Can the World Get Along Without Natural Resources?

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> 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.
>
> — Robert Solow (1974)

In the distant future, aliens come to Earth. They find a planet devoid of life. Looking closer, the aliens see that life on Earth *was* once abundant, but was wiped out by a mass extinction. Curiously, this event was driven not by geological disaster, but by one of the extinct species itself. In an orgy of consumption, an odd little animal put the planet under enough stress to drive itself — and the rest of life — extinct.

Then comes a startling discovering. Preserved in the sediment lies a document written by a member of the doomed species. What secrets does it contain? The aliens work for years to translate it, hoping that it offers a clue about what drove the species to overconsume. And indeed it does. The document heralds a remarkable delusion: "*The world can, in effect, get along without natural resources.*"

What a naive animal, the aliens conclude. While sucking the planet dry, the animal proclaimed its independence from natural resources. No wonder it went extinct.

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Let's hope this future is apocryphal. If, in the distant future, aliens do visit the Earth, I hope they find a planet teeming with life. Maybe they'll even find an industrious, upright-walking animal that has learned to live sustainably.

If this bright future does come to pass, it will be because we've managed to shed our delusions. Contrary to the proclamations of neoclassical economists (like Robert Solow), the world *cannot* get along without natural resources. That this fact needs stating is a testament to the shallowness of economic theory.

In this article, I discuss how economists reached such bizarre conclusions. And I offer some thoughts about the role that resources *actually* play in sustaining human societies.

The original sin

From its outset, the field of political economy was not designed, in any meaningful sense, to understand resource flows. Instead, it was designed to explain *class relations*. The goal of early political economists was to justify the income of different classes (workers, landowners and capitalists). They chose to do so by rooting this income in the 'production of wealth'. What followed from this original sin was centuries of conflating income with 'production'. This conflation is what allowed Robert Solow to proclaim that the world could "get along without natural resources".

Let's retrace this flawed thinking. It starts with a failure to understand property rights. Political economists largely understand property as a productive asset — a way of thinking that dates to the 17th-century work of John Locke (or perhaps earlier). Locke proclaimed that property rights stemmed from 'natural law'. A man, Locke argued, has a natural right to own what he 'produces':

> … every Man has a Property in his own Person. This no Body has any Right to but himself. The Labour of his Body, and the Work of his Hands, we may say, are properly his. Whatsoever then he removes out of the State that Nature hath provided, and left it in, he hath mixed his Labour with, and joyned to it something that is his own, and thereby makes it his Property. It being by him removed from the common state Nature placed it in, hath by this

> labour something annexed to it, that excludes the common right of other Men. For this Labour being the unquestionable Property of the Labourer, no man but he can have a right to what that is once joyned to, at least where there is enough, and as good left in common for others.
>
> (Locke, 1689)

Locke's thinking became known as the 'labor theory of property'. This theory (and its derivatives) is why political economists misunderstand the role of natural resources. Here's what happens. If we accept Locke's argument that you have a right to own what you produce, it follows that your wealth should stem from your output.

Most political economists after Locke accepted this reasoning (at least in part). That meant that the debate was not about whether wealth was 'produced', but rather, about *which* 'factors of production' were 'productive'. The physiocrats thought land alone was productive (Quesnay, 1758). Marx insisted that only labor was productive (1867). Neoclassical economists proclaimed that, alongside labor, capital too was productive (Clark, 1899; Wicksteed, 1894). The debate between these schools played out over centuries. The problem, though, is that it's based on a flawed premise. The debate assumes that value is 'produced'. (It's not.)

To see the flaw, let's go back to Locke's theory of property rights. Notice that it's not really a 'theory' in the scientific sense. It doesn't explain *why* property rights exist. It explains why they *ought* to exist. Locke proclaimed that a man ought to own what he produces. That is his 'natural right'.

