this cycle played out in the 1920s, when agriculture and coal had greater influence, is an open question. The displacement of farm labor through increasing capital intensity (ie., gasoline-powered tractors), however, and the effect on yields of poor weather and ecological damage seem clear. Meanwhile, Britain, with its peaking coal resource, increasingly yielded investment to the rising energetic power of the US.

attribute high interest rates to the Fed, the investment pulse, its tying up of capital resources in oil and gas, and the lower supply of oil also likely influence the former.

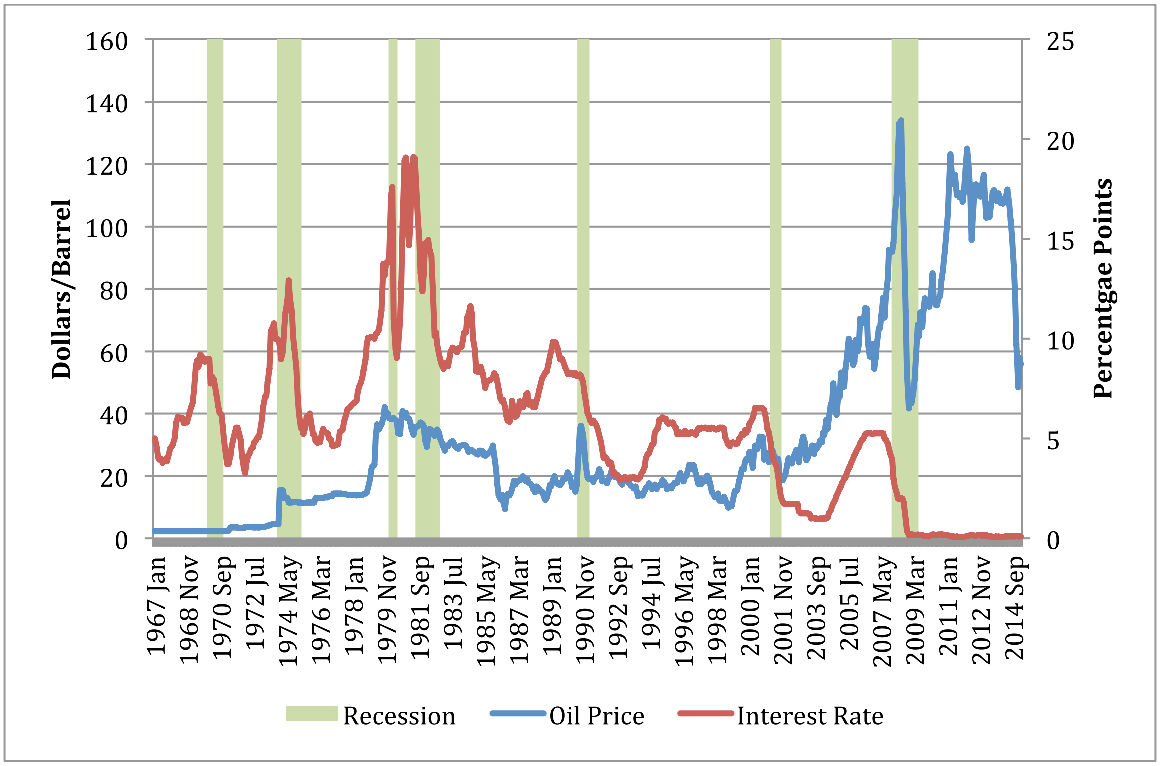

Figure 54. Interest Rates and Oil Price Spikes. *Note: Fed Funds and UK Oil Prices. Source: IMF IFS, FRED*

