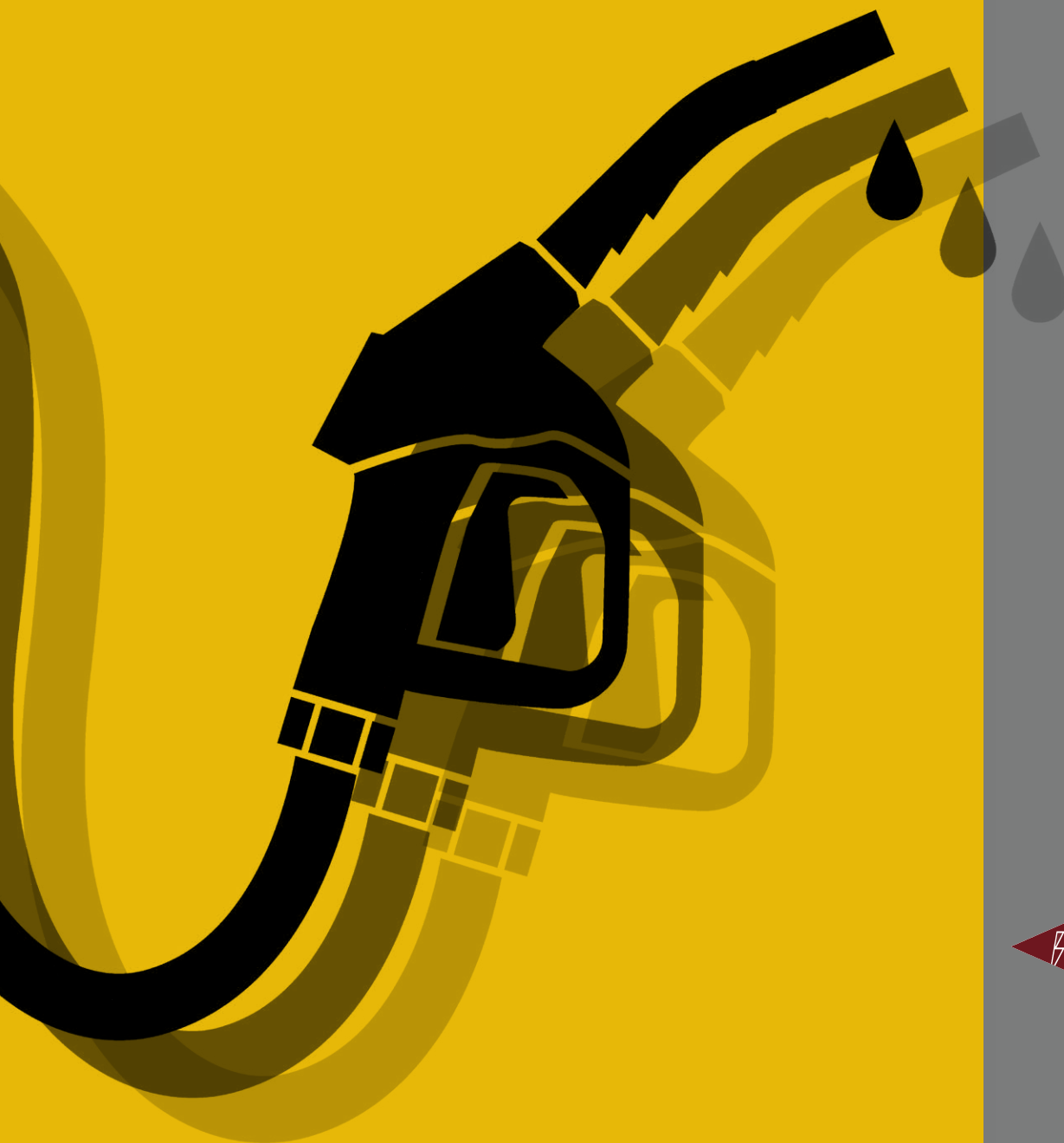


The Origins of Resource Pessimism and its Consequences

An EPRINC Working Paper

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“The strongest witness is the vast population of the earth to which we are a burden and she scarcely can provide for our needs; as our demands grow greater, our complaints against nature’s inadequacy are heard by all.” —Tertullan 3rd century¹

The modern era has seen two major threads of neo-Malthusian thought: fears that agriculture cannot sustain the future population and concerns about possible scarcity of nonrenewable resources like minerals and energy. This has caused various governments to undertake population control policies, crash programs to develop substitute fuels, and even suggestions that exploitation of asteroids for their mineral resources might soon be necessary. The proposed Green New Deal was seen to be motivated in part by a concern for the finite nature of resources.

But the various apocalyptic predictions based on these theories have virtually all failed, although proponents insist that only their timing is in error, not the concept. This report finds that most neo-Malthusian arguments are based on an incorrect understanding of resource estimates, including the nature and terminology, leading to the use of woefully conservative figures which then generate the apocalyptic warnings. Combined with the assumption that, since technological advances can’t be predicted, technological progress should not be assumed, arguments that consumption must be curtailed and even that economic growth should cease are based on fallacious notions.

Natural resources have played an enormous role in human history, from individual cases as when ancient Athens’ discovery of silver financed its navy and made it a superpower, to the U.S.-led oil embargo of Japan that resulted in the attack on Pearl Harbor. Throughout, uncertainty about resource availability has been a primary influence on decision-makers: new discoveries could not be predicted, and exhaustion of existing deposits was always a threat. This fed into a general concern about resource scarcity, which has played a significant role in policy making for much of the last century, usually, however, reflecting a misunderstanding of resources rather than actual scarcity.

Specific warnings of resource scarcity have a long history, and some discount them given the failure of past predictions, but it’s more important to consider *why*: is there a fundamental flaw in the analysis or simply a mistake in timing? The latter claim is made by many, such as Paul Ehrlich, who insist that their models (actual or conceptual) are correct but perhaps suffer from some bad parameters that make the timing wrong. (Not unlike the 16th century astrologers in London who, when the Thames failed to flood and destroy the city as they predicted, insisted that their work was scientific but due to a mathematical error, the flood’s actual date would be a century later.)²

Resource scarcity fears have seen expression recently in a variety of ways, including the founding of a number of companies intent on mining asteroids for minerals,³ and proponents of a Green New Deal arguing, “we must challenge the assumption that we can simply go on increasing the production and consumption of finite resources, as if there were no constraints.”⁴

This paper argues that neo-Malthusians suffer from an underspecified model, not just bad input parameters but omitted variables that guarantee the pessimistic, and invalid, predictions.

Correcting these errors results in a much better understanding of resources and a more optimistic outlook for the global economy and hopefully less economic waste.

Fears of scarcity have led to various policy initiatives, both globally and nationally, most of which proved wasteful. Some armed conflict has been the direct result of a desire to acquire resources of other nations, including land but mineral and energy resources as well. Most dramatically, Adolf Hitler talked of Germany's need for 'lebensraum,' to accommodate its population and sent armies (unsuccessfully) to the Caspian oil fields. But European nations also fought over access to what are now very mundane spices like pepper and nutmeg.

At the global level, the apparent resource scarcity in the 1970s created the impetus for what became known as the New International Economic Order.⁵ This anticipated a future shift of power from industrialized nations in the North to resource rich ones in the South. Some economists suggested that future dependence by the industrialized nations on scarce resources would give more economic power to the resource exporters. They argued for financial assistance in return for access to supplies of raw materials.

Related to this, there have been many attempts by resource importing nations to curry favor with exporters, partly in expectation of future scarcity. Most famously, numerous countries offered recognition to the Palestine Liberation Organization in 1973, during the Second Arab Oil Embargo, to attain exemption from the embargo, although ineffectively. Sadly, some countries adopted abusive population control programs in response to neo-Malthusian fears of overpopulation, and for a time energy polices promoted coal use in the place of supposedly- scarce natural gas, worsening global warming.

What's Off the Radar Can Hurt You

From 'business as usual' scenarios to Hubbert curves, coping with technological advance has long challenged forecasters, rather as the psycho-historians in Isaac Asimov's *Foundation* series could not foresee the mutant who disrupted their projected path of civilization. Oddly, although the media is constantly filled with stories of great advances in energy technology, such seem to be almost absent from socio-economic forecasts, except where proponents of a particular technology are

predicting its revolutionary success.

While some criticize a belief in the power of technology to solve problems, other commentators⁶ have criticized groups like the IEA for being overly pessimistic about the growth in renewables, suggesting an unacceptable degree of either conservatism about or bias against those energy sources, apparently unaware that these organizations (and virtually all others) have also done a poor job of projecting shale, as well as conventional, oil and gas production, prices, and so forth.

This paper will argue the issue on three levels: the philosophical difference between optimists and pessimists, the pessimists' deficiencies in interpretations of resources, and how that translates into mistaken expectations of economic crises.

Philosophical Differences

A simplistic definition of neo-Malthusians needs to be avoided, even aside from lumping them into one philosophical or ideological category. Many neo-Malthusians fit into a variety of groups such as environmentalists, liberals, socialists, anti-consumerists, science deniers, and Luddites, but it is quite possible to be a neo-Malthusian without fitting into any one of those other categories. (Indeed, using those terms interchangeably implies that the user has a certain political bias.) There is a very clear-cut distinction that will be made between neo-Malthusians and those other groups for this discussion, namely expectations of resource scarcity.

Certainly, many religions and philosophies urge people to focus on spiritual matters rather than the consumption of material goods, sometimes just on the grounds of eschewing wastefulness. This can be seen in such diverse characters as Pliny⁷ and Jimmy Carter, both of whom had policies that were informed by this philosophy.⁸ (Needless to say, wasteful is often subjective.) Thus, many find arguments about resource scarcity appealing because they promote conservation and reduced consumption. But that is a separate question from the abundance or scarcity of resources, just as curbing greenhouse gas emissions does not require fears of peak oil.

There does, however, seem to be a clear

psychological element of neo-Malthusianism. An interesting overview of natural gas supply expectations, published three decades ago, noted that experts seemed to be divided between optimists and pessimists, with the latter concerned about the difficulties that made sustaining production challenging and the former focused on the ability of the industry to overcome difficulties and sustain, even increase, production.⁹ Personality seemed to explain the difference more than any underlying theories or empirical results and this seems at least partly true in the broader debate about resources.

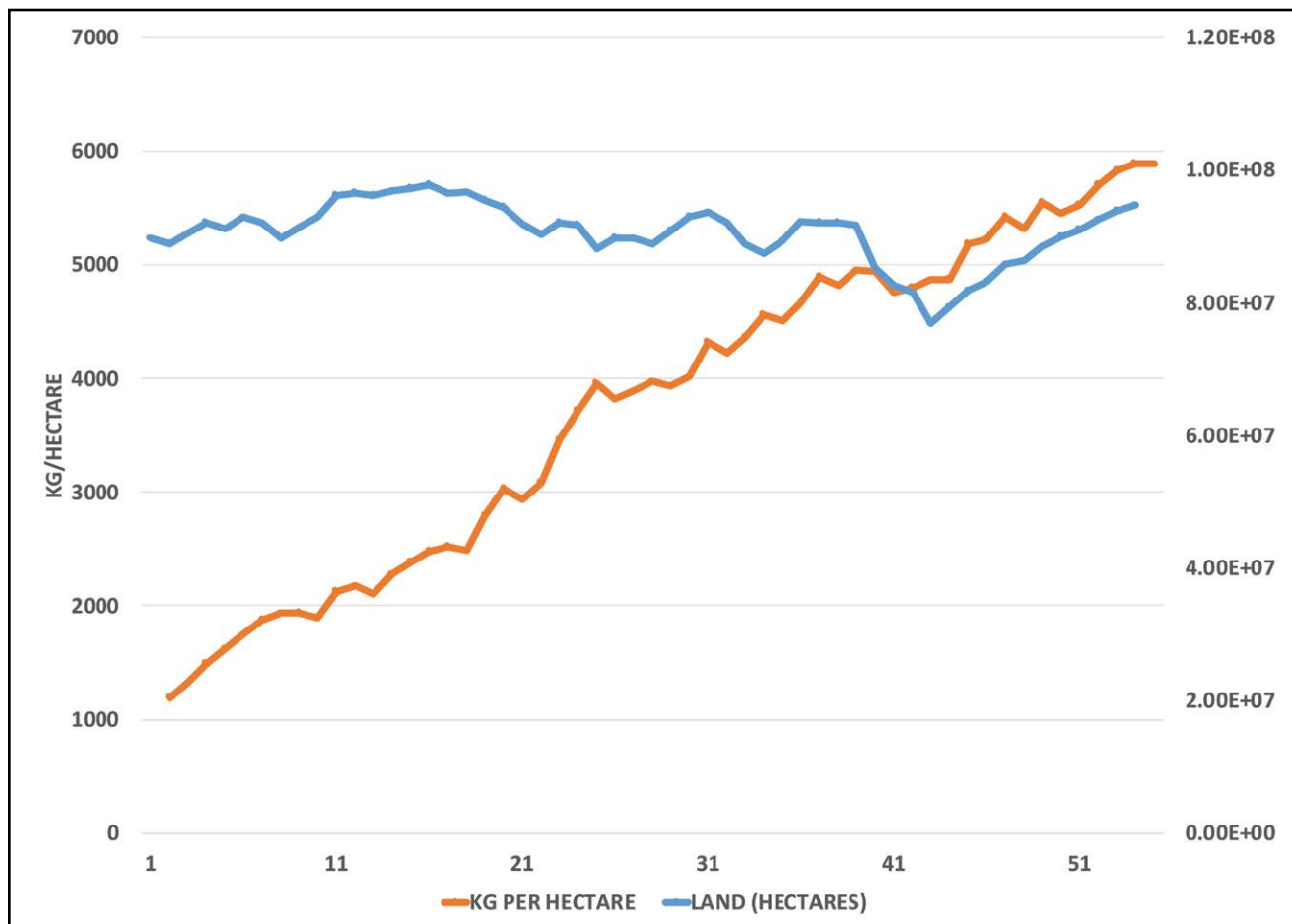
The same split is described more recently in the wonderful book, *The Wizard and the Prophet*, by Charles Mann¹⁰, which describes the dichotomy between those who foresee difficulties as leading to catastrophe and those who predict triumph over those same problems as the result of technological progress. (The views of the Prophets are usually taken to imply that mankind needs to reduce its consumption of resources, while the Wizards describe those fears as mistaken and the challenges surmountable.) As his models he uses William Vogt, whose views were formed by watching guano deposits dwindle on the Peruvian Chincha Islands; and Norman Borlaug, the initiator of the

Green Revolution, who sought ways to conquer agricultural resource constraints through research.

That a pessimistic bias influences neo-Malthusian work seems clear. For example, consider the negative outlook for China in *Ecoscience*.¹¹ “It is a strange irony that the potential for further raising of food production is probably considerably less in China than in India, precisely because so much has already been accomplished.”¹² In the first case, the point is great potential but problems, and in the second, less potential.

The reality is that neither China nor India, in the 1970s, had remotely mature or advanced agricultural sectors. India, as the authors admitted, was woefully undercapitalized but more importantly, the organization of Chinese food production by central authorities hardly offset lack of capital and technology, as well as the detrimental nature of ideologically based organization. Figure 1 shows cereal production per hectare over time and there is certainly no post-1970s slowdown in progress. Indeed, in the post-Mao era, food has become increasingly abundant, not scarce.

Figure I
Chinese Cereal Production



Source: World Bank.¹³

The Crisis of Scarcity

Vogt’s work was overshadowed by Paul and Anne Ehrlich’s 1968 *The Population Bomb*, which warned that humanity was rapidly outgrowing its ability to feed itself, and the Club of Rome’s 1972 *Limits to Growth*,¹⁴ which argued that exponential growth in a world of fixed resources was not sustainable in the long run. The ideas gained currency when they were followed by the first Oil Crisis in 1973/74, along with a spike in the prices of some agricultural products.

These views informed President Jimmy Carter, whose speech on energy policy included the memorable words “The oil and natural gas we rely on for 75 percent of our energy are running out.”¹⁵ The Iranian Oil Crisis confirmed to many that this was, indeed, in Carter’s words, “the greatest challenge our country will face during our

lifetimes.” Those like M.I.T.’s M. A. Adelman or Erasmus University’s Peter Odell who argued the problems were due to transient political issues instead of geological scarcity were derided as naïve.¹⁶

But prices for oil and other commodities retreated in the 1980s, leading to Paul Ehrlich losing his famous wager with Julian Simon on the prices of a basket of commodities, and the decade and a half of moderate oil prices that followed 1985 helped to convince many that scarcity was not a threat.¹⁷ For others, the lesson was that resource prices (and economics more generally) were inherently unpredictable, and some institutions abandoned the attempt at forecasting; most oil companies ceased issuing an annual long-term outlook by the late 1980s.

But neo-Malthusian views received new

impetus with the publication of “The End of Cheap Oil,” in the March 1998 *Scientific American*, which led to the founding of the Association for the Study of Peak Oil, and helped create an entire apocalyptic-industrial complex with books like *The End of Growth*, *Peak Everything*, *Half Gone*, and more. Essentially, many seized on the original Prophets’ stance that finite resources posed an imminent danger, one that could only be overcome by reducing consumption.