This change from 'is' to 'ought' is important. It means that we're not dealing with a scientific theory. We're dealing with a system of *morality*. The philosopher David Hume was perhaps the first to understand this moral sleight of hand. He noticed that moral philosophers made their arguments more convincing by framing what 'ought' to be in terms of what 'is'. Here's Hume reflecting on this trick:

> In every system of morality, which I have hitherto met with, I have always remarked, that the author proceeds for some time in the ordinary way of reasoning, and establishes the being of a God,

> or makes observations concerning human affairs; when of a sudden I am surprised to find, that instead of the usual copulations of propositions, is, and is not, I meet with no proposition that is not connected with an ought, or an ought not. This change is imperceptible; but is, however, of the last consequence.
>
> (Hume, 1739)

With David Hume's observation in mind, let's return to Locke's 'theory' of property. It's not a 'theory' at all — it's a morale treatise. According to Locke, we *ought* to own what we produce. But that doesn't mean that we *do*.

To see the consequences of this mistake, we need an actual scientific theory of property rights — a theory that explains why property exists, not why it 'ought' to exist. The most convincing theory of private property, in my opinion, comes from the work of Jonathan Nitzan and Shimshon Bichler (2009). To understand property, Nitzan and Bichler argue that we should turn Locke's idea on its head. Property isn't a 'natural right'. It's an act of *power*.

Property, Nitzan and Bichler observe, is an act of exclusion. If I own something, that means that I have the right to exclude others from using it. It's this exclusionary power that defines private property. Here are Nitzan and Bichler describing this act:

> The most important feature of private ownership is not that it enables those who own, but that it disables those who do not. Technically, anyone can get into someone else's car and drive away, or give an order to sell all of Warren Buffet's shares in Berkshire Hathaway. The sole purpose of private ownership is to prevent us from doing so. In this sense, private ownership is wholly and only an institution of exclusion, and institutional exclusion is a matter of organized power.
>
> (Nitzan and Bichler, 2009)

When we think like Nitzan and Bichler, we get a very different view of income. Recall that most political economists see property in terms of the 'things' that are owned. They then argue that income stems from these 'things'. Nitzan and Bichler upend this logic. Property, they argue, is about the *act* of ownership

— the institutional act of exclusion. Income stems from this exclusionary act. We earn income from the *fence* of property rights, not from what's inside the fence. In other words, if you can't restrict access to your property, you can't earn income from it.

With Nitzan and Bichler's theory of private property in hand, let's look at what goes wrong in political economy. Economists see income and conclude that it indicates the productivity of the owner's property. This means that when the distribution of income changes, it appears that the relative 'output' of each 'factor of production' also changes. So when the income flowing to natural resource owners declines, economists conclude (wrongly) that the resources themselves are becoming less important.

Here's an example. Most early political economists argued that there were three 'factors of production': land, labor and capital. But over time, land was slowly dropped, leaving only labor and capital. Here are William Nordhaus and James Tobin noting this shift:

> The prevailing standard model of growth . . . is basically a two-factor model in which production depends only on labor and reproducible capital. Land and resources, the third member of the classical triad, have generally been dropped.
>
> . . . Presumably the tacit justification has been that reproducible capital is a near perfect substitute for land and other exhaustible resources.
>
> (Nordhaus and Tobin, 1973)

According to Nordhaus and Tobin, land was dropped as a 'factor of production' because it could be replaced by capital. In other words, capital had become so productive that there was no longer a need for land.

Let's dissect this logic. Economists dropped land as a 'factor of production' not because of any change in physical reality. Humans, like all organisms, depend on the Earth's bounty for our survival. Without land, there is no food. And without food, there are no humans. So the importance of natural resources hasn't changed. Why, then, did economists rid their theory of land? They did so because of the original sin in political economy: from declining *income*, economists inferred declining contribution to *output*. As societies industrialized, the share of income flowing to agricultural land owners declined. To economists, this signaled that land had become less important.