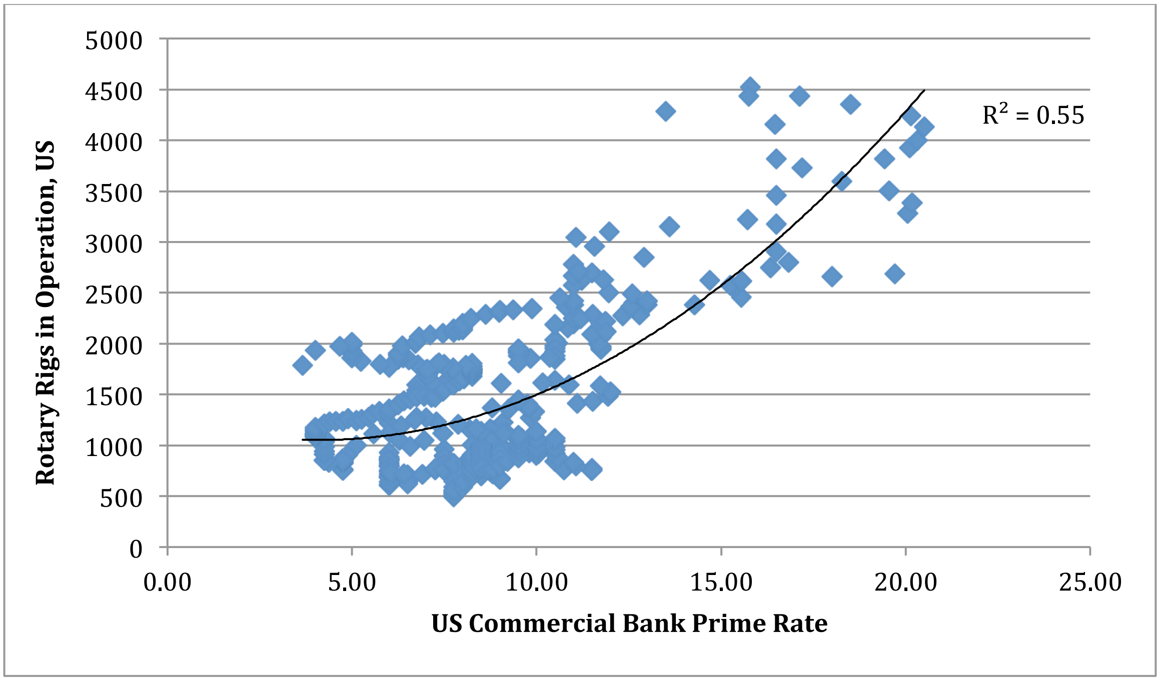

Figure 55. Correlation Between Drilling Activity and Interest Rates, 1973-2014. *Source: EIA, FRED*

The years 2004-2006 saw the only period of rising US interest rates in the 2000s. This coincided with a marked plateau period in the Chinese investment inflow into the United States, a unique five-quarter flat period sandwiched between large increases in that flow. This lends some further support to the idea that in setting target rates the Fed reacts in large part to the US BOP position—that the US money supply depended in large part on the Chinese financial inflow, converted into bank credit. This BOP position, especially the trade component, depends to an underappreciated extent on energy differentials that influence the terms of trade—whether in oil or cheap, high-yielding coal embodied in imported products.

Accordingly, the US saw a massive increase in its energy production after the 2008 collapse—a significant portion due to fracking wells for shale oil and gas—and a declining appetite for debt-fueled consumption of imports. This in turn narrowed the current account deficit, producing by 2014 a major appreciation of the USD exchange rate with regards to the Euro and the Yen. It seems oil producers allowed the price of oil to drop as the dollar strengthened, keeping its price stable from the perspective of Europeans and Japanese buyers (Frankel, 2014).

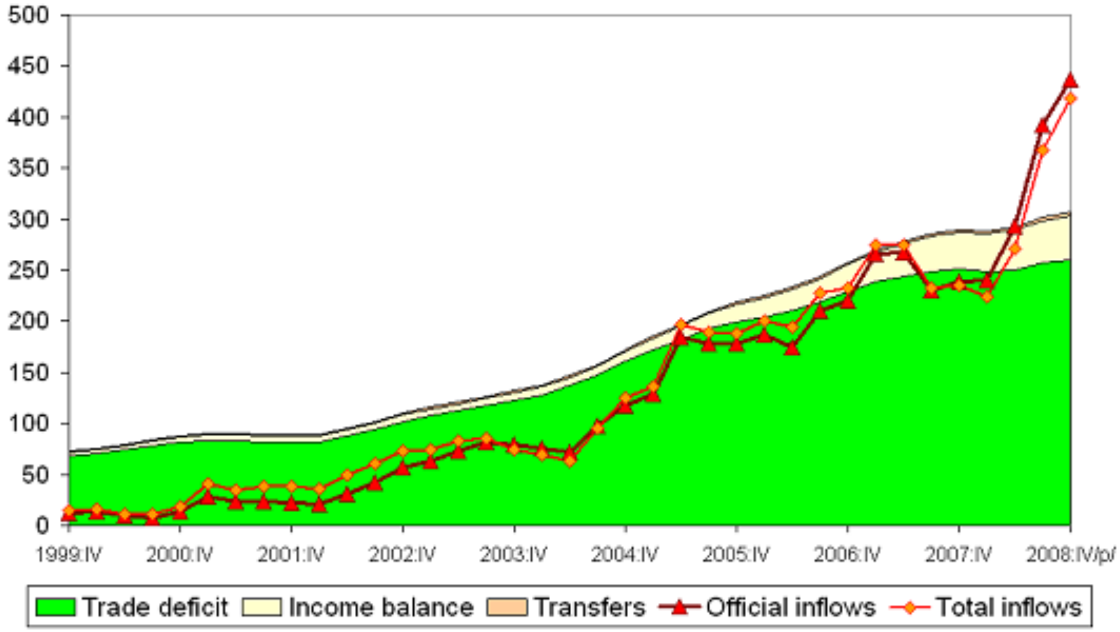

Figure 56. US Bilateral Balance of Payments With China (Billions), 1999-2008.
Source: BEA data, reproduced from image by Brad Setser, Council on Foreign Relations Blog, May 3, 2009

We have here a type of cascading overshoot effect. We can link together both Frankel's recent work on oil overshoot (2006) and Dornbush's classic work on the subject (1976) by explaining the two overshoots are *fundamentally tied.* We have, at the limits of these oil cycles, a sequence of overshoots of greater or lesser magnitude. The greater the overshoots are—the 1970-80s and 2000s being strong examples—the greater the forces for correction and resulting contractions. These two fundamental overshoots revolve around US corporate and debt growth in the 1960s-1970s and the 2000s, much of it overseas. This was financed by oil producing nations in the first case, joined by China and its coal in the second.