How has that worked out? Many have noted the fabulous failures of Ehrlich and the more modern members of the apocalyptic-industrial establishment like Richard Heinberg and James Howard Kunstler, and correctly labelled the error a failure to recognize the role of scientific and technological advances.¹⁸

This, in fact, remains the defining characteristic of neo-Malthusians: a belief that natural resources are finite and that this limits humanity’s economic potential. It appears that it was physicist Albert Bartlett who coined the term ‘flat earth economist’ to refer to those who were optimistic about resources, because the two-dimensional planet struck him as implying infinite resources. The Ehrlichs make reference to the finite nature of land by noting that the solar system would

be filled with people in 200 years—if you assume constant, exponential population growth.¹⁹

Oddly, although Thomas Malthus famously came to a pessimistic conclusion in his original publication, with additional research he realized that his initial estimates of food productivity growth were incorrect and that people seemed to be quite capable of increasing production to account for population growth.²⁰ (Few seem familiar with this aspect of his work, and while Malthusian is often used to refer resource pessimism, the term neo-Malthusian for current practitioners is more appropriate.)

But for their part, when the authors of *The Limits to Growth* revisited the work in 1992, instead of recognizing their initial failure to account for the dynamic nature of technological progress and its effect on resources, the authors doubled down on the original mistake by insisting that continued discovery of oil did not mean their model was wrong: “No, of course not. There were 450 fewer billion barrels of oil, 90 billion fewer tons of coal, and 1100 trillion fewer cubic meters of natural gas.”²¹ In other words, the resource is static and rising production doesn’t mean abundance, but that we are nearer to scarcity and exhaustion.

RESOURCES

One side of the neo-Malthusian coin is the scarcity of resources, which are not only finite, as described above, but very limited, leading to predictions that supply would be physically incapable of meeting demand at some point in the future. For the Ehrlichs, it was food supply that would be inadequate in less than two decades, since arable land was fixed and productivity gains seemed insufficient to cope with population growth. The LTG authors saw some decades of abundance before supply became constrained,

while more recently, the peak oil advocates have foreseen a physical peak in oil production within a few years—or in some cases, the recent past.²²

The failure of their millenarian predictions to prove out is at least partly due to their misunderstanding of resources and resource estimation. Specifically, many mis-understand the terminology involved in making resource estimates, rely on extremely conservative numbers, and don’t recognize that those estimates grow over time.

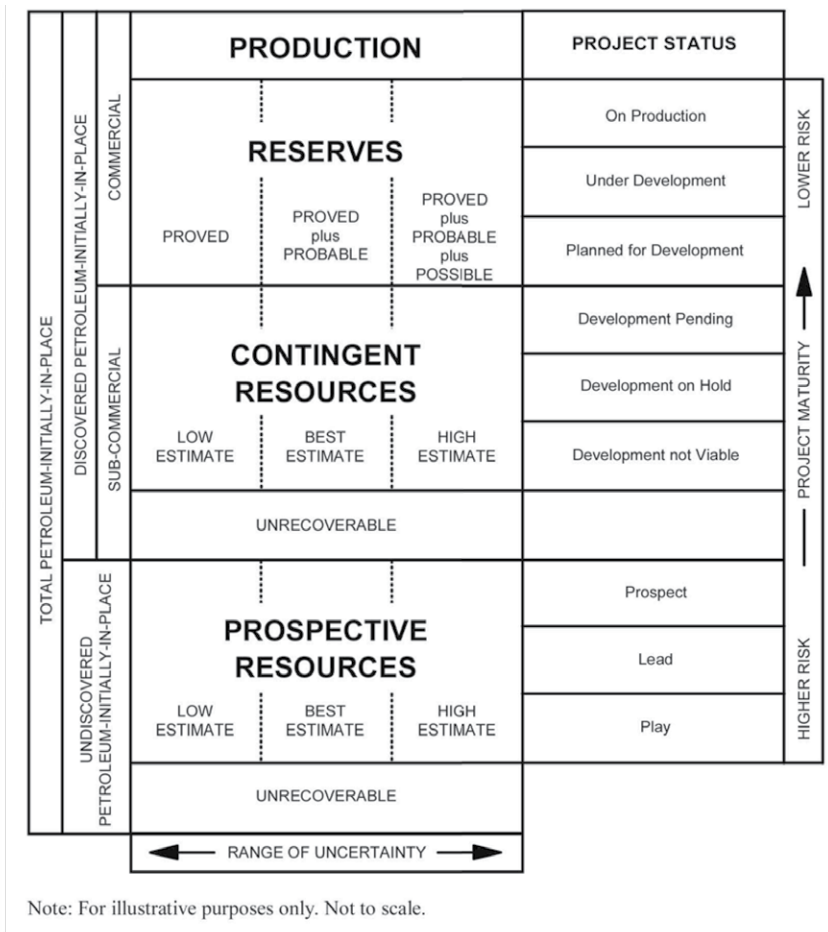
RESOURCE ESTIMATION

Estimating the existing amount of resources has been the first challenge for those attempting to measure abundance or scarcity. The conservatism of neo-Malthusian resource estimates has been much commented on. In 1989, Ron Bailey²³ noted that the resource assumptions used by the LTG team were woefully underestimated, such that most would have experienced exhaustion by now if the numbers they used were correct.

But the problem is more than simply conservatism. Neo-Malthusians are often unfamiliar with resource estimates and don't understand the terminology, causing them to report only a subset of the total resource, and/or they fail to recognize that resource estimates tend to be very conservative by nature.

The 1972 book *Limits to Growth* demonstrates both these mistakes. In the first place, the authors did not realize that "reserves" is the most conservative subcategory of resources, referring to discovered and economically feasible materials, not the entire resource base. Figure 2 demonstrates the categorization used by geologists, known as the McKelvey Box. The section in the upper left-hand corner represents "proved reserves," and excludes the portion of the resource that is either undiscovered or currently uneconomical or technically infeasible to produce at the time of the estimate. As shall be shown, this is generally a very small fraction of the total resource.

Figure 2
The McKelvey Box



Source: "Guidelines for the Evaluation of Petroleum Reserves and Resources," Society of Petroleum Engineers, 2001 p. 10.

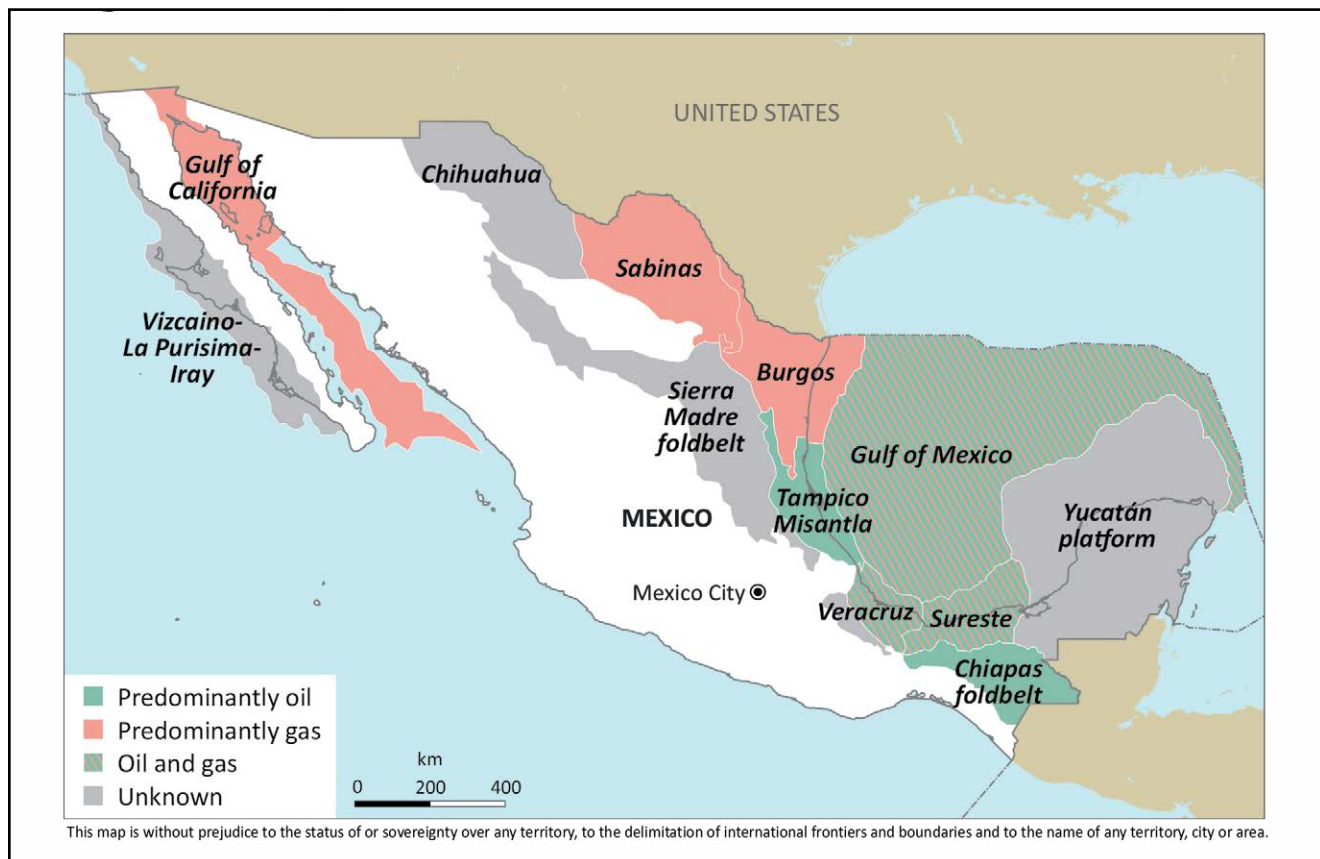
When the Limits to Growth was published, for petroleum resources they used the number of 455 billion barrels, which was actually “proved reserves”. In fact, estimates of the recoverable resource (URR) at the time were about four times that much, meaning their parameter describing the oil resource was only 20% of the prevailing estimate of the resource size.²⁴ As such, they were guaranteed to produce results implying scarcity much sooner than a more accurate estimate would have yielded.

But the second failure is not recognizing that these numbers grow, something M. A. Adelman and myself criticized in 1997 when talking about neo-Malthusian warnings of oil scarcity. The article was actually titled, “Fixed View of Resource Limits

Leads to Undue Pessimism.”²⁵ Combining use of a very small number, and assuming it is static, with constantly growing demand yields the typically premature estimate of resource scarcity and exhaustion.

This conservatism does not reflect scientific error, but misinterpretation of the estimates by inexpert observers. Geologists generally don’t make estimates for resources in unexplored or poorly studied areas, but focus on those that are reasonably well understood. In its recent review of Mexican oil, for example, the International Energy Agency published a map of the country’s geological basins, and the figure below indicates in how much territory the geological potential is unknown.

Figure 3
Mexican Petroleum Geology



Source: *Mexico Energy Outlook*, International Energy Agency, 2016, p. 64.

Similarly, the estimates describe what is recoverable with current technology and economics, since predicting either for decades in the future is extremely problematical. Casual observers often do not realize this and believe the estimates are both reliable and stable.

Table 1 shows how oil resource estimates have grown over time, using three specific sources for consistency as many different approaches are taken by different groups. Note that even the estimates

made by the Association for the Study of Peak Oil grew repeatedly even though they argued that their access to a database created by geologists enabled them to create robust numbers.²⁶ The National Petroleum Council, in 2007, published resource estimates showing how they are both highly variable and prone to growth over time: before 1960, only one estimate was more than 2 trillion barrels, in recent years, none have been below that level.²⁷

**Table 1
Evolution of Ultimately Recoverable Resource Estimates
Petroleum (billion barrels)**

Date of Estimate	Hubbert	Date of Estimate	USGS	Date of Estimate	Campbell
1956	1250	1982	1796	1989	1575
1969	1350	1991	2079	1990	1650
1973	2000	1994	2272	1995	1750
		2000	3000	1996	1800
		2010	3600	2002	1950

Table 2 shows just how seriously *The Limits to Growth* resource estimates were in error; it includes their estimate of resources (“base”) plus the amount that they described as technologically optimistic,

or five times base resources (5X), actual production since the book’s publication, and current estimates of both reserves and resources or the major mineral and energy resources.

**Table 2
Limits to Growth Resource Estimates vs. Reality**

	Base	5X	Production	Current Reserves	Remaining Resource
Petroleum	4.55E+11	2.28E+12	1.12E+12	1.69E+12	3.35E+12
Copper	3.08E+08	1.54E+09	1.97E+07	8.30E+08	6.60E+09
Nickel	7.35E+07	3.68E+08		8.90E+07	1.30E+08
Natural Gas	1.14E+15	5.7E+15	3.47E+15	6.59E+15	1.54E+16
Coal	5.00E+12	2.5E+13	2.04E+11	1.14E+12	1.77E+13
Aluminum	1.17E+09	5.85E+09		3.00E+10	6.50E+10*
Iron	1.00E+11	5E+11	5.11E+11	8.30E+10	2.30E+11

Source: USGS Mineral Commodity Summaries 2019.²⁸

*Midrange

In three of the six cases, consumption since the publication of LTG has exceeded their resource estimates, and in five cases, remaining reserves are *still* larger than the 1972 reserves. Oil, the subject of so much concerns, is a good example. The amount of oil produced since the publication of LTG to now, plus current known reserves, exceeds the ‘technologically optimistic’ number used in the LTG, which was 5 times then-existing reserves. For oil, that high-end number was 2.28 trillion barrels; since 1972, the world has consumed 1.1 trillion and still has 1.7 trillion of reserves, that is, not including undiscovered oil and assuming no future increase in recovery factor. In fact, when the latest URR number was produced, shale oil was not included, and there is now reason to believe it might exceed the conventional resource.

Growth in Resource Estimates

As time passes and technology improves, so does the recoverable proportion of known resources. Also, new areas are located, sometimes that were technically inaccessible before, such as deepwater petroleum, other times because they hadn’t been studied intensively.

Increase in the proportion of the resource which is recoverable is a major factor in the growth of the recoverable resource and is nothing new. Mussolini’s government exploited slag deposits from ancient abandoned Roman mines to extract remaining ores that the Romans could not, and

mine operators in South Africa long ago began reprocessing the ‘tailing dams,’ large heaps of material discarded by earlier miners who were only able to extract a portion of the resource contained therein.³⁰

Oil companies, similarly, have used methods like water, gas and/or steam injection to recover oil left behind in a deposit, and the average amount recovered from fields has increased from 10% in the early twentieth century to 35% now. This helps to explain why estimates of the recoverable amount of oil, including undiscovered oil, was about 2 trillion barrels in the 1970s but is now considered to be between 3.5 and 4 trillion barrels.³¹

And technology adds new resources by allowing access to them; U.S. offshore data provides an excellent example of this. In 1965, oil under water depths of more than 100 meters (300 feet) would not be included in ‘recoverable resources’ because the industry was not able to develop fields in water that deep. With the development of new production methods, including tension leg platforms and subsea satellite templates (unmanned equipment on the sea floor), an increasingly larger amount of oil is added to the ‘recoverable resource’. Table 3 shows the way in which the ability to drill in deeper and deeper water increased U.S. oil reserves; the amounts might seem small, but they are *proved reserves*, the most conservative estimate of the resource.

Table 3
Evolution of U.S. Gulf of Mexico Proved Reserves (million barrels of oil)

	Production Method	Water Depth	Reserves
1965	Jack-up	300'	11,289
1978	Compliant Tower	1000	1,696
1990	Floating Production Systems	2000	1,334
1995	Tension Leg Platform	5000	4,684
To present	Subsea/Spar	Deeper	2,493

Source: Lynch (2016) p. 246.