Let's make this shift more concrete. Go back a few centuries and the wealthiest people were, without exception, *land owners*. Fast forward to the present, however, and this landed aristocracy hardly exists. The wealthiest people are now almost exclusively the owners of capital. And these capitalists sometimes own nothing but ideas (intellectual property). Wealth, it seems, is dematerializing. The world can get along without natural resources!

No. This thinking is flawed. It's the Lockean mistake in action. Economists assume (wrongly) that income reflects productivity. They then mistake income redistribution — from the landed aristocracy to industrial capitalists — as a decline in the importance of 'land'. But it is no such thing. Land remains the basis of all human activity.

Agriculture? We can do without it

The conflation of income with productivity has led economists to misunderstand the role of natural resources in human societies. Economists see that the *owners* of natural resources earn a trivial share of income. And so they conclude (wrongly) that natural resources *themselves* play a trivial role in the economy. It's an embarrassing mistake with troubling consequences.

Take, as an example, the need to fight climate change. If you ask a climate scientist, they'll likely say that climate change poses a dire threat to humanity (for instance, Hansen, 2010). Their reasoning is simple. Climate change could potentially make farming impossible in much of the world. So if we want to avoid mass starvation, we'd best curb our fossil fuel habit.

In contrast, if you ask a neoclassical economist about fighting climate change, you'll get a very different answer. Climate change, they'll likely say, isn't much of a problem. True, it may cause much of our arable land to become barren … but don't worry. Agriculture, they'll observe, is a tiny part of GDP. So even if we destroy our ability to farm, 'economic output' will remain virtually unchanged.

Given its absurdity, you might think that I'm making this reasoning up. But I'm not. William Nordhaus — whose work on the economics of climate change has been enormously influential — uses the same reasoning to downplay the impact of global warming. Here's how he peddles it:

> [T]he process of economic development and technological change tend progressively to reduce climate sensitivity as the share of agriculture in output and employment declines and as capital-intensive space heating and cooling, enclosed shopping malls, artificial snow, and accurate weather or hurricane forecasting reduces the vulnerability of economic activity to weather
>
> . . . More generally, underground mining, most services, communications, and manufacturing are sectors likely to be largely unaffected by climate change—sectors that comprise around 85 percent of GDP.
>
> (Nordhaus, 1993)

Although climate change may destroy our food supply, we shouldn't worry. According to Nordhaus, we'll all be safe inside our air-conditioned offices, with productivity unimpaired. For this tortured logic, Nordhaus was awarded the Nobel prize in economics. Noting the irony, anthropologist Jason Hickel aptly called it the "The Nobel Prize for Climate Catastrophe" (2018).

Here's what's wrong with Nordhaus' reasoning: it conflates income with productive importance (political economy's original sin). Nordhaus sees agriculture's declining share of national income and concludes (wrongly) that farming is becoming less important to human societies.

Let's quantify the trend. Figure 1 shows the share of US income earned by people working in agriculture. This share declined precipitously over the last two centuries. In 1840, more than half of all income went to people in agriculture. But by 2010, this figure had shrunk to less than 1%. Today, US farmers earn a trivial share of all income.

If you think like Nordhaus, the evidence in Figure 1 tells you that agriculture is becoming less important. It's such a minuscule part of the economy that if we got rid of it entirely, GDP would shrink by less than 1%. So bring on the climate change!