In both cases, monetary mechanisms forestalled corrections of imbalances, and the eventual biophysical correction, as reserves stretched to their limit, produced large dislocations in the economy. These dislocations, in 1981-82 and 2007-2009, restored some balance to the United States vis-à-vis external trading partners and financers through deep recessions, while producing in 2008 a concomitant global financial crisis. This collapse occurred mainly in the highly leveraged institutions used to finance energy's disequilibrium system in the 2000s.

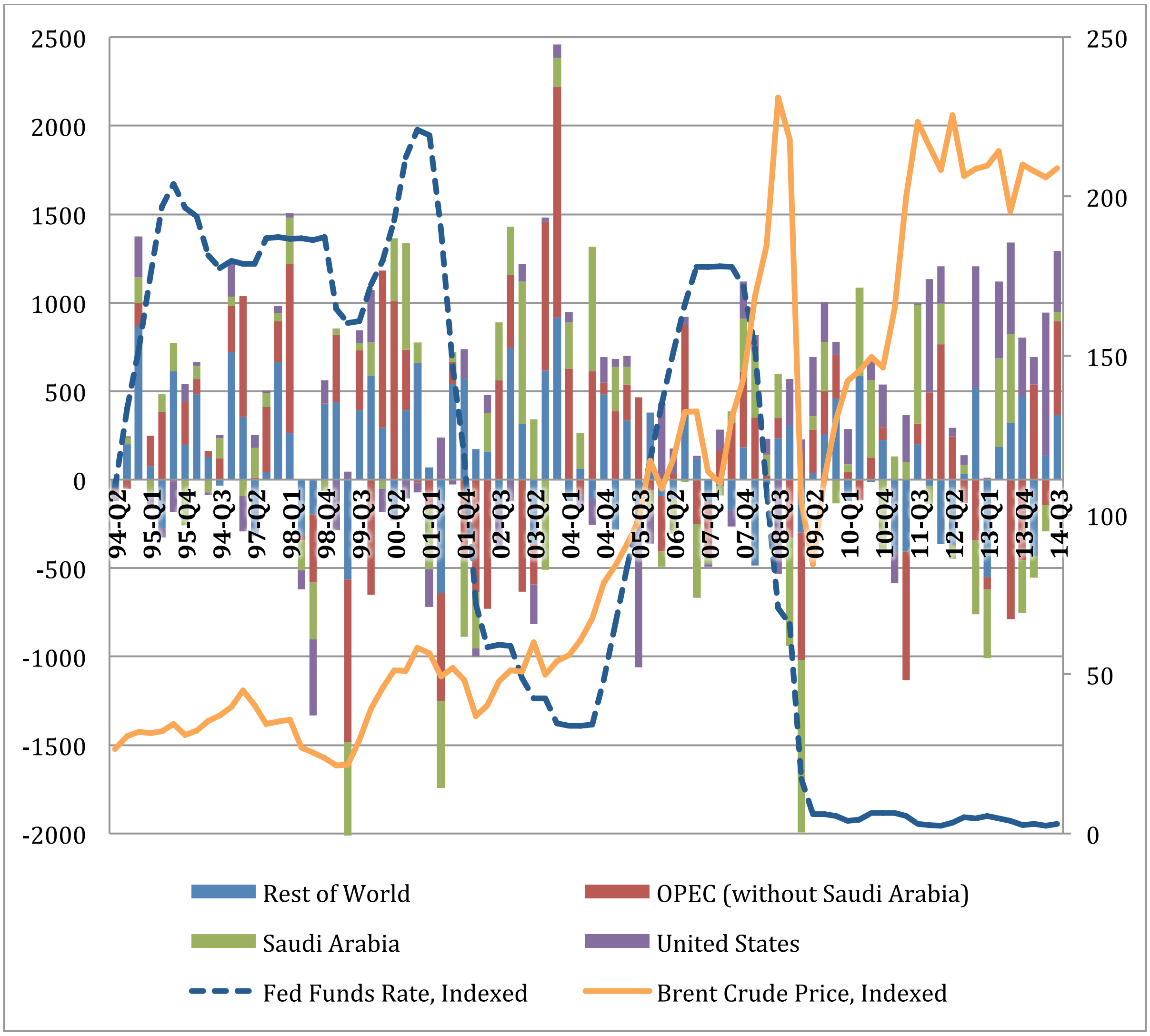

Figure 57. Quarterly Changes in Production Rate By Area (Left Axis), with Indexed Fed Funds and Brent Price. *Note: Fed Funds and Brent price both indexed to series average and measured on the right axis. Source: EIA, FRED, IFS*

Overshoot, in the Dornbush and Frankel sense, revolves around prices in the economy—of foreign exchange and oil, respectively—that appreciate above or below their long-term value in response to a shock, usually of monetary policy. A high interest rate “surprise” would, in theory, send the price of both oil and foreign exchange below their long-term equilibrium value, then above it, as other aspects of the domestic economy with greater lags or “stickiness” catch up. The result is similar to a signal dampening to its baseline value after some impulse.