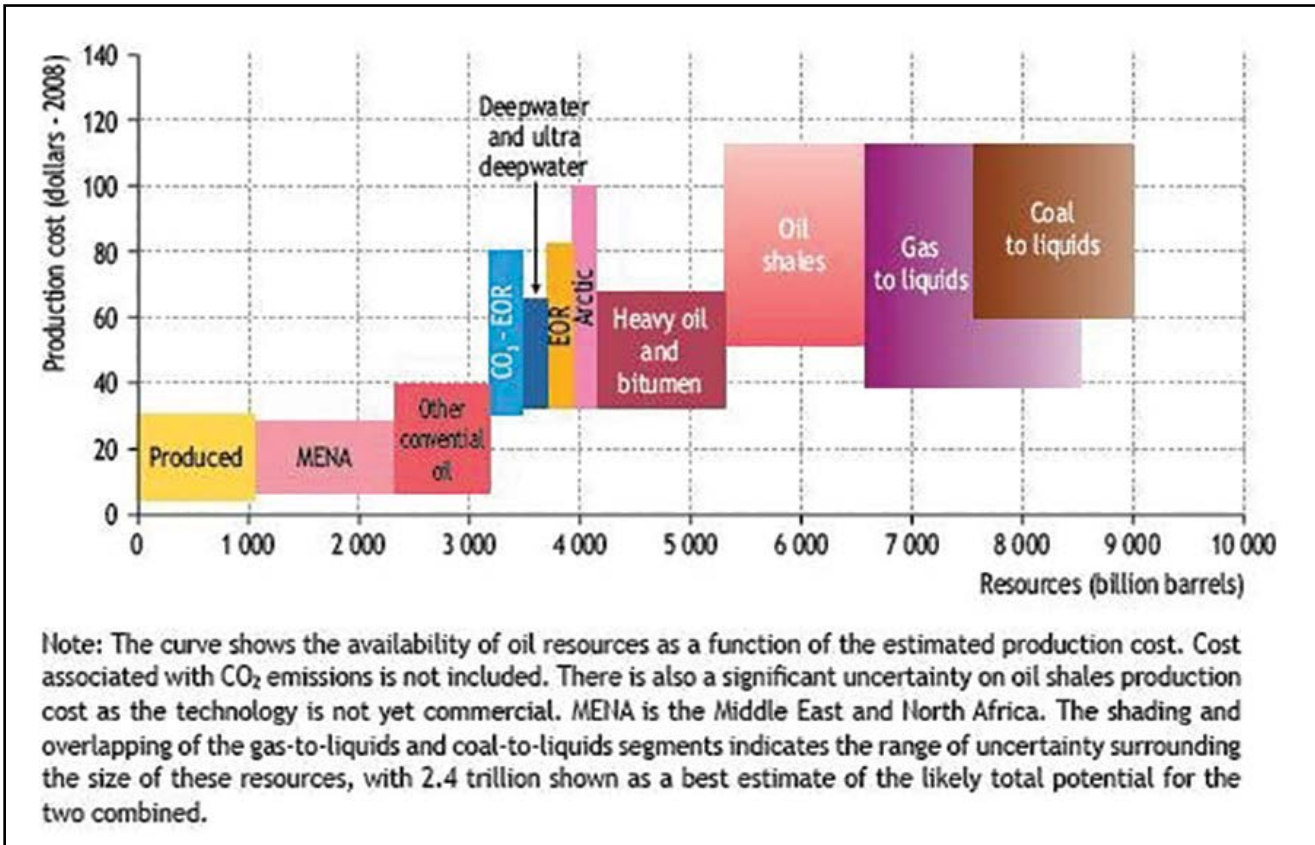
Similarly, the application of hydraulic fracturing has meant that a large new resource is now viable. Even a decade ago, resource estimates tended to exclude shale oil while considering heavy oil and oil shales (kerogen, a rock that could be processed to produce oil). Now, an estimated 400 billion barrels of shale oil are thought to be technically recoverable worldwide.³² While that only adds about 10% to the world’s ultimately recoverable resource estimate for petroleum, it is a very preliminary estimate which covers only a fraction of the world’s basins.³³ Plus that estimate assumes a 3-5% recovery factor, an amount that is likely to grow over time. (Indeed, even in the U.S., whose geology is well understood, the estimates have increased repeatedly.)

The magnitude of the effect technology has on the recoverable resource for shale oil can be seen in the Bakken shale, where two decades ago, the USGS estimated that it contained 151 million barrels of recoverable oil, but after repeated increases, the

region is now thought to have over 8 billion barrels of petroleum liquids.³⁴ Similarly, the recoverable resource in the Permian recently increased from 2 billion barrels in 2011 to 66 billion barrels now.³⁵ The numbers will certainly grow larger in the future.

But shale oil was not actually included in most resource estimates until recently: it would not appear in the McKelvey box. A typical example of estimates of petroleum resources can be seen in Figure 4, which the International Energy Agency published in 2008. They put the recoverable estimate at roughly 5.5 trillion barrels, meaning the total, in-place amount would be more than 20 trillion barrels since recovery factors for unconventional oils have usually been on the order of 10%. So, if shale oil (not oil shale, which is kerogen) is included, the in-place petroleum resource is greater than 30 trillion barrels, or nearly 100 times the estimate used as the “optimistic resource” levels used by the LTG modelers.

Figure 4
Petroleum Resource Supply Curve



Source: IEA, *Resources to Reserves — Oil and Gas Technologies for the Energy Markets of the Future*, 2005, p. 17.

This is typical of many resources: estimates do not include so-called unconventional sources, such as manganese nodules on the sea floor, methane hydrates which are an enormous, but currently infeasible, natural gas resource or various minerals dissolved in seawater. In a famous case, low-grade taconite ore is now a major source of iron: as the Minnesota Department of Resources says, “When the high-grade natural iron ore was plentiful, taconite was considered a waste rock and not used.”³⁶

Certainly, 100% of a resource will never be produced, but on the time horizons used in these long-term studies, substantial technological

advances should be expected that greatly increase the recoverable resource. Since resources that are currently recoverable can meet decades of demand, there is ample time for new technologies to increase recovery factors much more.

To summarize, neo-Malthusians have often used estimates for Earth’s resources that are actually a subset of resources, not understanding the nomenclature but also not realizing that the estimates are usually only of the recoverable portion of the resource, which tends to grow over time. The result is that their estimates of resources are far too small and have led them to incorrectly predict resource scarcity and exhaustion.

THE ROLE OF PROGRESS

Simon’s central premise was that people are the ultimate resource. “Human beings,” he wrote, “are not just more mouths to feed, but are productive and inventive minds that help find creative solutions to man’s problems, thus leaving us better off over the long run.”³⁷

Ultimately, the amount of resources is not only increased by advancing technology, but the utilization of the resource is generally improved by such. As shall be shown, technological advances can literally mean that a limited resource can

provide an ever-increasing supply, specifically in agriculture. This has made a mockery of many predictions such as those of the Ehrlichs, especially as they ignore or downplay technological advances in the future.

Skepticism

Neo-Malthusians typically argue that scientific and technological advances can't be predicted and thus shouldn't be assumed. Typical is the book title, *Too Much Magic: Wishful Thinking, Technology, and the Fate of the Nation*, by James Howard Kunstler, where he refers to a belief that progress can solve problems as “techno grandiosity (or techno triumphalism or techno narcissism).”³⁸ Similarly, Richard Heinberg says, “Climate scientists, in turn, have come up with a series of proposals that are the *equivalent of magic*: They deliver desired results, but only if you believe in miracles.”³⁹ [Emphasis added.]

Paul Ehrlich has expressed a similar opinion: “Ehrlich accepts his prediction of widespread famine in the 1970s underestimated the ‘green revolution’ which industrialised farming. But he still dismisses hope that technology will allow mankind to stretch resources ever further. ‘Can we solve this technologically? Theoretically, since we can't know anything for certain, so we could come up with a *magic way* of producing food and that could save us.”⁴⁰ [Emphasis added.]

The natural response to dismissal of progress as being magical can be found in the famous quote of Arthur C. Clarke's, who said, “Any sufficiently advanced technology is indistinguishable from magic.” Heinberg, Kunstler and the Ehrlichs are each confusing their inability to understand progress with an inability of others to create it, rather as those who argue aliens must have been involved in building the pyramids because they don't understand how the ancient Egyptians accomplished the feat.

The pace of progress in the past or the future does not appear to be explicitly addressed in these or many other neo-Malthusian works. Instead, asserting that it is impossible for sufficient progress

to be achieved to cope with perceived problems is more common. *Ecoscience* specifically says, “It is certainly evident that no conceivable increase in the food supply can keep up with current population growth rates indefinitely.”⁴¹ This is apparently nothing more than an assertion, which the authors treat as self-evident.

Similarly, in LTG, the authors comment “Reduction to less than one-fourth of the present rate of pollution generation is probably unrealistic because of cost...” as well as noting the physical difficulty of reducing some types of pollution such as thermal or radioisotopes from nuclear power and “asbestos particles from brake lining.”⁴²

Which highlights the misuse of “conceivable” in terms of technological progress. What the Ehrlichs and Holdren claim is inconceivable has, in fact, happened for four decades since their book was written and shows no sign of ceasing. Additionally, many forms of pollution have been reduced far more than the LTG authors thought possible or at least economically feasible. From 1980 to 2016, the amount of SO2 in the atmosphere dropped by 87%, and with minimal economic impact.⁴³ Numerous countries have banned asbestos in brake linings showing that it is indeed quite feasible.

Since it has been fifty years since the publication of *The Population Bomb*, forty-six since the first version of *Limits to Growth* and forty since *Ecoscience* appeared, it might be argued that the various authors should not be faulted for failing to predict long-term technological progress.

Except that is precisely what they were doing, albeit predicting no progress. The World3 model in LTG shows trends to the year 2100, meaning there was an explicit expectation about progress or, more accurately, the lack thereof during the following one and quarter centuries.

**“That’s how the well-trained mind is known to me...
What you don’t reckon, you think can’t be true.” —Mephistopheles in Faust⁴⁴**

Assume What’s Unseen Doesn’t Exist

And this reflects the belief that progress can’t be predicted, and therefore shouldn’t be counted on to solve problems, as in Kunstler’s earlier comment about techno-grandiosity or the peak oil view: “It’s no use having bland statements about the power of technology,” says Dr. Campbell. “I just want to know where and when.”⁴⁵

There is an analogue in geology, where resource estimates have traditionally made the explicit decision to ignore possible future technological advance; only those resources that could be produced with current conditions would be considered “recoverable,” and enumerated. The USGS, in fact, makes little or no mention of recovery factor, even though improvements in it are important in determining future growth in available resources. But in making those resource estimates, it is not intended to imply that the advances won’t occur, just that they are not being taken into account.

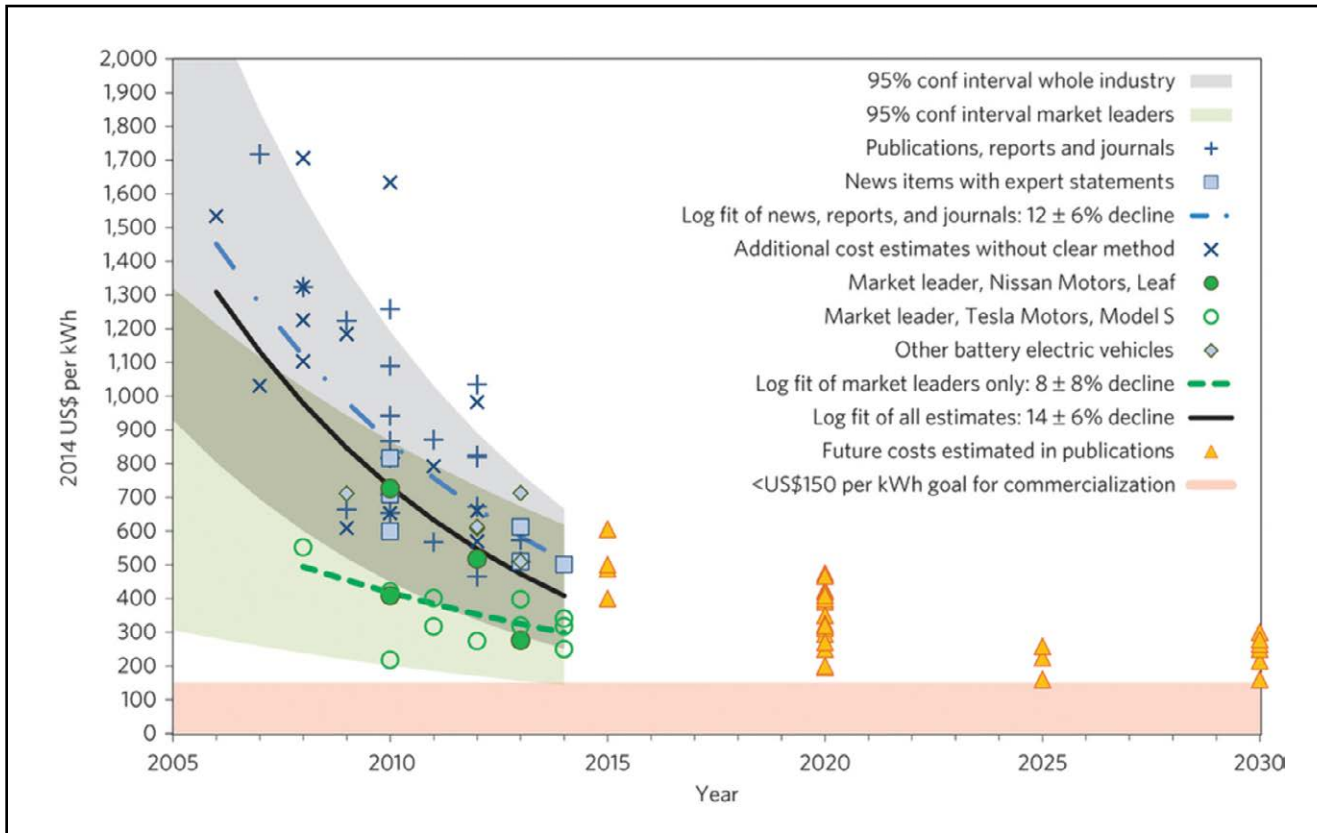
At the micro level, this sometimes comes into play when it is argued that since the success of any given well can’t be predicted, it is not appropriate to assume discoveries will occur when the reality is that, in an oil province with any significant history of discoveries, extrapolating discovery rates into the future is valid, with the understanding that discovery size tends to decline.

Examples of how this led decision-makers astray includes the British Gas policy of importing natural gas from Norway at a price far above what it paid companies producing gas in the British North Sea, refusing to pay them more because even with higher prices you couldn’t predict discoveries, and the U.S. offering elevated prices for imports while keeping domestic natural gas under price controls. Similarly, many LNG importers refused to sign contracts with natural gas producers until they had found sufficient reserves to cover deliveries throughout the entire contract period.

Certainly, there are numerous technological advances that would change the world’s resource outlook, but cannot be predicted. A battery superior to lithium-ion batteries now widely used in electric vehicles might revolutionize the transportation industry and reduce petroleum demand significantly, but predicting such is problematical, especially since apparent breakthroughs have repeatedly failed to prove viable, as Steve Levine describes in *The Power House*.⁴⁶

On the other hand, many are happy to project the *evolutionary* progress in existing batteries (Figure 5), since that reflects the real-world experience throughout the economy, thanks to what Julian Simon called *The Ultimate Resource*, humanity.

Figure 5
Evolution of Lithium-Ion Battery Costs



Source: Nyquist et. al. Nature, cited in <https://www.iflscience.com/technology/battery-costs-drop-even-faster-electric-car-sales-continue-rise/>

The error lies in thinking of progress as occurring primarily in large, discrete, highly visible steps. Sometimes the impact of technological progress is obvious, such as the largely automated telephone system which replaced individual operators making connections or automated teller machines that reduced the need for bank tellers dramatically. Similarly, the Green Revolution in agriculture and the advent of hydraulic fracturing of shale in petroleum production strike many as singular moments in the abrupt transformation of their industries.

For most people, technology appears to involve what Mark Mills calls, “deep transformations, the kinds that define historical epochs,” which he notes is partly due to the perspective of hindsight. As he says, “getting to the moon seemed to happen quickly, but it was 40 years after the invention of the rocket that John

F. Kennedy issued his challenge, and then almost another decade before the 1969 landing.”⁴⁷ In effect, new inventions are typically aggregations of many components in new ways as well as their being improved upon.

Similarly, while the Green Revolution had a large impact on agricultural productivity, an enormous number of other, often minor advances have occurred in the past two centuries. Some, like the mechanization of work or the use of artificial fertilizers, could be listed by any schoolchild. But the many changes in our understanding of seed genetics, soil chemistry, and animal husbandry are less well known. The typical harvester used on a large farm today probably does not include a single part that hasn’t been made better and/or cheaper than one even a few decades ago. What can be seen in the data is the results of all these advances.