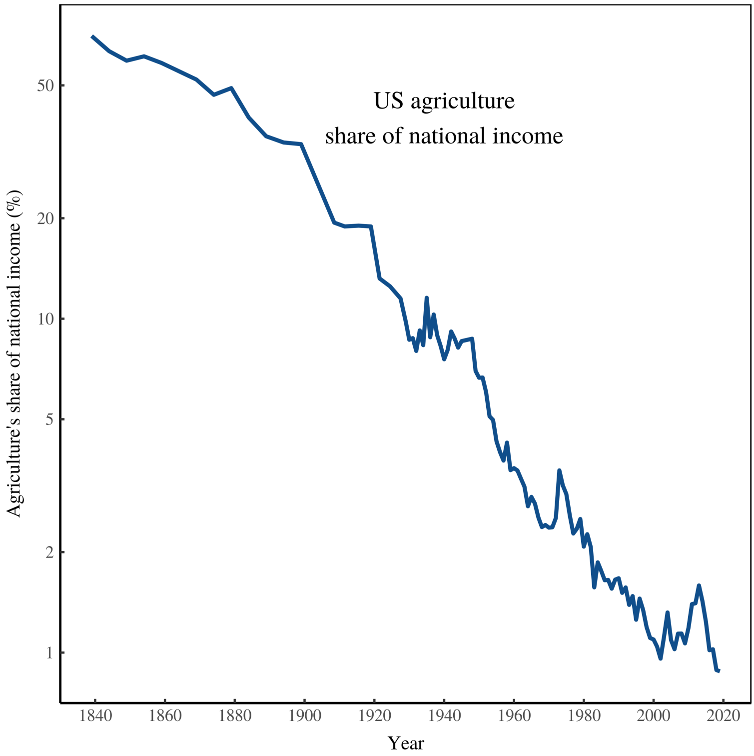

Figure 1: The share of agriculture in US national income

For data sources, see notes.

Unfortunately, there's a fatal flaw in this thinking. The decline in agriculture's income share says nothing about agriculture's biophysical importance. To see the biophysical importance of agriculture, we should look not at the income-accounting table, but at the *kitchen table*. No agriculture … means no food … means no humans.

Far from indicating agriculture's irrelevance, the evidence in Figure 1 shows agriculture's continued *importance*. Industrial society is possible only because so few people are needed to grow food. (That's why farmers earn such a tiny share of all income. There are hardly any of them!) Modern farmers harvest a staggering quantity of food. This allows the rest of us to do the non-farming activities that we take for granted.

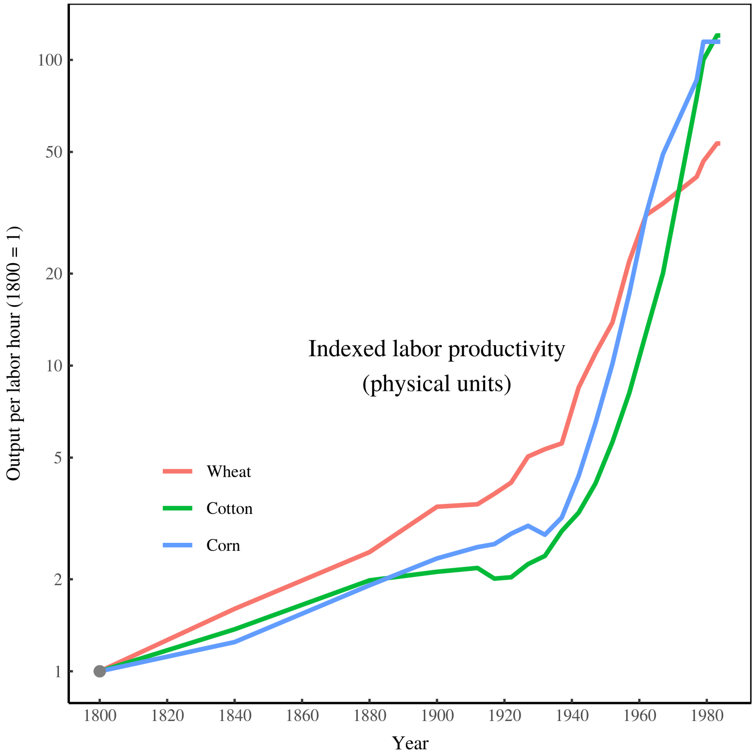

Figure 2: The exploding labor productivity of US agriculture

I plot here the trend in the output per labor hour of US-produced wheat, cotton and corn. Data is indexed so that productivity equals 1 in the year 1800. Output is measured in physical units (bushels for wheat and corn, bales for cotton). For data sources, see notes.