This may seem fundamentally different from the ecological overshoot paradigm, in which a burst or pulse of resources induces a population to multiply beyond its food supply, crash, then return to some long-term equilibrium (Catton, 1982). Yet I argue that what drives the Dornbush and Frankel overshoot revolves around a burst of resources typical of the oil harvest cycle. The Middle East oil pulses of the 1960s and 1970s helped produce the linked monetary-oil overshoot of the 1970s. Likewise, the oil pulses of the 1990s, including newly available oil from the former USSR, coupled with the Chinese coal pulse of the 2000s, helped produce monetary-oil overshoot in the US that led to a partial collapse of global banking.

Overshoot can be seen revolving around the gold-oil link, with its extremely stable average ratio. This fundamental relationship links the world’s monetary system to its physical system, as both elements move in reciprocal cycles with the dollar. Other commodities are subject to similar dynamics but less important as influences on the monetary system, or as ultimate limiters. The impossibility of substituting for energy, and oil’s long dominance over transport, help explain this[57].

Table 11. Granger Tests, Total Oil Supply, Fed Funds and Brent Price, 1994-2014.
Results indicate that the US reacted as a producer, following Saudi, OPEC, and Rest of World Production. Put another way, Saudi Arabia seems to balance rest of world production, while the US balances Saudi Arabia. The US accounted for much of the world’s new production post-crisis. Source: Data from FRED, EIA, IMF IFS

Granger Results, One-Quarter Lag		
	F.statistic	**p.value**
World.Oil.Prod -> Brent.Price	5.89	0.02
Brent.Price -> Saudi.Oil.Prod	6.55	0.01
Brent.Price -> US.Oil.Prod	4.66	0.03
Brent.Price -> Fed.Funds	4.15	0.04
Fed.Funds -> Saudi.Oil.Prod	4.25	0.04
Impulse @ 0	**1 Month**	**2 Months**
World Oil Production	Brent Price	Saudi Prod US Oil Prod Fed Funds

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[57] Concentration of political economic power in oil producers likely also matters.

Granger Results, Six-Quarter Lag		
	F.statistic	**p.value**
Fed.Funds -> Brent.Price	2.95	0.01
Brent.Price -> US.Oil.Prod	5.29	0.00
Brent.Price -> Saudi.Oil.Prod	2.52	0.03
Brent.Price -> OPEC.Oil.Prod	2.32	0.04
Fed.Funds -> Saudi.Oil.Prod	2.76	0.02
Impulse @ 0	**18 Months**	**36 Months**
Fed Funds	Brent Price	OPEC Prod
	Saudi Prod	Saudi Prod
		US Prod