EMPIRICAL MEASURES OF PROGRESS

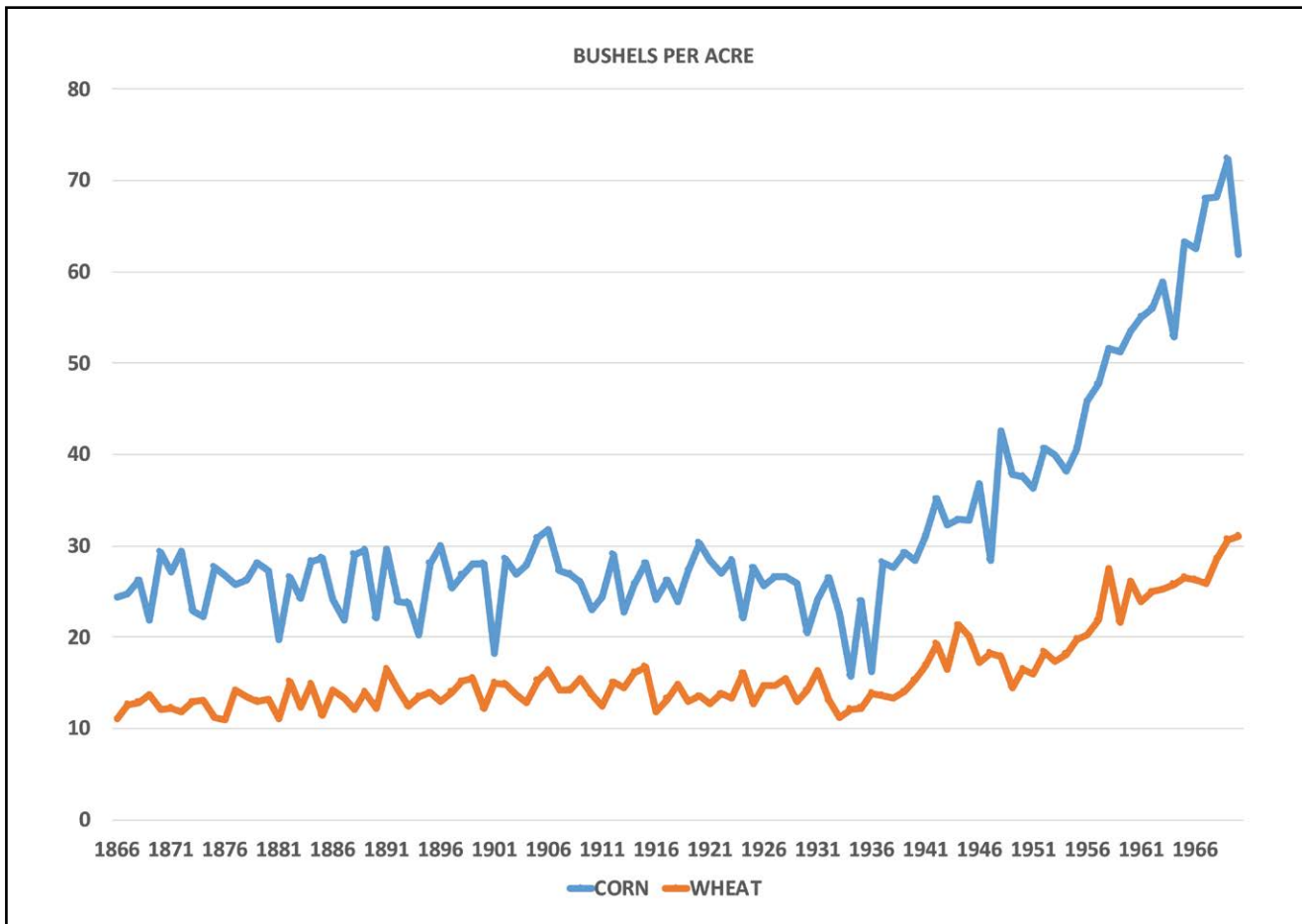
Various estimates of progress have been made, from Robert Solow's seminal work to John Tilton's review of productivity growth in the mineral industries to the U.S. Department of Agriculture's Total Factor Productivity estimates. All find progress, improved outputs relative to inputs, to be irregular but to be the norm across time and space.

And there are longer data series which predate those, although obviously not as reliable. Figure 6 shows the food produced per acre in the United States and Figure 7 shows the bushels per

labor-hour. Labor productivity improved throughout, but production per acre was relatively stagnant in the 19th century, improving substantially after the Great Depression. Wheat produced per acre actually declined by less than 0.1% per year in the 19th century, presumably because the abundance of low-cost (or free) land in the West did not encourage productivity improvements.

Wheat produced per man-hour, on the other hand, improved by 1.2% per year during the century.

Figure 6
Historical Agricultural Productivity in the United States: Bushels per Acre

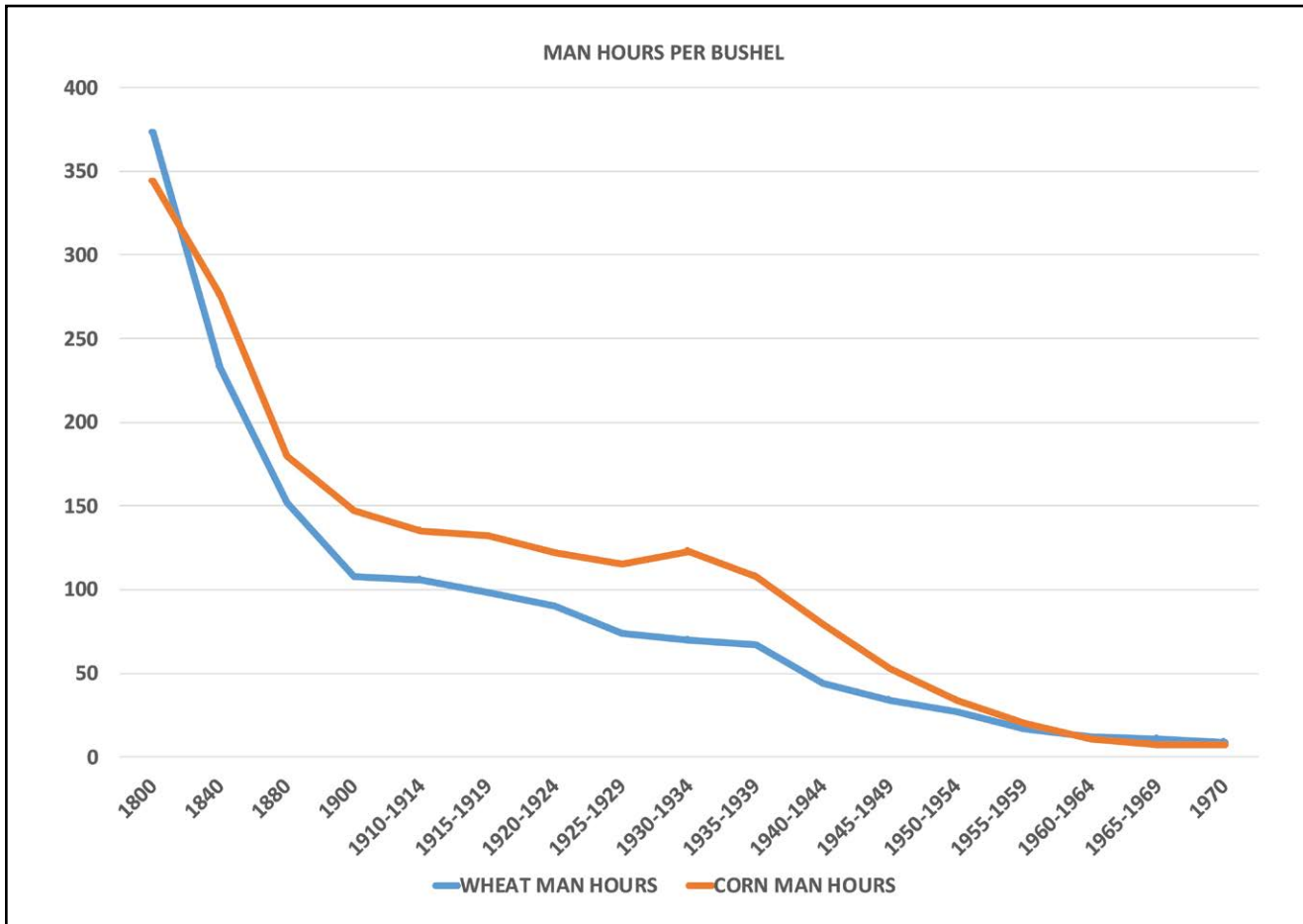


Source: Bureau of the Census, *Historical Statistics of the United States: Colonial Times to 1970*, 1975.

Yields per acre began improving in the post-World War II years, growing by 2.8 percent per year to 1970, while man hour per bushel continued dropping by 6 percent per year. For corn, the numbers are similar, though with less progress before World War II: From 1870, man-hours per

bushel declined by slightly less than one percent per year, while yield per acre increased marginally. From 1939, however, man-hours per bushel declined by 8.5 percent per year, while yields increased by 3.3 percent per year.

Figure 7
Historical Agricultural Productivity in the United States: Labor Hours per Bushels

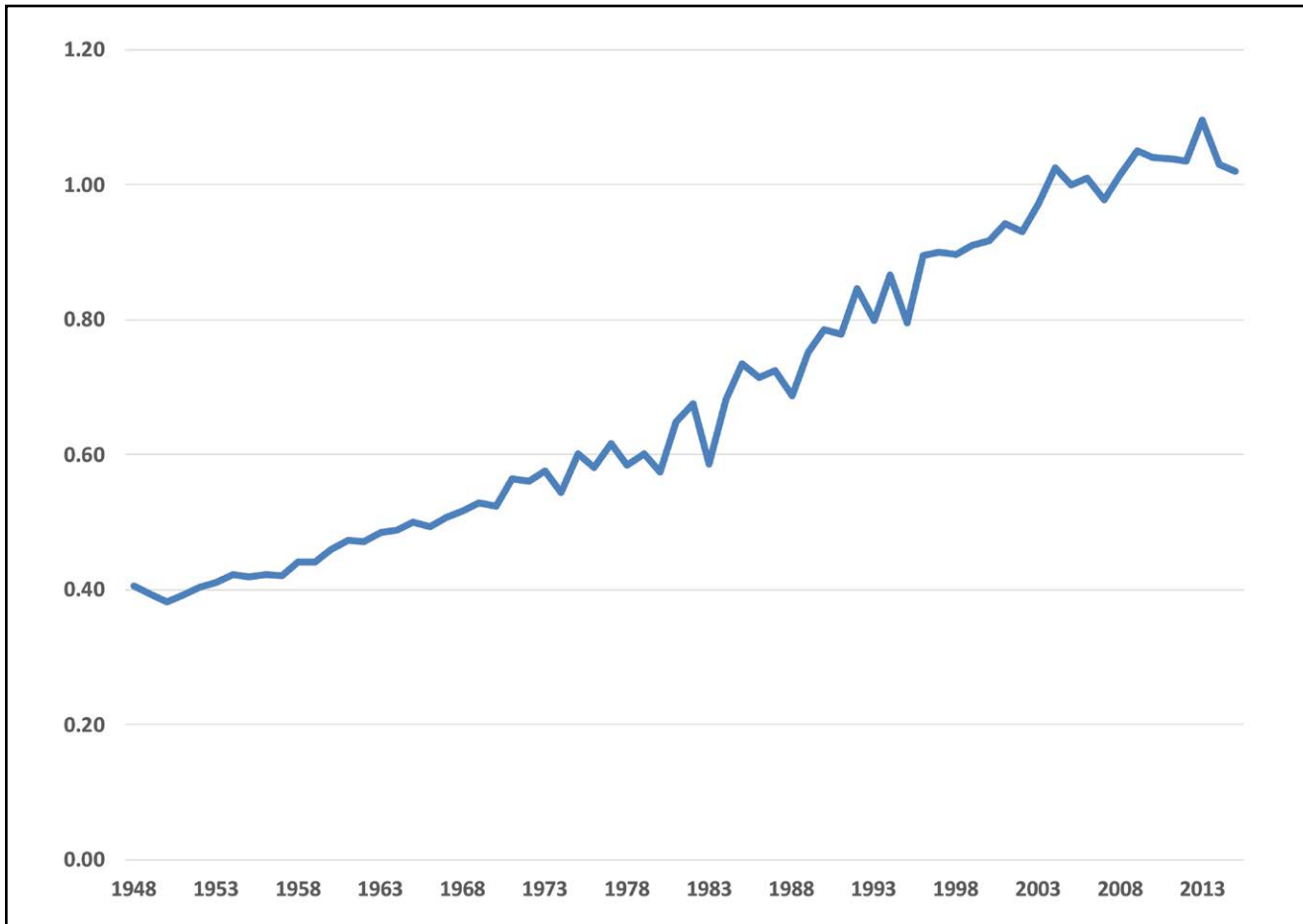


Source: Bureau of the Census, *Historical Statistics of the United States: Colonial Times to 1970*, 1975.

A more sophisticated measure of agricultural productivity in the post-WWII United States is shown in Figure 8, where the U.S. Department of Agriculture has estimated Total Factor Productivity, that is, the results of all inputs and outputs to provide an aggregate measure for the sector. Again,

although there are fluctuations in the data, the results show fairly constant growth of 1.4% per year over the period, and neither a sudden change from a technological revolution or some slowing from decreasing returns to technology is apparent.

Figure 8
Total Factor Productivity for the U.S. Agricultural Sector (2005=1)

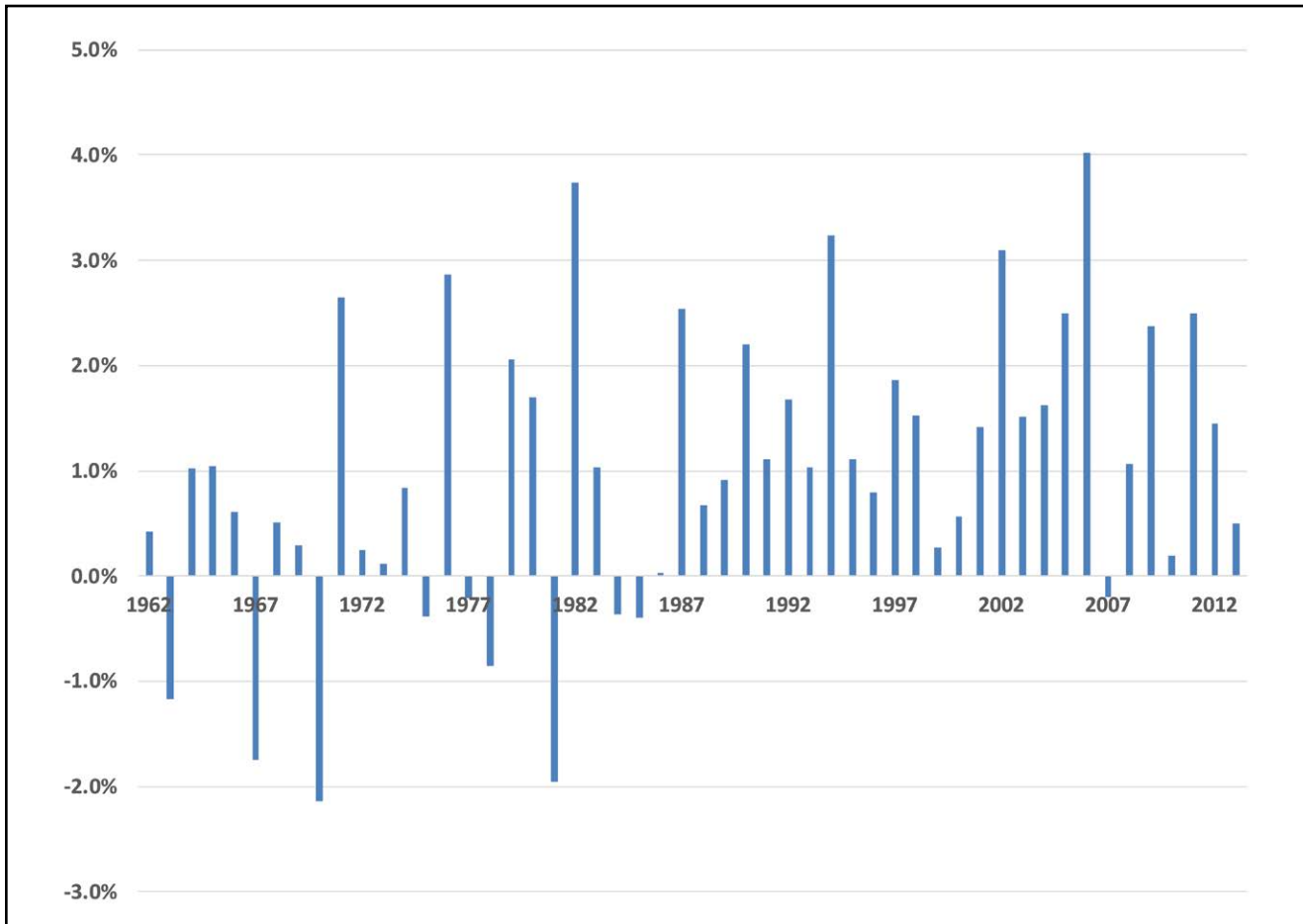


Source: U.S. Department of Agriculture, Economic Research Service.⁴⁸

Despite the presence of any number of governments that hinder more than assist agriculture, the global story is one of widespread progress. As Figure 9 shows, total factor productivity in world agriculture has improved

almost every year since 1961 (the earliest data), and the growth has accelerated since 1989. Before that, progress was about 0.4% per year, afterwards, 1.5% per year.