Let's look at the growth of this agricultural harvest. Figure 2 shows the labor productivity of US farmers over the last two centuries. I've plotted the harvest of three crops: wheat, cotton and corn. For these crops, the increase in labor productivity is spectacular — about *50-fold* for wheat and *100-fold* for corn and cotton. This enormous harvest is the basis for our industrial society. Without the bounty of modern agriculture, urban life would be impossible.

We can now see the flaw in Nordhaus' reasoning. If climate change decreases the productivity of agriculture, we lose the basis for our industrial society. If farmers can't feed people in cities, urban-dwellers will have to move back onto the land. Presto … no more industrial society.

The price problem

In tying the concept of 'output' to income, neoclassical economists fool themselves. Their accounting system leads them to believe that natural resources are unimportant. Here's what happens. When the price of a natural resource decreases, so does its apparent contribution to 'output'. So as resources become cheaper, economists mistakenly think that societies are becoming less dependent on the Earth.

This thinking gets it utterly wrong. The price of a natural resource doesn't indicate its importance to society. The role of natural resources is, in reality, *invariant*. Today — just as we have always been — we are utterly dependent on natural resources for our survival.

So what, then, should we make of the price of natural resources? In an important sense, the price of a resource is *inversely* related to the resource's importance. The cheaper a resource becomes, the more we tend to depend on it.

As an example, take electricity. A century ago, electricity was expensive and its use was rare. Today, electricity is cheap and we use it in almost all aspects of life. Figure 3 quantifies this cheapening of electricity, measured in terms of work time. I've plotted here the work time required for an average US worker to purchase 1 megawatt-hour of electricity. (A megawatt-hour is roughly the amount of electricity used by a modern US household in a month.) In 1900, it took about 1000 hours of paid work to purchase this amount of electricity. Today it takes about 5 hours — a 200-fold decrease.

Electricity is, for modern Americans, astonishingly cheap. To neoclassical economists, this cheapness signals that electricity production contributes virtually nothing to economic output. But this conclusion is fallacious. Americans use electricity in profligate quantities *precisely because it is cheap*. Less than 1 % of national income is devoted to buying utilities.

For neoclassical economists like William Nordhaus, this means that we could wipe out the entire utilities sector, but still retain 99 % of economic 'output'. In the real world, things are different. If we wipe out the utilities sector, industrial society disappears.

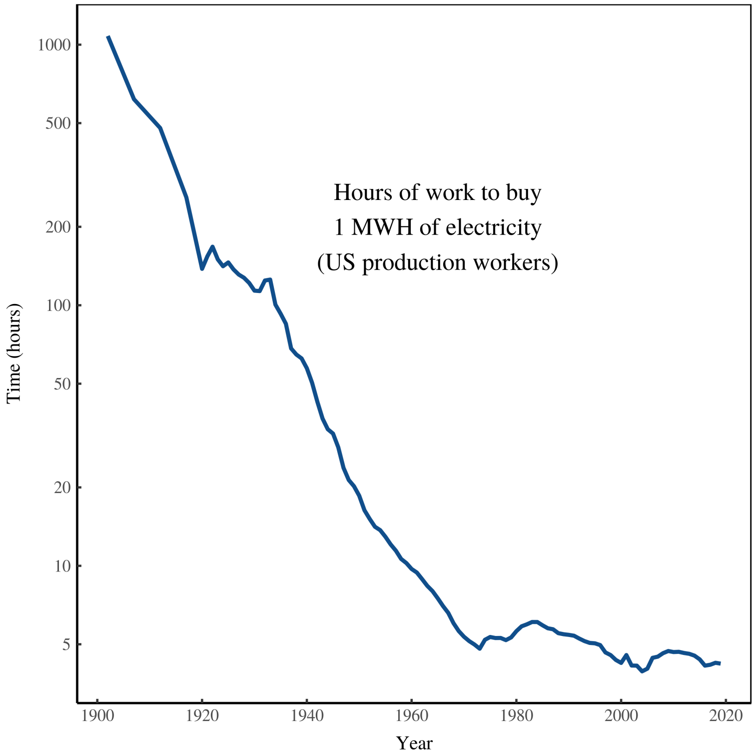

Figure 3: The falling relative price of electricity

I plot here the average number of working hours required for a US production worker to buy 1 MWH of electricity at the residential price. For data sources, see notes.