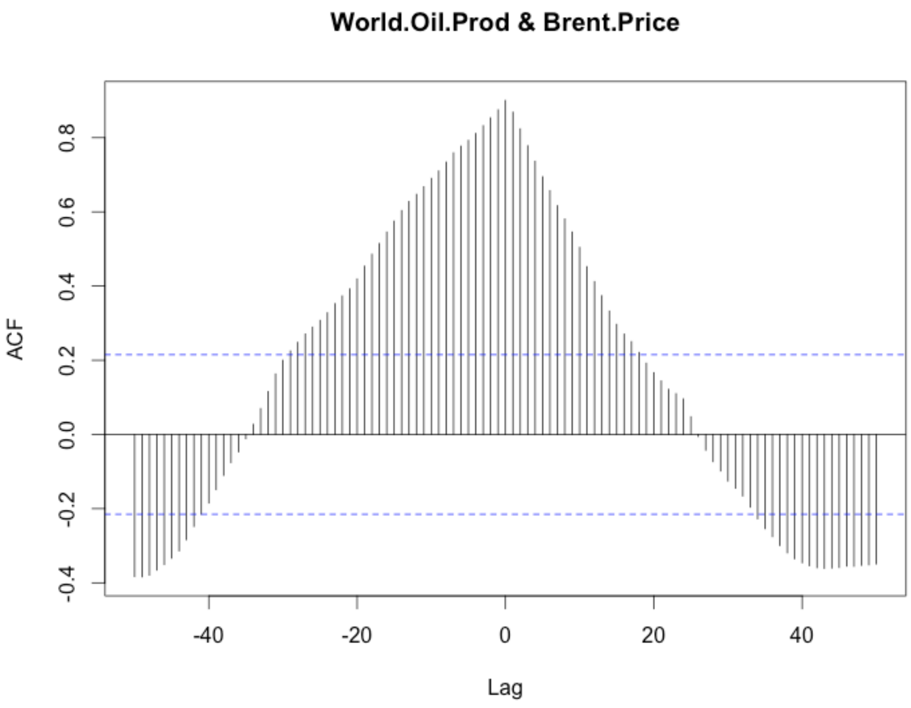
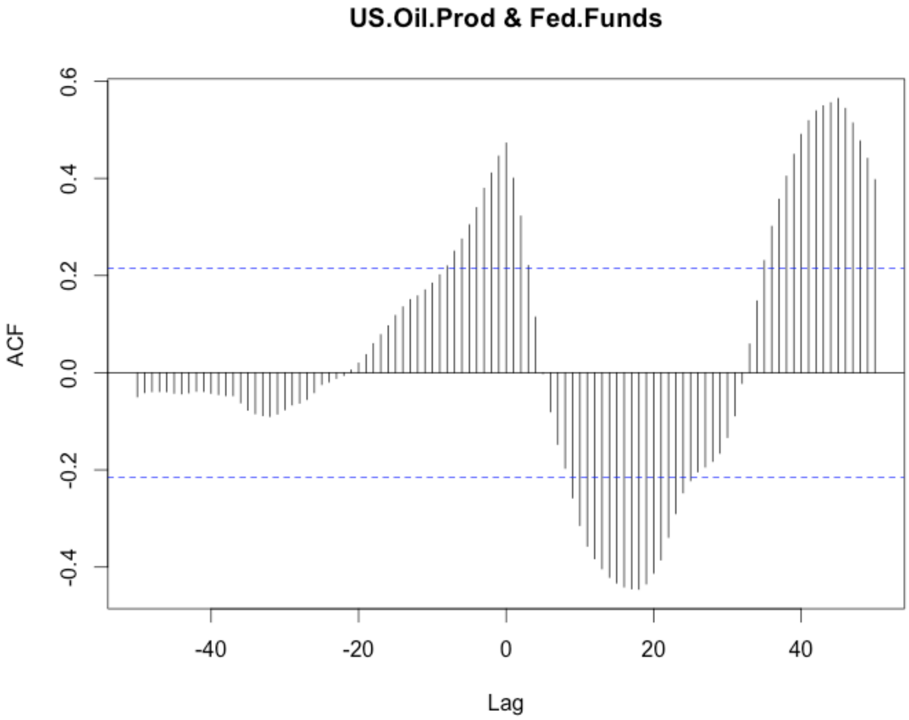


Figure 58. Bivariate Cross-Correlations, 1994-2014, Maximum 50 Lags (Quarterly). Above, world oil production (leading) and the Brent price are tightly correlated, peaking at zero lag, with relatively straightforward dynamics. US oil production, below, leads the Fed Fund rate with a positive short-term correlation, then oscillates, lagging it over longer periods. Source: EIA, IFS, FRED



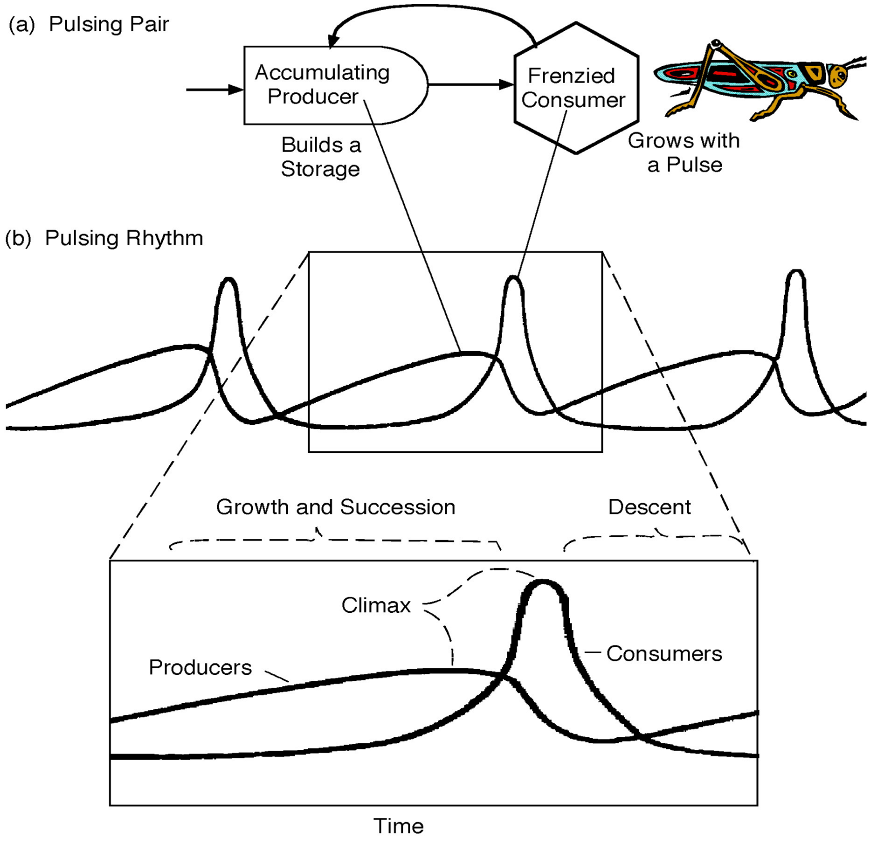


Figure 59. Odum's Consumer and Producer Pulse Paradigm. *Reproduced from (Odum, 2007, 56)*

Here we can revisit Odum's pulsing paradigm for a heuristic on what might be happening. In effect the US interest rate helps indicate the balance between producer and consumer pulses—it often signals where we stand in them and the availability of the most crucial resources that ultimately limit the money supply. Oil is both the exemplar and probable limiter of this cycle. In fact, it is the oil signal around which the United States—and arguably the globalized postwar world it constructed—pulses.