Figure 9
Annual Change in Total Factor Productivity, World Agriculture

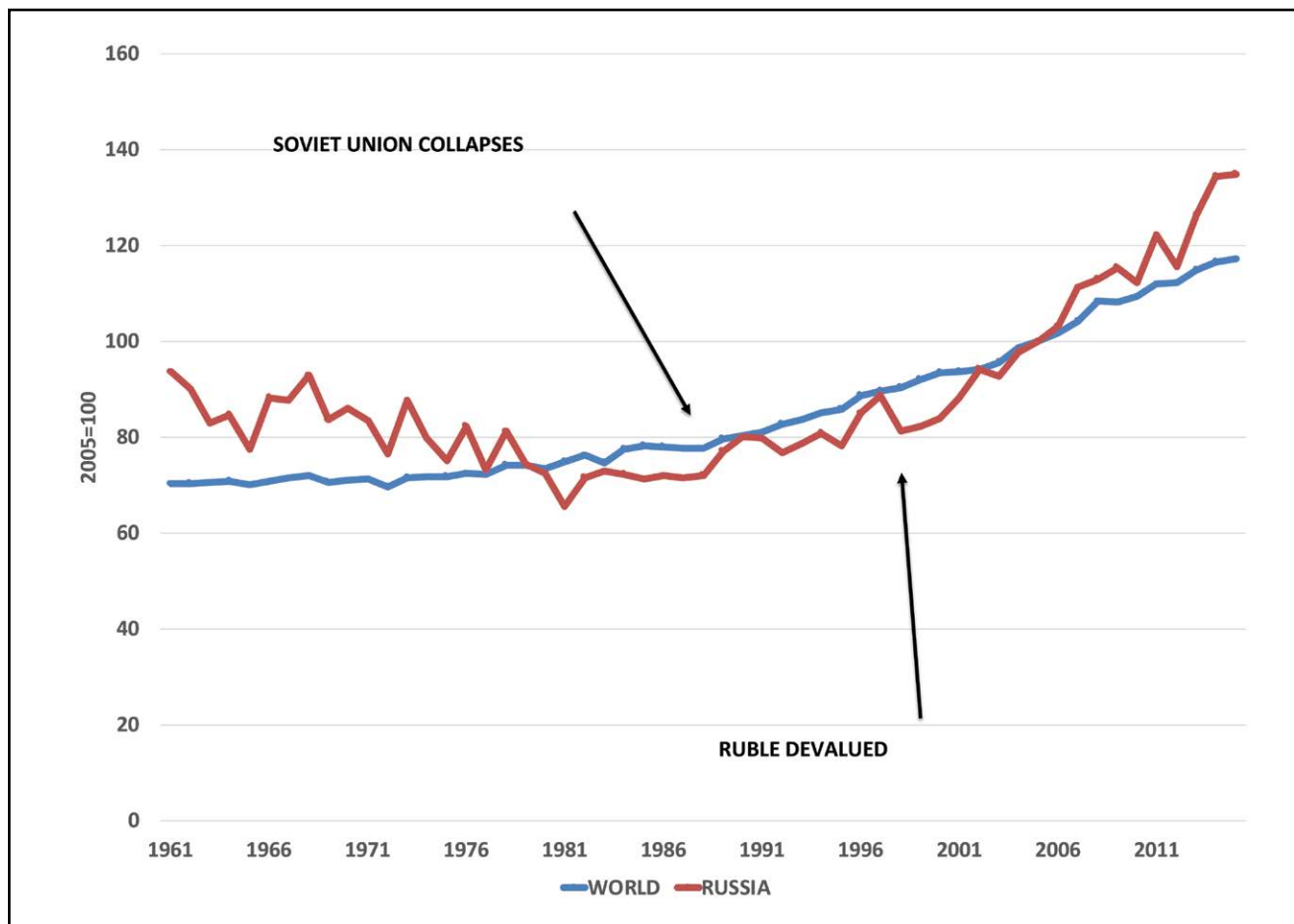


Source: U.S. Department of Agriculture, Economic Research Service.⁴⁹

It is probably no coincidence that the inflection came at about the time of the dissolution of the Soviet Union (1989), as Figure 10 shows

Russian total factor productivity, which began a significant improvement after that year.

Figure 10
Total Factor Productivity, Russia and the World



Source: U.S. Department of Agriculture, Economic Research Service.⁵⁰

To reiterate, from this data, it is impossible to see the impact of any given technological advance. On the other hand, at any given point, it would have been correct to assume that progress would continue into the foreseeable future. For neo-Malthusians to argue otherwise, or that believing it to do so constitutes “Magical Thinking,” is simply mistaken.

Predicting Progress and the End Thereof

From the Christian Book of Revelations to those thinking the Mayans predicted the world would end on December 21, 2012, an apocalypse and a devastated world has often been predicted, while reality has been more mundane. However, the arguments that technological progress cannot continue as before appears based on little more than assumption, rather than a specific prediction that

progress will cease or explanation for why it would.

True, some scientists have argued that the major advances are all behind us, between the discovery of DNA and quantum mechanics, and that all future progress will be merely tinkering on the edges or, so to speak, engineering. But it isn’t necessary to have such breakthroughs to continue improving results: gene editing has helped but so have many other aspects of agriculture, including simple empirical research into optimal fertilizer levels, for example.

This presumption that progress will cease is hardly new: one can imagine a New Yorker cartoon with cavemen looking at the wheel and fire and insisting they’ve done it all. Anecdotes abound of predictions that progress and discovery will end, such as a young Max Planck being advised in 1875 against studying physics as all discoveries

had been made.⁵¹ Or the oft-quoted but apparently apocryphal statement that no more patents were needed as everything had already been invented.⁵² The debunker of that myth does, however, note the comment in Ecclesiastes that “there is nothing new under the sun.”

The circumstances under which progress would cease boil down to some form of catastrophic collapse of civilization, in which case the remaining population will have plenty of resources, or

possibly a more or less global authority whose ideology, religious or otherwise, forbids research. This seems unlikely outside of the world of fiction. True, the Catholic Church banned the work of Copernicus, but the Pope now flies in airplanes. Even Mullah Omar of the Taliban had a satellite dish and Range Rover. No government since the Khmer Rouge has successfully turned back the technological clock, and it seems all but impossible now.

How can progress be modeled? Years ago, Nobel Prize winner Robert Solow demonstrated the contribution of technological progress to economic growth, in part by estimating the unexplained remainder after the contributions of capital and labor had been analyzed. But even now, the precise impact of computers on productivity and economic growth remains debated, and it is more common to observe progress through its impacts, such as total factor productivity analysis, rather than estimating the effect of specific advances.

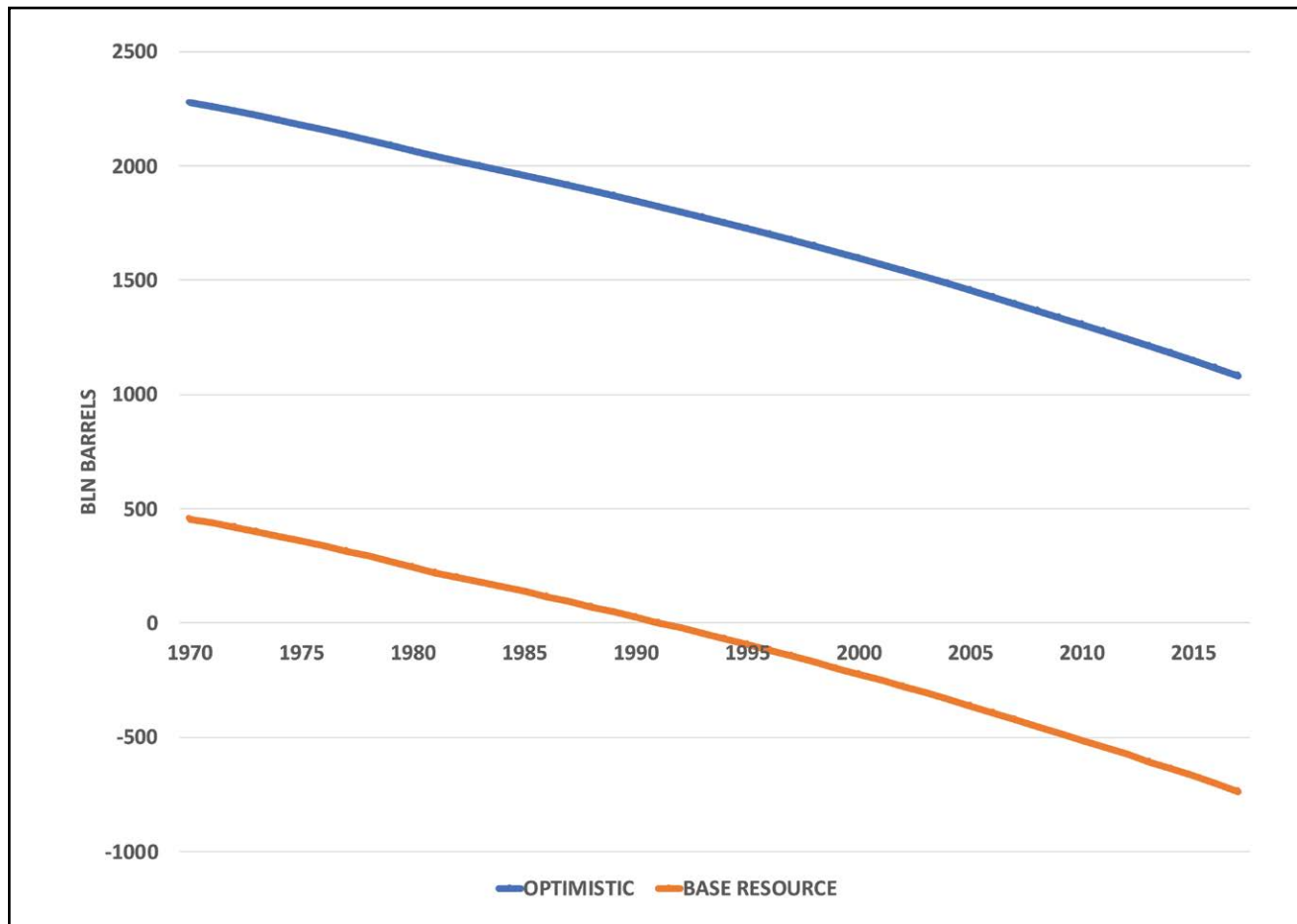
Perhaps because *The Limits to Growth* authors, who published in 1972, were explicitly modeling the world economic system, they were forced to be more explicit about their treatment of technological progress, best summed up by, “When we introduce technological developments that successfully lift some restraint to growth or avoid some collapse, the system simply grows to another limit, temporarily surpasses it and falls back.”⁵³ In other words, technological progress is not treated as an ongoing process, but rather a one-time impact, increasing the amount of resources assumed available when the model begins. So, population and economic growth are dynamic, but technology—and resources—are static.

Energy forecasters currently tend to use a

measure such as ‘autonomous energy efficiency improvement’ to allow for technological advance which improves energy efficiency without explaining the particular changes. This aggregate measure is somewhat reminiscent of economists arguing that if the oil price goes up, supply will increase, without actually projecting specific discoveries; it differs in that they at least are using an explicit independent variable rather than assuming an ongoing level of discovery. This has proved to be a valid approach to modeling oil supply, just as though you cannot predict the next advance in, say, kale seeds, you can easily assume that there will be progress in agriculture similar to that which has occurred over past decades.

In essence, the neo-Malthusian model takes resources as fixed and consumption as growing exponentially, so that available resources decline at an increasing rate. Clearly, in this stylized model the resource depletes quickly to zero as consumption continues to rise, but no adjustments occur to the initial resource endowment. In other words, the resource currently remaining is equal to the original resource, minus the sum of production from time zero to the present. Taking the case of oil and using the resource numbers from LTG, the results are shown in Figure 11.

Figure 11
Oil Resources in the LTG Model

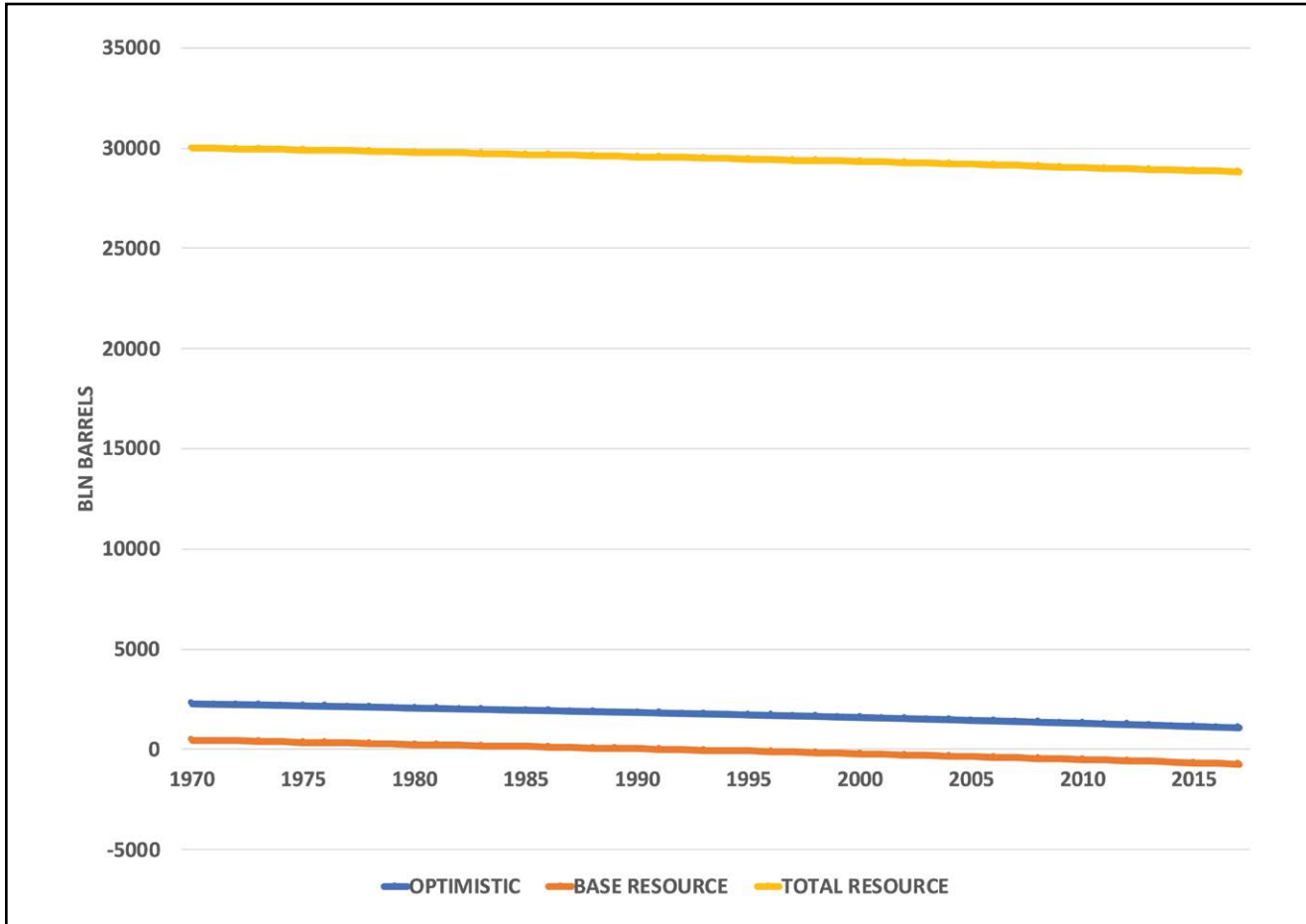


Source: Production data from BP Statistical Review of World Energy 2018.

Two corrections should be made to this flawed approach. The first is to recognize that the total petroleum resource is much greater than the amount thought recoverable at any given time (and with then-existing conditions). As mentioned, the resource in place is somewhere near 30 trillion

barrels, including heavy oil and shale oil, but not oil shales (kerogen). In other words, instead of using a value of 455 billion or 2,275 billion as the LTG authors do, the problem recedes into insignificance, as Figure 12 shows.