The energetic basis of society

Unlike economists, physicists have long understood the importance of natural resources to society. And they've recognized that energy is the 'master resource' (Zencey, 2013).

Without the flow of energy, the universe would be a boring place. There would be no galaxies, no stars, no planets and no life. Absent energy flows, the universe would be an unchanging soup of matter and radiation. All of the structures that we take for granted are created by energy flows. (For a compelling exposition of this principle, see Chaisson, 2002.)

Back to economics. I could dive into the physical laws that tell us why energy is important to human society. But instead, I'll defer to Steve Keen, who has a knack for good metaphors. When it comes to the importance of energy to the economy, Keen notes:

> [L]abour without energy is a corpse, while capital without energy is a sculpture.
>
> (Keen et al., 2019)

An apt metaphor. Without energy flows, our machinery would be useless. Not to mention we'd all be dead. But beyond metaphors like this, how do we understand the importance of energy to the economy? A popular approach among ecological economists is to reform neoclassical theory by adding energy to production functions. (Ayres and Warr, 2010; Cleveland et al., 1984; Hannon and Joyce, 1981; Kummel, 1989). The idea is that, alongside labor and capital, energy is a 'factor of production'.

While well intentioned, I'm skeptical of this approach. There are many problems, but I'll focus here on just two. First, I think that the concept of 'factors of production' is flawed. It's rooted in a mistaken attempt to explain class-based income in terms of the contribution to production. The problem is that class divisions don't tell us about the biophysical underpinnings of society. They never have and they never will.

Second, I think it's a mistake to even try to explain 'economic output'. Why? Because I don't think it *exists*. Ask yourself this question — what is the 'output' of a cow? What is the 'output' of a bacteria? Are you struggling to find an answer? That's because the question is ill-posed. Organisms don't have 'outputs' in any meaningful sense. They have *throughputs*. Organisms transform matter and energy into forms that are useful. Both the cow and the bacteria take in energy and matter, and then use it to maintain their structure and to enable their activity. They have no 'output' ... only energy throughput (Fix, 2015).

When we think this way, production functions become irrelevant. There's no need to relate economic inputs to economic outputs, because the latter doesn't exist. Instead, there's only the flow of energy. When framed this way, the study of 'economic growth' becomes the study of energy transformations. We needn't get 'real' GDP involved. That's good, because it's a flawed metric (Fix et al., 2019).

Using energy to harvest energy

When it comes to understanding the role of energy, one of the most interesting things we can do is study the *use* of energy to *harvest* energy (Hall and Klitgaard, 2012). In broad terms, this is what life is all about. Organisms use energy so that they can harvest more energy. A gazelle eats grass so that it can find more grass. A lion eats a gazelle so that it can find more gazelle. And so on.

In this regard, natural systems are fairly static. We don't see lions investing ever-increasing energy (per capita) in hunting their prey. If a lion pride reaps a bonanza (like an elephant), they don't turn around and immediately hunt for more elephants. They eat the bonanza and then sleep for days. For most of our history, humans probably did something similar. We harvested the energy we needed, and no more. If there was an excess supply of energy, we (like the lion) used it up with leisure time.

Then something changed. At some point in our history (probably when we started farming) humans started to behave differently. We invested excess energy into harvesting *still more energy*. This new behavior created a dramatic feedback loop that eventually led to industrial society.

Let's think about how this feedback loop works, using the example of harvesting coal. Humans have mined coal for millennia. For most of this time, we used nothing but a pick. Even today, that's how coal is mined in some parts of the world (Fig. 4). It's a back-breaking task filled with danger.