War, Suspension of Convertibility, and Oil

We cannot leave out the role of conflict in this analysis, or the simple fact that the oil harvest cycle to some extent coincides with a war cycle. Importantly, the two largest postwar disruptions in the oil price occurred in the 1970s and 2000s, during times of major foreign wars for the United States. The 1991 event also fits this pattern, though 1979-82 may not, at least upon first glance.

This may be partially attributable to a higher risk premium in oil markets increasing the price, along with potential or realized supply cuts due to conflicts (Hamilton, 2005). There is demand-side impact as well, with extra consumption from the various militaries involved. During the Vietnam War, the United States alone required one million barrels a day for its military: "Strategic and tactical jet fuel, gasoline, and naval fuel consumed by the U.S. Air Force, U.S. Navy and allied armed forces averaged a million barrels per day…" (Nguyen, 2008, 223). Such a large bump in demand has a large effect on the tightly balanced global oil market. It cannot pass without notice that high-price, high-investment phases of the oil harvest cycle to a large degree coincide with US military conflicts.

To go much further into the relationship between war and oil lies beyond the scope of this work, except as it affects the oil supply and external balances of the United States. Regarding the latter, sovereigns throughout history have commonly suspended convertibility, or gold flows, during wartime. The United States government expanded its balance sheet by approximately an order of magnitude during World War I and II—and again between the two. Careful perusal of Friedman and Schwartz's appendix tables (Friedman and Schwartz, 1963, 749-765 (A-3)) detail these enormous expansions. The aftermath of both wars involved adjustment necessitated by the return to convertibility and external balance.

The Nixon administration's 1971 suspension of convertibility between the dollar and gold may be categorized as an example of this historical pattern. Meanwhile, the pegging of the Chinese yuan to the US dollar—and the attendant "Wal-Mart dollar" recycling—almost certainly helped the US finance its Iraq and Afghanistan wars (Friedman, 2007). This pegging—or prevention of adjustment—in turn helped create excess global demand, money "sloshing" around the system (Elliot, 2008), and then the linked monetary-oil overshoot.

This places the experiences of the United States in the 1970s and 2000s in a new light. In both cases a large strain on the Treasury, along with heavy oil use in the theaters of war, produced increasing external imbalance and pressure on the US currency. Capital recycling, in the case of oil revenues from foreign producers in the 1970s and from China in the 2000s, helped finance these imbalances.

Summing Up the Cycles

How do these effects produce and resolve external imbalances for the United States? Perhaps the best way to see the entirety of the argument is that the US—both a large producer and consumer of energy—dwells mainly in "consumer" mode during a global energy pulse, when oil prices are low. Its rising imports stimulate exports and growth abroad, as with the extreme case of China in the 2000s. Meanwhile, growing oil demand abroad, attendant on growth and auto uptake in particular, similar to the case in Western Europe and Japan in the 1960s, eventually begins soaking up the surplus from that energy pulse.

This normally corresponds to a worsening US trade position, putting pressure first on the current account, then on the currency in a floating regime[58]. This in turn pushes the oil price up, as occurred in the 1970s and 2000s. The oil price tends to overshoot, producing a boom in oil investment which switches the United States into producer mode. Now rising expenditure in exploration and development of oil, and in resource development in general, exerts contractionary pressure on the US internal balance via mechanisms discussed in Chapters 4 and 5. This reduces US imports and slows growth abroad that depends on those imports, as with Japan, Europe, and later China. Domestic interest rates rise, attracting foreign financial flows—they did not rise far in 2004-2006 before this mechanism kicked in.

Meanwhile, the US in producer mode unlocks new energy resources and improves its terms of trade, strengthening the dollar and eventually producing another round of monetary easing. The length of the intervening period depends on both the severity of the downturn and the external imbalances it helped correct. Notably, the US has had ostensibly expansionary monetary policy, with high liquidity available via foreign investment, throughout the recent producer period from 2008-2014, when it raised production by more than 3 million barrels per day, mostly from shale oil deposits in Texas (2 million bbl/day) and North Dakota (1 million bbl/day). This partly reflects the continued willingness of China, now the key global producer or "workshop of the world," to finance the US deficit position through continuing purchase of US securities. Yet the massive growth in excess reserves held at the Fed,

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[58] Again, there is a benefit to the US running deficits to a certain point—its major trading partners can all maintain surpluses. In this way, beggar-your-neighbor policies may be defanged, as the US accepts its deficit and the rest get surplus. The results of this for US consumption and standards of living are difficult to tease apart.

however, may make the post-crisis period less expansionary than it seems at first glance. Bank credit grows far more slowly now than before the crisis.