Figure 12
Oil Resources in the LTG Model with Corrected Initial Resource Estimate

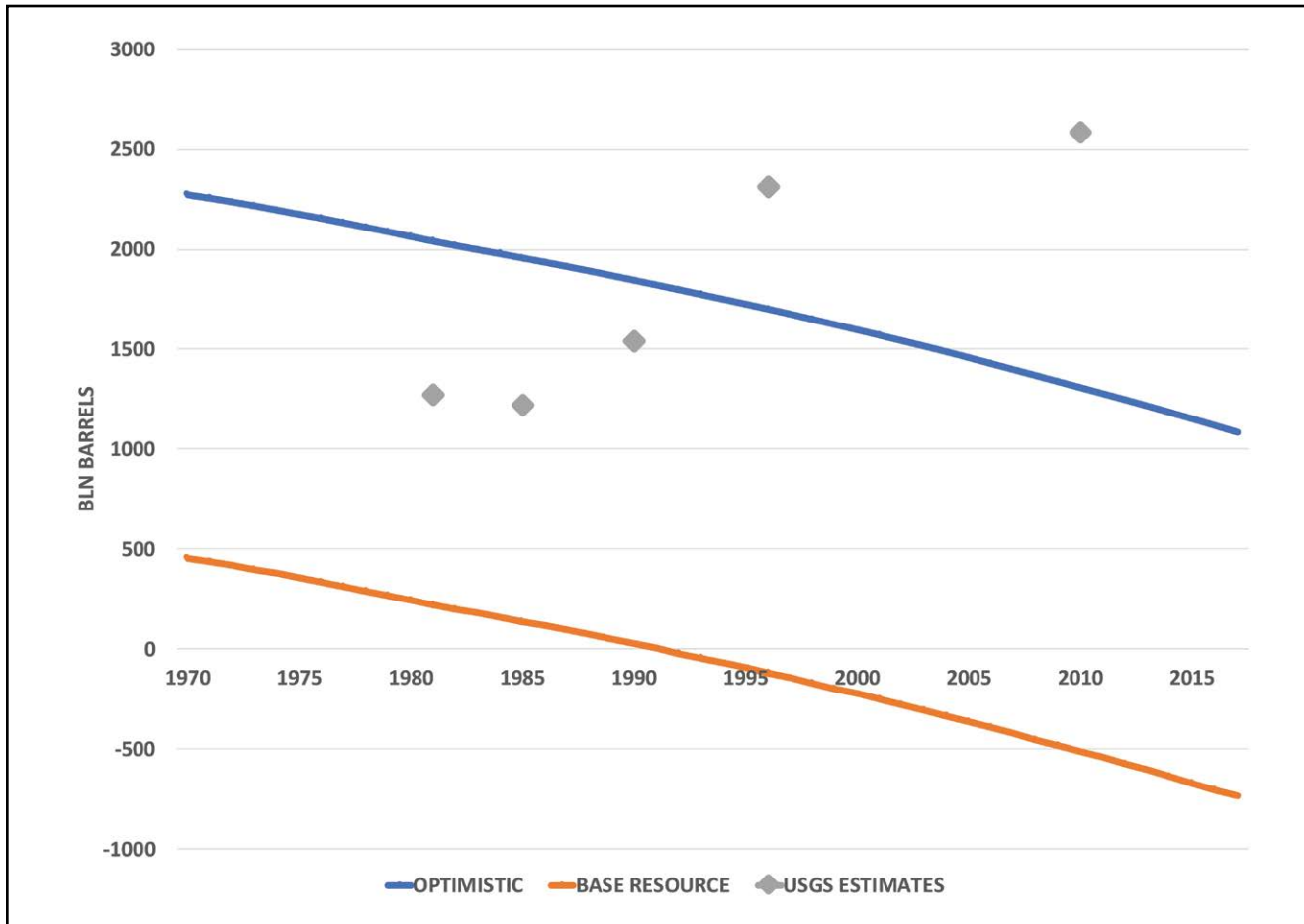


Source: Ibid and Lynch (2016).

Alternatively, a more empirical approach would involve showing how estimates of increasing recoverable petroleum resources compare to those that the LTG team projected. The initial resource endowment would represent not the recoverable resource but the total resource, and total current resource would be the remaining recoverable resource at any point in time. Here the pessimistic outlook is reinforced by failing to understand that the recovery factor improves over time.

The impact of failing to examine improved recovery factors can be seen in Figure 13, where the actual USGS estimates of undiscovered oil is added to estimates of existing reserves, and the reality, as some have said, is that the world is “running into oil” not out of it. Again, these numbers do not include shale oil, which is likely to double the recoverable resource base as well as kerogen, which would add a sizeable fraction more.

Figure 13
Recoverable Oil Remaining with Dynamic Recovery Factor



Source: Ibid.

Quantitatively, while world oil demand grew by 1.4% per year from 1981 to 2017, the estimated recoverable resource base grew by 2.4% per year. Ultimately, then, the amount of recoverable resource remaining has increased faster than consumption and petroleum is actually more abundant than when the LTG authors warned of scarcity.

This is in many ways at the core of the debate between neo-Malthusians and Cornucopians, where the latter believe that technological progress can overcome the constraints of resources, while

the former argue against it, as Charles Mann described in his book *The Wizard and the Prophet*. In some ways, it's a question of connecting the micro and the macro. Specific and unique advances in technology can have an outsized effect on performance of the national economy. However, many analysts are reluctant to build general progress into their assessments of future performance of petroleum production or the national economy because these advances cannot be easily identified or foreseen.

Neo-Malthusians also exhibit other errors. Interesting, while neo-Malthusians believe that one shouldn't take the long-term trend in progress as given, they are prone to a similar, but inverse, mistake: they extrapolate from short-term events into the long-term. Illuminating examples include the Ehrlichs' 1968 *The Population Bomb*, where they highlighted two bad harvests in 1965-66 while chiding optimists⁵⁵ for emphasizing short-term population trends.

More recently, an unusual confluence of bad harvests in the Ukraine, Australia and other areas led to a spike in food prices in 2007/2008, which contributed to renewed fears of scarcity. The Center for American Progress published an article claiming, "Food prices and political instability are rising sharply in a world agricultural system that is in transition and under pressure from changing diets, market turmoil, and rising energy costs."⁵⁶

Many neo-Malthusians talk of their fear of exponential growth, whether it is the Ehrlichs' concern that the human population, left unchecked, would cover every square inch of the solar system in only 200 years, or the LTG authors description of a lily pad that doubles in size every year until it covers the pond it's in and kills its aquatic life. But this type of extrapolation, while possibly an interesting intellectual exercise, has little bearing on the reality of demographic or economic systems.

This is evident from the failure of so many projects that rely on extrapolation, whether the

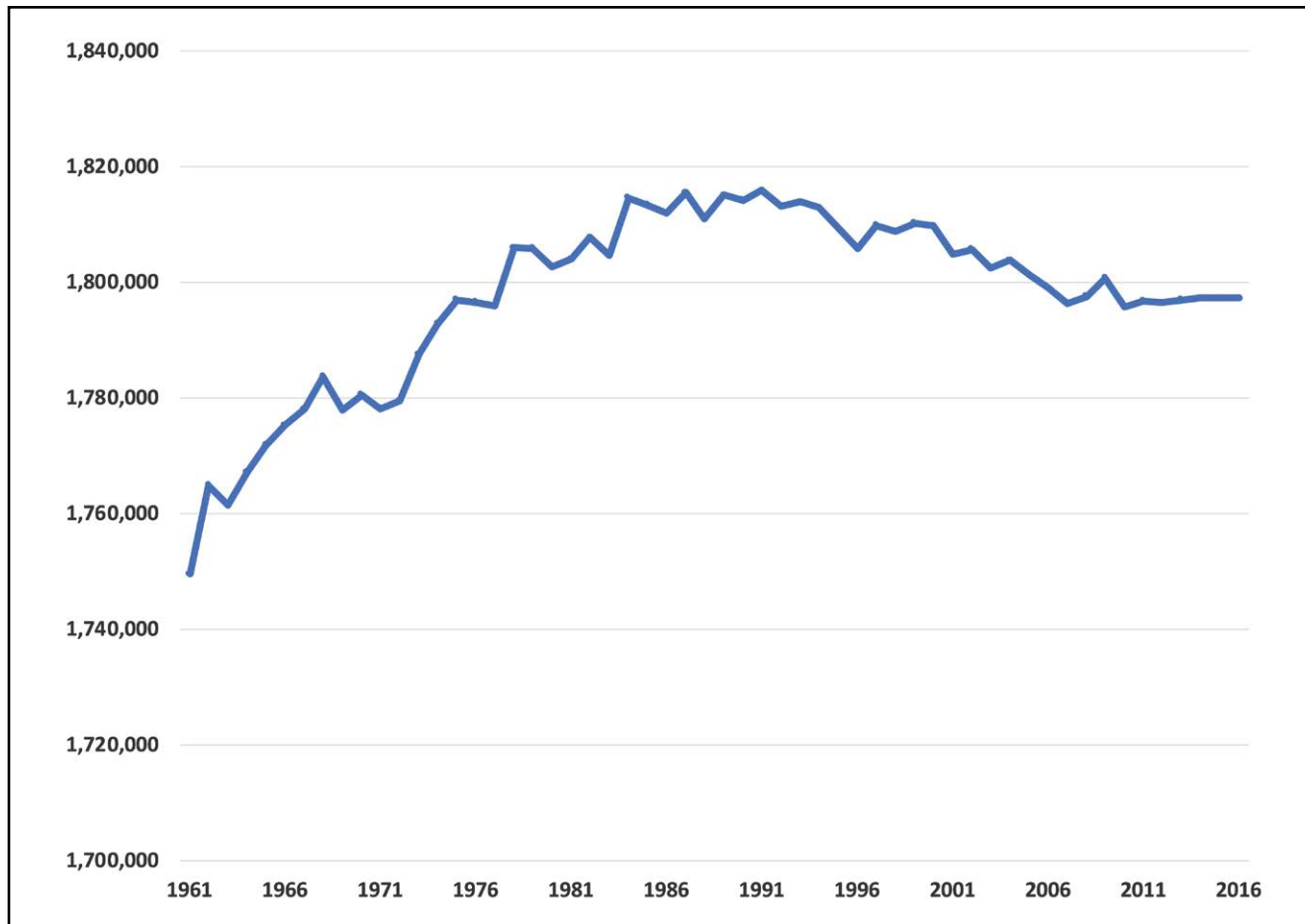
LTG modeling of resource consumption or the peak oil advocates belief that oil production, once in decline, could be extrapolated to a zero point, regardless of the source of the decline. This simplistic approach is equivalent to noting the reproductive power of mice and thinking that in ten years, there would be four billion mice and in twenty years, four trillion mice per person.

But that ignores countervailing variables, such as death by all causes including predators and old age. Or, based on the amount of oxygen in the Earth's atmosphere and the average amount consumed when a human breathes, predicting an end to oxygen supplies in five million years.

Not accounting for the generation of atmospheric oxygen by plants creates a false (if not too scary) impression.

The simplest example of the effect of omitted variables on resource modeling can be found in the fears of topsoil erosion. Fears that soil erosion will become a major constraint on agricultural productivity have long been typical of neo-Malthusians, with Ehrlich et al. in *Ecoscience*⁵⁷ commenting, for example, "It is estimated that half the farmland in India is not adequately protected from erosion, and on fully one-third of the farmland, erosion threatens to remove the topsoil completely." How did this work out? Figure 14 shows the arable land in India, which is now virtually identical to the amount in 1977, when *Ecoscience* was published.

Figure 14
Arable Land in India (sq km)



Source: World Bank.⁵⁸

The issue is addressed in Odum (et al.)⁵⁹ who describes the net loss of earth as erosion minus formation rate. However, the more important fact is not replacement of topsoil through formation from the underlying material, but the transfer of eroded topsoil to other arable land. Approximately 95% of topsoil is estimated to have originated elsewhere.⁶⁰ That is, much of the material that erodes simply replaces eroded material at other sites, so that net erosion is far smaller than the pessimistic estimates.

Other feedback effects can be important as well. Most notably, technological advance greatly increases the amount of resources, the efficiency of their production and use, but also the availability of substitutes. The decision by 19th century billiards champion Michael Phelan to put forward a prize for a synthetic billiard ball helped to extend the ivory resource base and reduce poaching, at least for a

time.⁶¹ (It can only be hoped that something similar is done for current ivory demand.)

Similarly, the copper resource was not used up in 36 years, as LTG suggested, because zinc was added to pennies in the U.S. and fiber optics replaced many copper cables. The 31 years of petroleum resources they assumed were, in part, replaced by natural gas, coal, and nuclear power and possibly in the future, electricity from those and other sources such as solar and wind (which are finite in theory, but in practice, not so much).

The Omitted Policy Variable

Many arguments have been put forward to explain differing rates of economic progress, from Jared Diamond’s ecological theory in *Guns, Germs and Steel*⁶² to Joel Mokyr’s *The Levers of Riches: Technological Creativity and Economic Progress*,

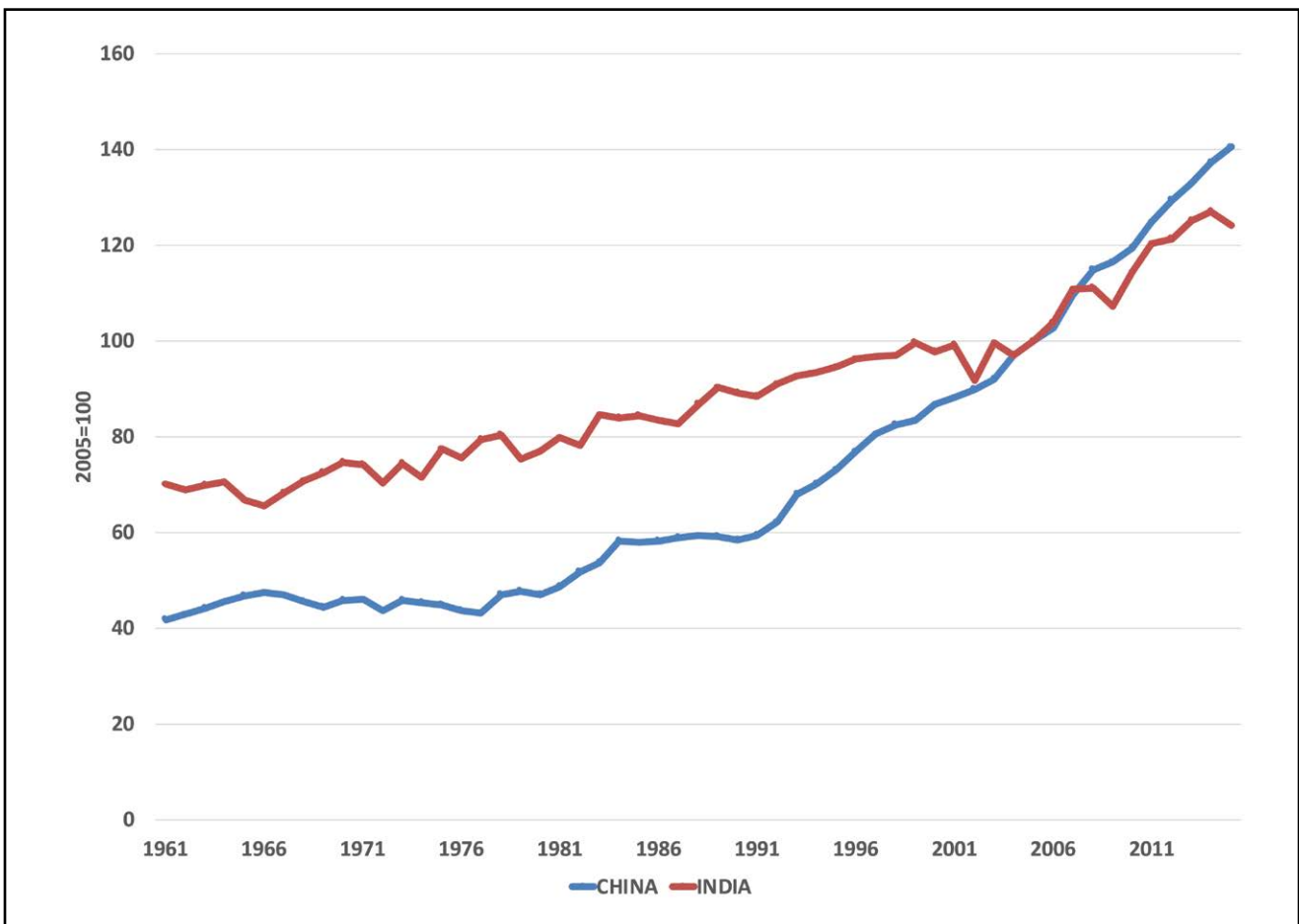
which shows the impact of the policy or regulatory environment on encouraging innovation.⁶³ Few would disagree that government policy matters, but at least some neo-Malthusians drastically misinterpret the effect.

For example, *Ecoscience* put forth the argument that the policy environment in Maoist China was favorable for agricultural productivity, stating, “Behind China’s success in raising agricultural productivity lies its unique social and economic system, which has been designed to provide maximum incentive for production of food or factory output....”⁶⁴ Adding, two pages later, “It is a strange irony that the potential for further

raising of food production is probably considerably less in China than in India, precisely because so much has already been accomplished.”⁶⁵

The reality is very different. Figure 15 shows Chinese and Indian total factor productivity since 1961, and beyond a doubt, Chinese productivity accelerated after the late 1970s (and the 1977 publication of *Ecoscience*) but mostly subsequent to the death of Mao and introduction of broad reforms which reduced central government control and interference. It would appear obvious that, while the centralized control of agricultural production generated some increases in output, it was at the cost of greater inputs, not productivity.

Figure 15
Total Factor Productivity in Agriculture for China and India



Source: U.S. Department of Agriculture, Economic Research Service.⁶⁶

The case of Russia reinforces the point. As we saw above, in the nearly three decades before the collapse of Communism and the Soviet Union, Russian agricultural productivity was actually declining. Afterwards, the combination of reform and the 1998 ruble devaluation led to a very noticeable acceleration in productivity gains. Conceivably, there might have been a coincidental improvement in long-term weather trends after the fall of the Soviet Union, but that would be a mighty coincidence indeed.