Let's think about this coal mining in energetic terms. When we mine by hand, we're using our bodies to convert food energy into work. In return, we get energy from coal. Note that the two types of energy come in different forms (food and coal). Since it's hard to use coal to grow more food, there's a limit to how much coal we can mine by hand. (If everyone mines coal, no one can grow food.)

The solution to this problem is to use *coal power* to mine coal. This sets the

Figure 4: A coal miner in Punjab, India

Source: Reuters

Figure 5: A coal miner with a pneumatic drill

Source: Staffordshire Multimedia Archive

Figure 6: An excavator at the Garzweiler coal mine in Germany

Source: Wikimedia commons

feedback loop free. We mine coal and then convert it into electricity (or, in the earlier days, convert it into steam power). Then we use this electricity to harvest more coal. By the earlier 20th century, many coal miners were no longer using picks. Instead, they used pneumatic drills like the one shown in Figure 5. They were using fossil-fuel power to harvest more fossil fuels.

Modern coal miners have taken this process to a monumental scale. They don't even bother with hand-held tools. Instead, they use giant excavators to mine coal on a scale that is hard to fathom. Figure 6 shows an excavator in a German coal mine. Each bucket on the extraction wheel is the size of a car.

On the surface, this feedback loop appears as changing technology. The imagery above makes that clear. But under the hood, the feedback loop is fundamentally about energy. We are using ever increasing quantities of energy to harvest still more energy.

Let's have a look at this energy feedback loop in quantitative terms. We'll compare the energy *harvested* by the energy sector to the energy *used* by this sector. Figure 7 shows such a comparison in the US oil and gas sector. The blue

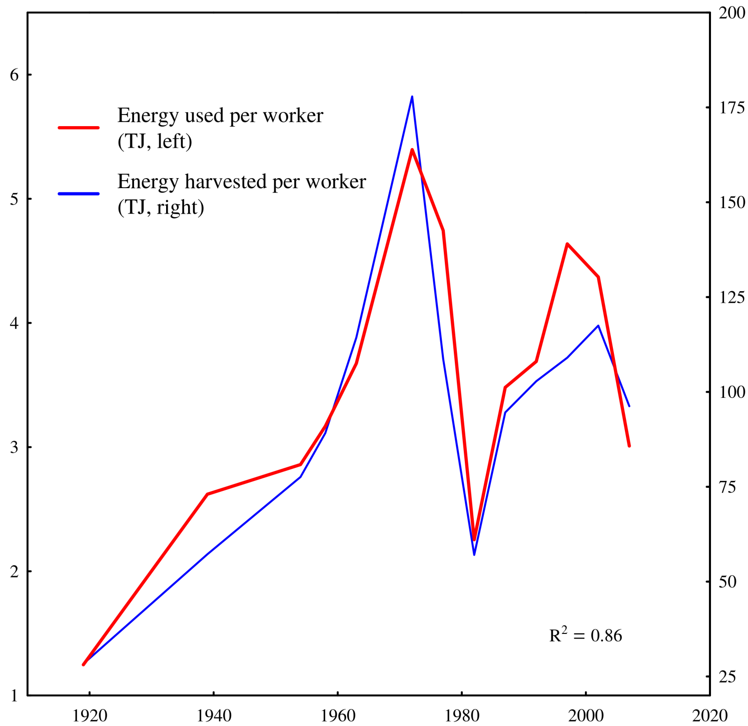

Figure 7: Using energy to harvest energy in the US oil and gas sector

For data sources, see notes.

curve shows the energy *harvested* per worker in the oil and gas sector. The red curve shows the energy *consumed* per worker in this sector. As expected, the correlation is tight. The only way to harvest more energy is to use more energy.