The US absorbed an excess of Chinese goods during the 2000s—far more than it could truly afford. Rather than adjusting gradually to the growth disparity instigated by the Chinese entry into WTO in December 2001, US-China monetary policy allowed a tremendous imbalance to build between the two nations. As widely recognized (Rajan, 2011), this helped produce a violent correction in 2008, when financial mechanisms that helped manage the flow of "Wal-Mart dollars" collapsed.

Notably, oil began its 2000s rise from December 2001, a neat local minimum, and saw no significant correction until the financial crisis of 2008. Its peak in July 2008 was a klaxon signal of a massive imbalance in the US trade position. It was also a means of correcting that imbalance, influencing the US domestic environment—as it has since the end of the Bretton Woods period—through a combination of constricted consumer demand, reduced investment, and the attendant job destruction[59]. An extremely fragile, illusory financial system, built upon energy's disequilibrium system in the 2000s, finally fell apart under its pressure.

How can we avert the next crisis? We must take seriously the notion that interest rates and the money supply depend in part on the amount of energy available to society—on the phase of the energy pulse. This notion is not new: "If we look ahead to a distant time when all of the resources of the Earth will be near exhaustion, and the human race reduced to complete poverty, we may expect very high interest rates indeed" (Hotelling, 1931, 287). While complete poverty does not seem imminent, and while one may question Hotelling's vision for possibilities of the evolution of human society, the relationship between the resources devoted at any one time to securing society's metabolic flows—oil chief among them—and the concurrent macroeconomic conditions remains rich territory for ecological economists in the age of climate change.

Intensified mining of more expensive oil and gas helps correct the US external balance, but eventually misdirects resources at its peak. US employment suffers inordinately due to the low elasticity of employment in the oil and gas industry (if we assume an economy-wide average for its feeder industries). I argue this may fairly be called an overproduction of US resources, which may have more profitably, from the global perspective, be left in the ground.[60]

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[59] As Frankel (2006) notes, oil prices used to be taken as a solid indicator of future inflation. This is likely due to its rapid adjustment to changes in exchange rates—most prices in a domestic economy take longer to adjust. Here, again, lies the central point of his overshoot model (and Dornbush's, which involves foreign exchange rather than oil).

[60] "If interest rates or degrees of impatience vary among the mine-owners, this fact will also affect the order of extraction" (Hotelling, 1931, 284).

This over-investment in oil and gas produces job destruction. This is how the US adjusts to external imbalances in the laissez faire post-Keynesian age—through its oil industry, which transmits the signal from the rest of the world. This answers Hamilton's question (2005), posed over the last 25 years—why do US recessions all begin with oil price spikes? Children of booms and devaluation, the oil shocks help the US adjust through a combination of import restriction and export encouragement. In other words, without a gold standard, oil becomes the primary *physical* negative feedback mechanism controlling US expansion[61].

The length of the energy pulse period roughly corresponds to the productive burst from mines and wells called forth by the investment pulse preceding it (see Jakobsson, 2013, for lifetime production curves of typical wells). During longer investment pulses a period that more or less resembles a "lost decade" sets in[62], as with the 1970s-80s, and the mid-2000s into the following decade. Smaller versions last a few years, as in 1989-1991[63]. Rising energy prices flatten total investment, reducing the expected marginal efficiency of capital (profit rate) across many sectors, while increasing it for oil and gas, energy, and associated feeder industries.

Importantly, oil was the key source of trade imbalances for the US in the 1970s—oil costs themselves accounted for most of the US trade deficit, and in some years were many times the absolute value of the total US BOP. In the 1980s, the total trade deficit outpaces oil import costs, the latter becoming a smaller fraction of the deficit. By the 1990s and 2000s, the globalizing US runs larger and larger trade deficits, with oil costs increasing again relative to the rest of the deficit. From 2001 the coal-fired China deficit and the oil deficit become the two largest components of the BOP.

"Peak oil" theorists miss something when they talk about infinitely rising prices in the oil market. Though conventional oil production has slowed considerably since 2005, somewhat validating references to it as the global peak year, conventional oil has at least a short-term substitute in shale oil and other new sources. Yet the diminishing-return, lower-surplus profile of these alternatives necessitates an adjustment of the global economic system around them.

The global disequilibrium system rests in part on the fact that the distribution of resources diverged from the distribution of power during Bretton Woods. According to many international relations theorists, the US last had "legitimate" hegemonic power in 1971 (see Spiro, 1999, 18). By this point it had fallen far behind on cheap energy resources. Expanding the US money supply so sharply in early 1970s, as US

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[61] Which may be, again, why recent US expansionary periods match, roughly, the productive life of oil wells brought on in the most recent investment pulse. This also corresponds to Jevon's idea on the timing of agricultural fluctuations and sunspots.

[62] Again an energy-focused investigation of the Great Depression tantalizes.

[63] Former Soviet oil coming to Western markets as this period ended was likely important.

oil constraints began to bind, drove a great deal of demand and likely worsened the situation domestically and internationally (Barsky and Kilian, 2004).