There would appear to be a political bias at work here. The Great Depression saw the belief in liberal circles in the need for the government

to stabilize commodity markets, especially for agricultural products but oil and gas as well (mostly by the Texas Railroad Commission and its fellows). The 1970s, as mentioned, saw some intellectuals argue that markets were not correctly setting energy prices. More recently, the 1990s saw a surge in promotion of industrial policy, whereby the U.S. government would guide industries to accomplish, for example, the Japanese economic miracle.⁶⁷ Many neo-Malthusians such as the Ehrlichs and Holdren appear to favor government as the source of progress, which enhanced their pessimism about future progress in authoritarian countries like China.

It has been argued that even following bad neo-Malthusian policy prescriptions can yield positive results by imposing a conservative constraint on resource usage. Thus, expecting mineral production to peak soon can encourage the resource-owning government to avoid spending all its revenues now, minimizing the effect of the resource curse. Unfortunately, this tends to be offset by the tendency for neo-Malthusians to produce optimistic price predictions which encourage aggressive spending patterns by governments (most of whom need little encouragement to do so, to be sure).

The negative impact of such can be seen in cases like that of the Mexican national oil company, PEMEX, which was “one of many producers poised to benefit from steadily climbing prices as the global industry, before the shale boom, faced ‘peak oil,’ the assumption that most of the world’s supply was known and diminishing.”⁶⁸ When oil prices fell in 2014, it went into a tailspin, with massive layoffs and diminishing investment.

Indeed, some governments have been advised that leaving oil in the ground is a better economic policy than producing it and banking the surplus revenue, on the grounds that oil prices will rise faster than interest rates.⁶⁹ (This is a separate argument from El Mallakh’s discussion⁷⁰ of absorptive capacity which argued that some countries were not capable of absorbing rapid increases in mineral revenue due to lack of infrastructure and industrial and human capital.)

But keeping oil in the ground is only profitable when the right time periods are analyzed, that

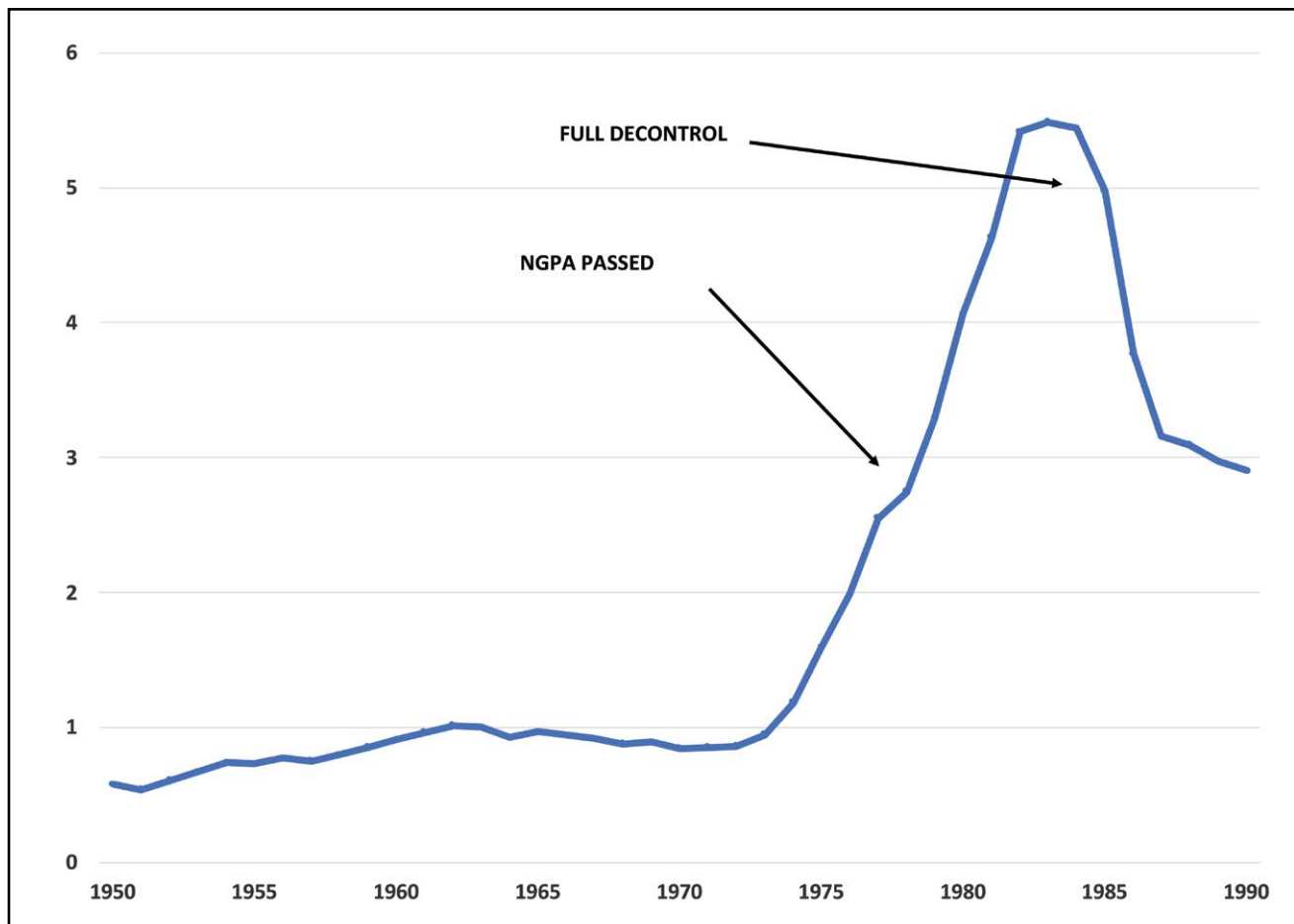
is, starting when oil prices are relatively low and ending when they have spiked. However, no investments are made ex post facto and mineral prices show no long-term tendency to increase, and certainly not above the rate of interest.

The inverse of leaving resources in the ground was the way significant amounts of money were wasted on unneeded energy resources, especially after the 1970s oil crises, from fast breeder reactors to exploration in the Canadian Arctic and synthetic fuels projects (gas to liquids, coal to gas and oil shale mining). The last was even indulged in by some major corporations with nearly all the investments wasted, which explains why so few big oil companies have embraced the peak oil theories. (Lynch 2016 chapter 3)

Conserving Scarce Natural Gas

Undoubtedly the most egregious energy policy mistake stemmed from a belief that natural gas resources were very limited, and its consumption needed to be restricted to so-called “noble uses” (not power generation). In the mid-1970s, natural gas was short in the United States because of decades-long price controls (see Figure 16), and elsewhere in the world because the infrastructure to deliver gas from remote sources was not developed. The Carter Administration, which began gradual price deregulation in 1978 with the Natural Gas Policy Act (NGPA), and the International Energy Agency both encouraged the consumption of coal for power generation instead of gas, resulting in billions of tons of additional CO₂ emissions, along with those of heavy metals and other pollutants.

Figure 16
U.S. Natural Gas Average Wellhead Prices (2017\$/Mcf)



Source: Energy Information Administration.

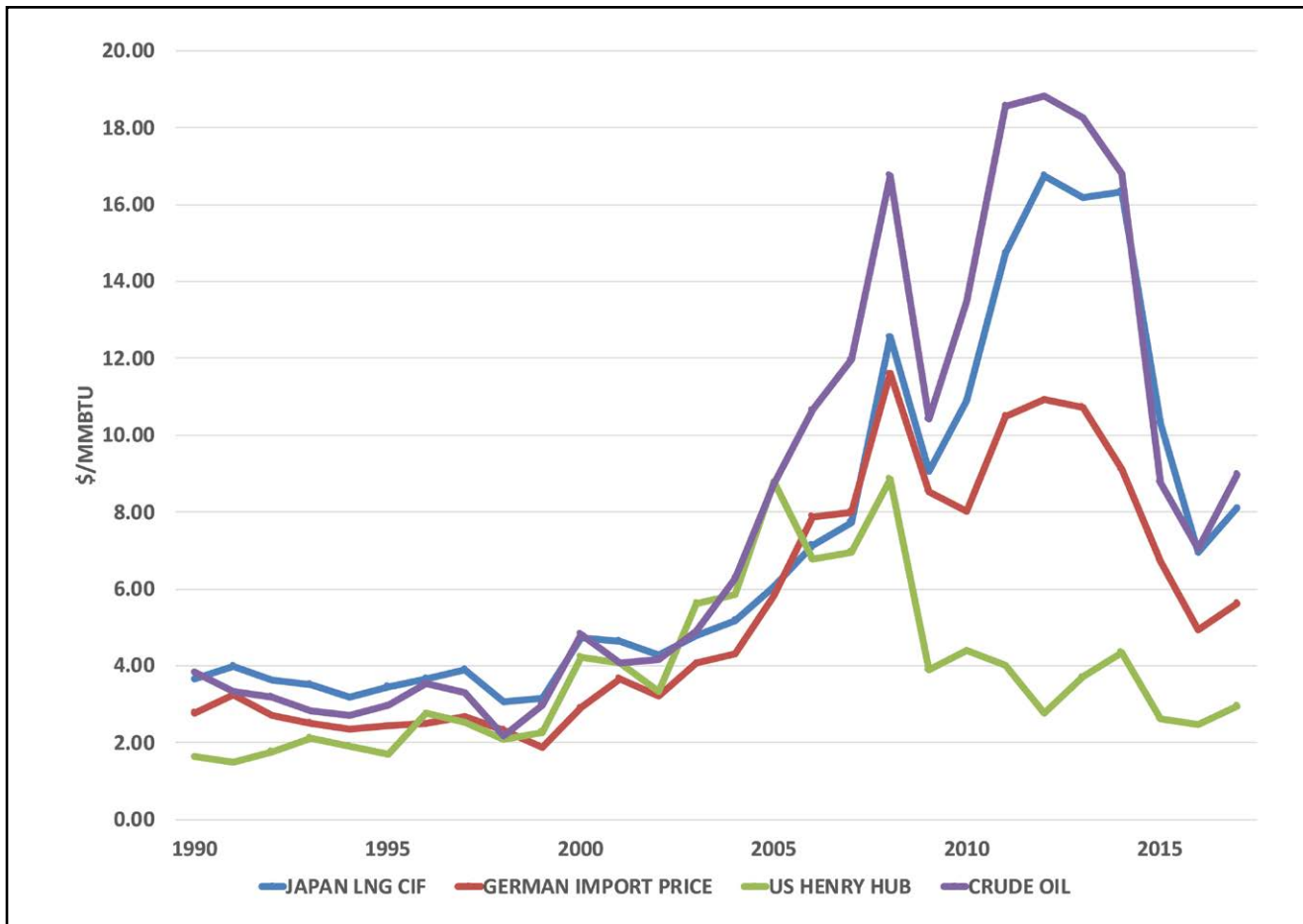
Additionally, billions were spent (and many more billions of investment planned) on projects to bring unconventional or expensive gas to markets. The most egregious project was the Alaska Natural Gas Transportation System (ANGTS), a 3500 mile pipeline intended to bring natural gas from the North Slope of Alaska to the continental United States at a cost of \$30 billion, by far the biggest energy project at that time and, for the most part, since.

The U.S. also wanted large-scale development of synthetic natural gas by converting coal-to-methane at the Great Plains Synfuels Plant in a throwback to the early days of the industry, when “town gas” was produced in many cities in the 19th century (and some in the 20th) from coal.

This was built at a cost of \$4 billion and continues to produce small quantities of natural gas, but the project was never economically viable.

Additionally, many countries signed contracts for natural gas imports at oil-related prices, as Figure 17 shows, on the grounds that oil and natural gas were roughly equivalent fuels or that producers deserved as much money for natural gas as oil, rather than the market equilibrium price. Since there have been, until recently, relatively few natural gas exporters, oligopolistic behavior allowed them to continue this practice for decades. Aside from enriching producers, the practice kept natural gas prices artificially high in much of the world and thus reduced its competitiveness with oil and coal.

Figure 17
Natural Gas and Crude Oil Prices



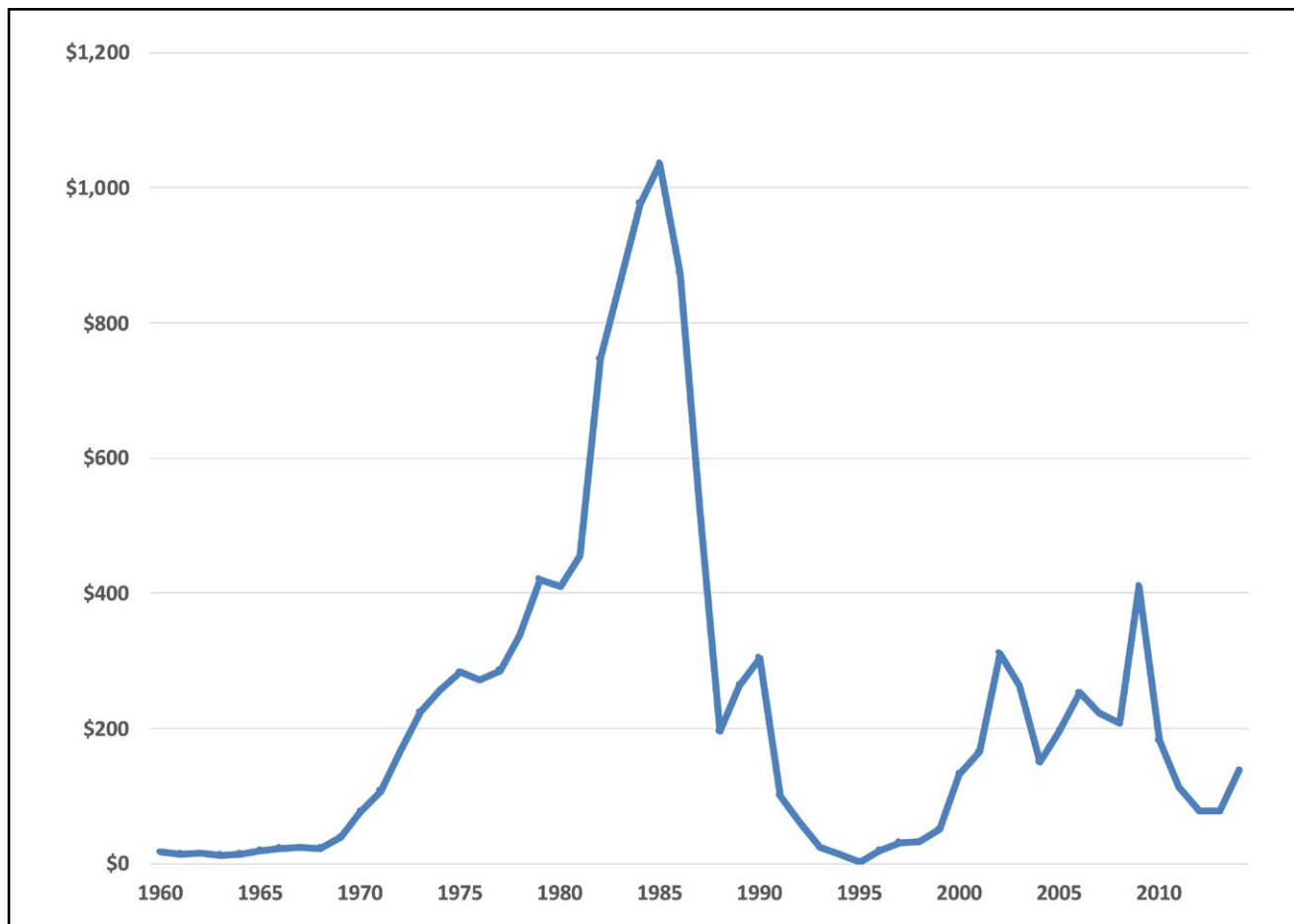
Source: EBP Statistical Review of World Energy, 2018.

Canadian Oil and Natural Gas

Two policies related to petroleum were implemented in Canada that reflected a belief in the scarcity of resources which both resulted in significant economic waste. For one thing, the federal government, believing that market prices were not correctly reflecting scarcity, decided to

accelerate development of Arctic resources by heavily subsidizing exploration there after the 1979 Iranian Oil Crisis. As Figure 18 shows, exploration investment reached a peak of over \$2 billion in 1984 (2015C\$) for the Northwest Territories which primarily involved drilling in the Arctic.