Neoclassical economics has not resolved the debate between "supply" (ie., Hamilton 2005) versus "monetary" (ie., Frankel 2006, Barsky Kilian, 2004) explanations of the 1970s oil world and beyond. Doing so requires deeper investigation into their interrelationship. The US supply situation in the early 1970s required monetary adjustment[64], which entered back into prices and produced "stagflation"—inflation without growth. Pressure on the trade balance built up by the early 1970s could not be sustained under Bretton Woods.

Price conditions did not ease until the early 1980s in the US, and then again in the early 2010s—by mid-decade in both cases, oil markets had returned to a more stable long-term trajectory. New resources came on—Alaska and offshore in the 1980s, shale oil in the 2000s—while decisions of the swing producer (Saudi Arabia) also played a part. Both cases also featured a generational change in global financial arrangements: the unilateral floating of the dollar in 1971 and the WTO accession of China in 2001. Both produced monetary overshoot (1971, 2001), a sharp price rise (1973-74; 2002-2004), then oil overshoot years (1979-80, 2006-08), after which the price gradually declined to where it was prior to the overshoot (1986,2014).

The energy trade has a disproportionate effect on the US economy and its macroeconomic indicators—it is not simply proportionate to its average percentage of GDP. There are simple analogies for smaller but higher-level control systems that have effects far greater than their flow magnitudes in ecology (Odum, 1988) and perhaps also anatomy. Assuming a simple linear relationship often misleads, thus identifying the main determinants of "systemic causation" (Lakoff, 2014), or using network-based modes of analysis, such as artificial neural nets, should be high on the list of ecological economics researchers.

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[64] Other adjustment mechanisms rather than a unilateral floating of the global reserve currency could be imagined. The resulting US economic contraction and lifestyle changes may have been judged too damaging by the politicians who made the decision. They came in any case over the next ten years; adjustment of the global trade system cannot be avoided forever, unless it ends or changes to something with a fundamentally different basis.

Conclusion: Future Work

Where can we go from here?

There is much research and work left to be done on tightening up the oil harvest cycle postulated in Chapters 4 and 5—and on the ideas of oil as enforcing some external balance in Chapters 6 and 7. The complex set of hypotheses here, by more quantitative methodological standards, remains untested. While a more formal statement will be necessary, my goal was to describe the history and evolution of a central part of our global social system. Capturing its structural changes with any degree of realism, without importing heavily distorting assumptions, lies beyond most quantitative methods with which I am acquainted. While artificial neural nets, maximum entropy, and other network- or information-based statistical methods hold much promise for the topics here, they must be investigated in future works.

These accounts also call out to be integrated with a less quantitative history. Most of the rich politics of the main periods in question—the decade or so following both 1971 and 2001—remains invisible in this narrative. While this was a conscious strategy, to attempt to peer beyond the litany of event-driven cause and effect satirized by Jevons in the beginning of Chapter 3, the real utility of the major findings here lies in their future reflection against specific political economic events and narratives—as tools and schema for future work.

There are two other key concepts I believe will greatly advance the theoretical and practical work done here. One may aid this general approach, above, of bringing people back into the picture. The other, perhaps, tends more toward a deterministic account that pushes in the opposite direction.

The first concept is an old one, the notion of *surplus* used by the classical political economists, then more or less discarded by the marginalist revolution and the neoclassicists. This is not consumer or producer surplus as used in partial equilibrium frameworks, but surplus as the year's bounty—what we collectively produce in a year above our system's maintenance needs. It relates to the profits in this system, but *surplus*, with a clear biophysical analogue and sense, is preferable.

Through surplus we might more closely approach the topic of income inequality, now a plague on the United States in particular, with its attendant political distortions. Surplus, distribution of the year's overage, is not only an easy way to keep one's eye on the central issues of political economics—*it is the central issue*. As our global society considers ideas of differential growth or degrowth, low-carbon transitions, and ways of accommodating rising demands for better living standards from billions of people, surplus will only increase in importance.

Closely related to this idea is the second concept, the Odum pulsing paradigm that seems to determine the magnitude of the surplus in many systems. A better understanding of the pulsing paradigm, and deeper application of it to political economic systems, seems to be an important way of bringing more ecological content into economics. The pulsing paradigm relates to many important topics in complexity and resilience theory, including complex adaptive cycles and systems on the edge of chaos. Given the evidence of pulsing in the global monetary-energy system, integrating the Odums' contribution into political economy seems useful.

In the types of studies I perform, at the boundary of ecological economics, energy analysis, and political economy, environmental determinism always threatens to overrun the narrative. Are we all just cogs in a great energy and information processing machine? We avoid this error by remembering that future human innovations and collective decisions remain the missing variables in our models. Evolution is atheoretical; emergent properties can rarely be logically derived from constituent parts. While pointing out the great shadow weight of resource constraints on economic systems, we cannot forget its counterweight: the irrepressible human desire to invent—to create and recreate the world in which we live so that it may tend, in the best of times, more closely to our collective dreams.

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