Figure 18
Canadian Exploration Expenditures in the Northwest Territories



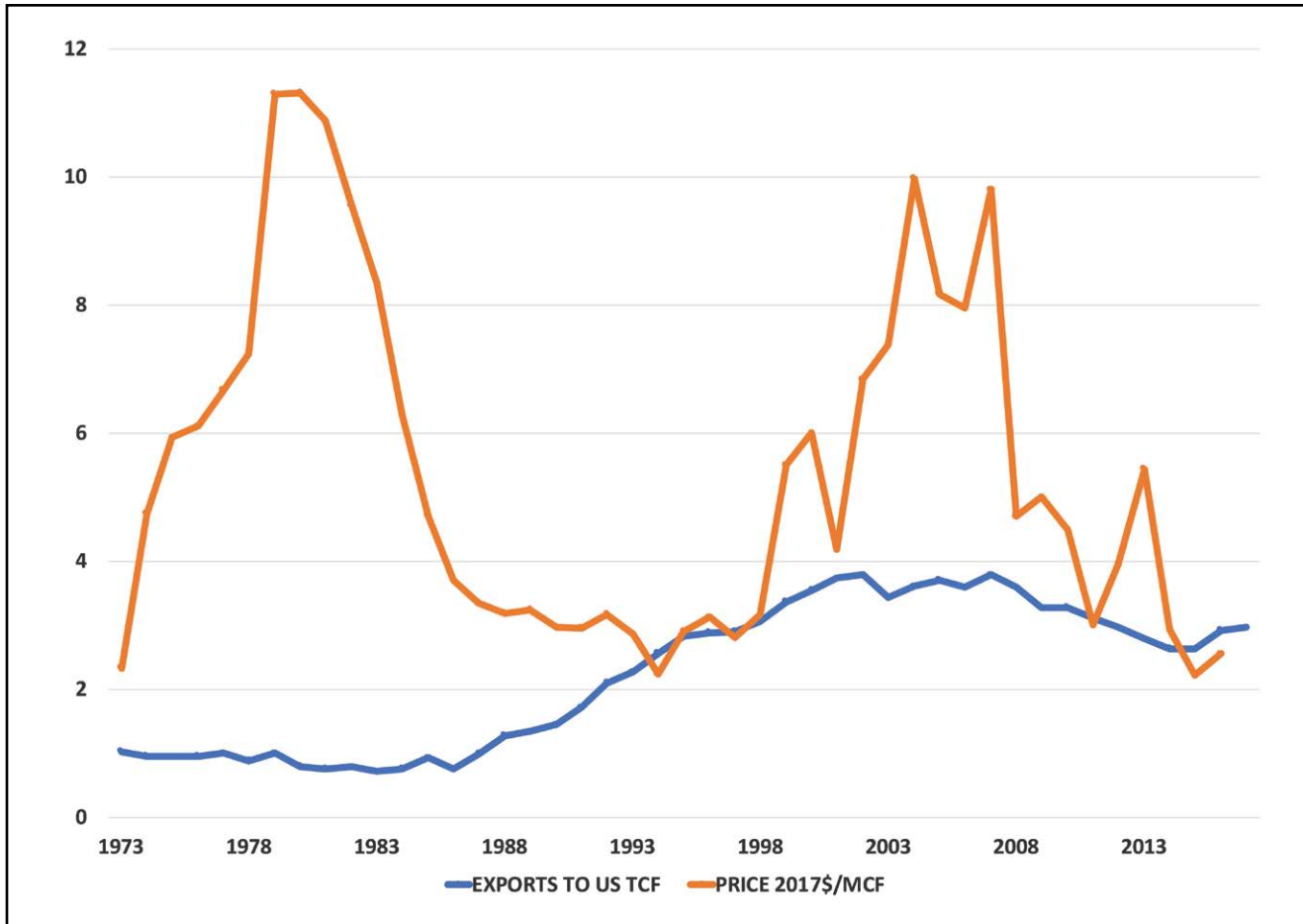
Source: Canadian Association of Petroleum Producers.

On natural gas, the policy of misinformed conservation preceded that of the United States. Concerned about having sufficient natural gas for its citizens' needs (including industry), the Alberta Conservation Board in the early 1950s estimated that existing reserves were insufficient to meet the province's needs in the coming three decades, and so no exports were permitted. This was later modified to requiring reserves to meet twenty-five

years of future demand, which the industry was ultimately able to meet.⁷¹

Thus, as Figure 19 shows, U.S. gas imports from Canada were relatively low during the period of highest prices, and when prices declined in the early 1980s, a more liberal provincial policy allowed the industry to boost exports enormously. The economic losses from discouraging sales until after prices dropped were significant.

Figure 19
Canadian Gas Exports to the U.S.



Source: U.S. Energy Information Administration. (which would be over 90% Canadian).

Next Generation Nuclear Power

In the 1970s, it was thought that the Fast Breeder Reactor was the solution to the problem of finite uranium resources, as it produced more nuclear fuel than it consumed by irradiating its fuel rods and increasing the burnable isotope. As one study explained, “The most common argument presented by Japan for closing the fuel cycle is that uranium resources on a global basis will eventually be limited....”⁷²

But in fact, uranium resources were never scarce, rather reserves were. After a spate of exploration aimed at finding reserves for atomic-bomb programs, demand for the mineral dropped off by the 1960s and minimal exploration translated into minimal discoveries. Then, as extremely

optimistic nuclear power programs proliferated in the 1970s, (the Shah of Iran planned to build 23 Gigawatts of capacity, for example), the existing reserve base looked woefully inadequate. As Table 4 shows, in 1975, after the first oil crisis boosted expectations for nuclear power, there was only 1.8 million metric tons of reserves known in the world.

But partly in response to expectations of higher demand and partly due to much higher prices (the result of extraneous political developments), the price of uranium soared sending geologists scrambling for new deposits. Which were duly found and led to a three-fold increase in resources. At present, inferred resources in situ are estimated at 10.7 million metric tons of metallic uranium.⁷³

Table 4
Recoverable Uranium Resources Over Time (thousand metric tons)

	Reasonably Assured Reserves and Resources	Additional Reserves and Resources	TOTAL
1967	1064	957	2021
1970	1222	1128	2350
1973	1549	1536	3085
1975	1816	1688	3504
1977	2194	2097	4291
1979	2572	2470	5042
1981	2288	2709	4997
CURRENT			10653

Source: Neff (1984); World Nuclear Association.

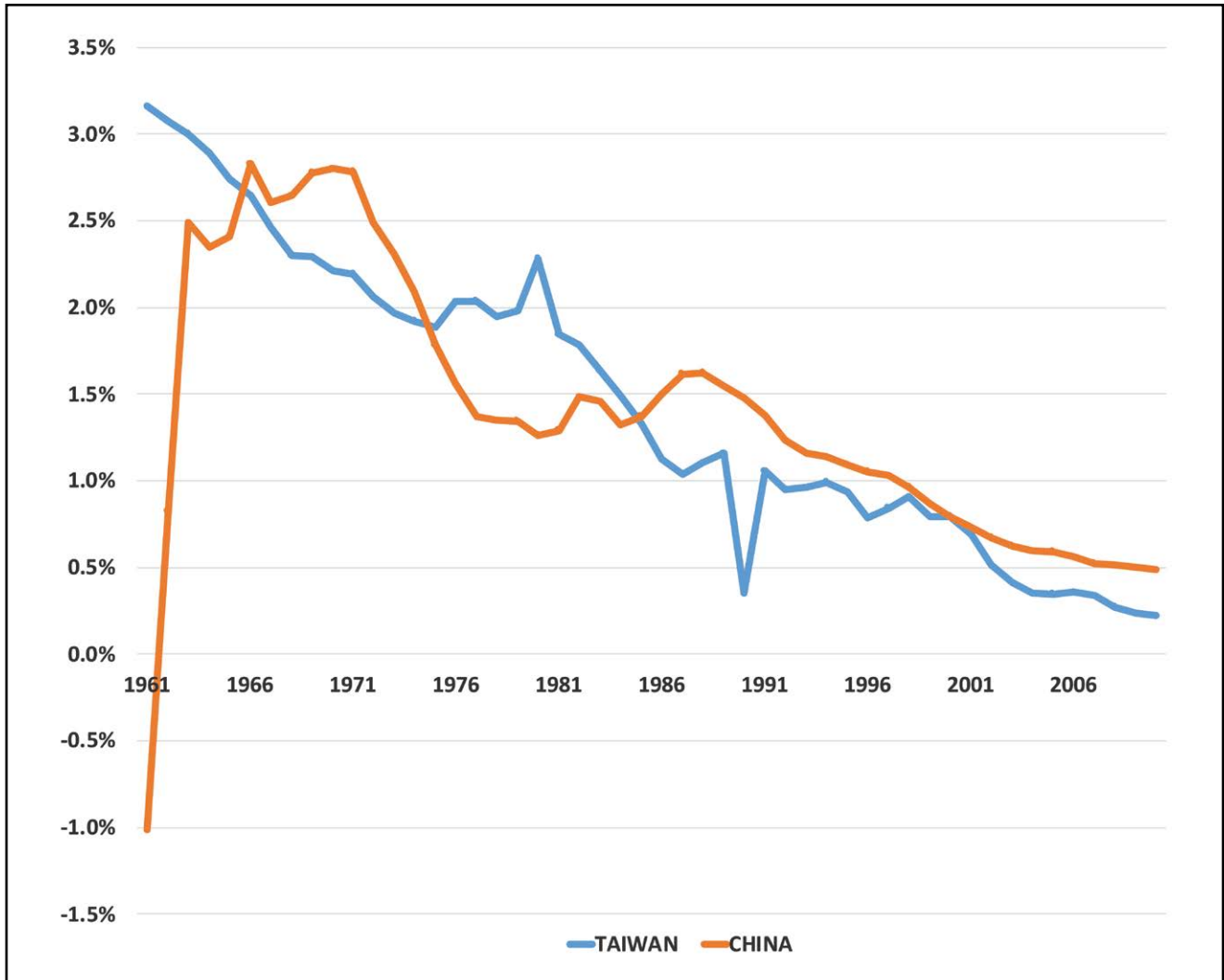
Agriculture and Population

Agriculture is probably the best test of the neo-Malthusian theories, since arable land is much more fixed than other resources. Reclamation of desert, swampland, and coastal areas is possible but will always be limited. Instead, progress is aimed almost exclusively at improving the efficiency of utilization of the resource (land) and has been an untrammled success. Fears of rising malnutrition have left the world coping with an obesity epidemic: the real threat is the opposite of what was claimed.

And the impact of this misguided belief in

sustainable population levels has been harsh. Arguably, this is the most inhumane result of the neo-Malthusian viewpoint, as birth control policies have been practiced aggressively in some countries such as China and India, where coercion is said to be used to induce women to undergo abortions and/or sterilization. Comparing Chinese population growth rates with those in Taiwan, where there are no specific population policies, shows just how needless the Chinese one-child policy has been. (Figure 20) The repressive population controls could be said to be used as a corrective for inefficient economic policies.

Figure 20
Annual Change in Population



Source: China from World Bank, Taiwan from St. Louis Fed.

Resource pessimism has genuine consequences in policy formation. At the most fundamental level, it leads policy makers to allocate public resources on initiatives and public works efforts with little or no return, i.e., it is wasteful. These financial resources are likely to have a much higher return when allocated to a wide range of traditional requirements in civil society. The new Green New Deal (GND) is a case in point. It is an expensive crash program to find substitutes for non-renewable resources, including arable land. The question posed by Rex Weyler, a cofounder of Greenpeace International, “Will Peak Oil Save Earth’s Climate?” shows the danger of such miscalculations.⁷⁴ He suggests that our low carbon future is coming from necessity as we are quickly running out of oil and gas and we have no choice but to embark on an expensive transformation away from fossil fuels. However, technology is expanding the petroleum resource base, especially natural gas. Low cost natural gas is also contributing to a reduction in U.S. carbon emissions as gas substitutes for coal in the electric power sector. U.S. carbon emissions have declined since 2007 even as the U.S. has become a leading world producer of oil and gas.

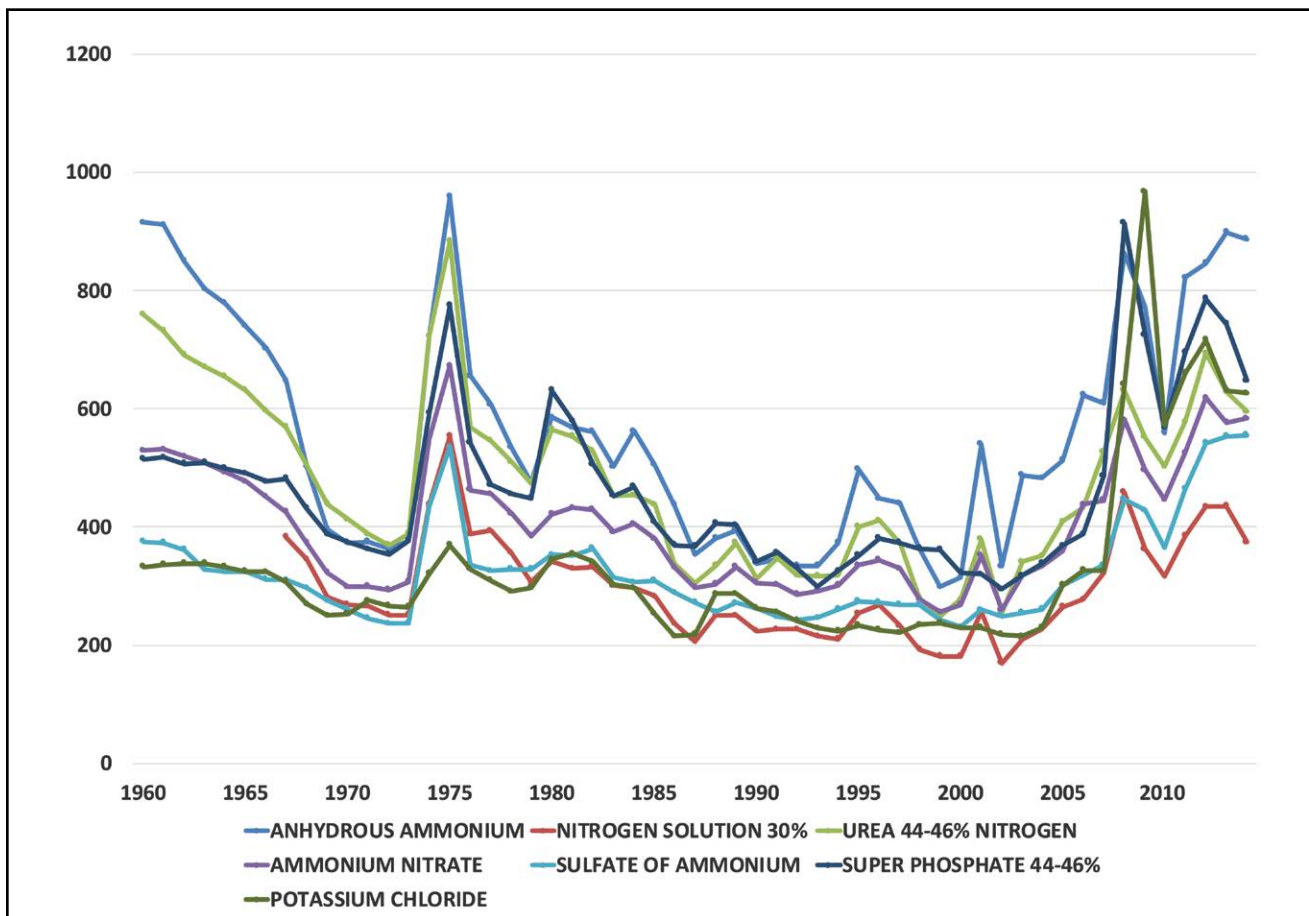
And yet, the popularity of neo-Malthusian theorists remains untouched by the continued failure of their predictions. Paul Ehrlich is often lauded even by those who recognize his failed

predictions, presumably because they don’t realize that his entire concept is incorrectly specified. We need no more to control population to avoid widespread starvation than we need a crash program to generate oxygen so that future generations will not be asphyxiated.

Perhaps the best way to demonstrate the Wizard’s dominance of the debate is to return to William Vogt, and his fears about depletion of the finite guano resource. In the 1870s, the price in England was apparently roughly 12 English pounds per ton, which would be about \$0.30 per pound, adjusted for inflation.⁷⁵ At present, Peruvian bird guano sells for approximately \$3-4/lb. through online sales.⁷⁶

One could argue that we are seeing rising prices from a scarcity of guano (although 1.6% per year increase is not spectacular). This price is not likely to be comparable because the small-scale, boutique nature of current guano sales makes it closer to organic cake than bread. Commercial fertilizer represents a more accurate index. Fertilizer sales are currently running at \$0.20 to \$0.45 per pound, mostly on the lower end of the range. As shown in Figure 21, fertilizer prices, when adjusted for inflation, have remained relatively flat peaking only during periods of high petroleum prices (1973, 1979, 2000s), petroleum being a major input to the manufacture.

Figure 21
US Fertilizer Prices (2016\$/ton)



Source: Economic Research Service, U.S. Department of Agriculture.

None of these observations suggests that untrammled consumption of every resource is desirable, especially given concerns about climate change and ocean pollution. But we should also recognize we have made remarkable progress in improving our environment. According to data from the U.S. Environmental Protection Agency, the U.S. continues to experience remarkable improvements in both air and water quality.⁷⁷ Disagreeing with

aggressive population control methods does not require opening national parks to housing and believing coal resources are enormous doesn't necessitate burning them all. But it is always preferable for policies to be made based attention to sound research, attention to scientific methods, and a careful weighing of costs and benefits as opposed to invalid theories and feeling that the apocalypse is just around the corner.

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