A side note about history. Figure 7 vividly shows the impact of the 1970s oil crisis — the confluence of two different events. First, US oil production peaked in 1970. Second, in the 1970s the oil cartel OPEC limited the export of oil to the United States. Because of both of these factors, the price of oil rose rapidly. In response, exploration for oil exploded. Thousands of people pored into the energy sector hoping to earn a wildcat windfall. But little new oil was found, and so the energy harvested per worker declined. When the price of oil eventually fell (in the 1980s) people stopped wildcatting. The production of oil, however,

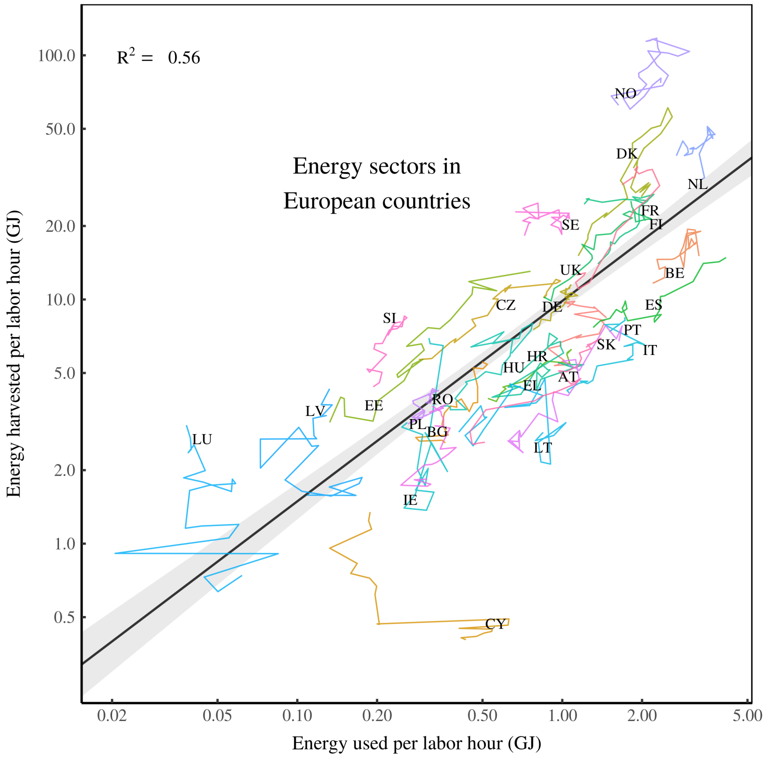

Figure 8: Using energy to harvest energy in European countries

The x-axis shows the energy used by the energy sector (per labor hour) in various EU countries. The y-axis shows the energy harvested (per labor hour) by the same sector. Lines indicate the path through time of countries over the years 1990–2018. For data sources, see notes.

remained roughly constant. So the oil harvested per worker increased.

The US oil and gas sector is hardly alone in using energy to harvest energy. We expect this linkage in all societies. Looking at European countries (Fig. 8), we see similar behavior. The energy *harvested* by the energy sector is tightly linked to the energy *used* by this sector.

The scale of energy flow

Most of us (myself included) don't appreciate the magnitude of our fossil fuel habit. To put the scale of fossil fuel exploitation in perspective, it's helpful to compare it to something we're more familiar with — *food*. Let's convert the energy harvested by an industrial nation into the energy equivalent in corn. We'll use Norway as our example.

Norway's energy sector harvests about 100 billion joules of energy for every person-hour. That's equivalent to harvesting *27 metric tonnes* of corn for every hour worked. Think about that — nearly 30 tonnes of corn for every hour of work.

How much corn is this? It's about *4000 times* more corn per labor hour than pre-industrial farmers could harvest. And it's about *30 times* more corn per hour than modern industrial farmers can harvest. (For calculations see notes.) This is the potency of fossil fuels.

We cannot do without natural resources

The physicist Arthur Eddington once remarked: "if your theory is found to be against the [laws] of thermodynamics I can give you no hope; there is nothing for it but to collapse in deepest humiliation" (Eddington, 1928). Neoclassical economics profoundly contradicts these laws. Yet sadly, we're still awaiting its humiliating collapse.

Neoclassical economics is founded on an embarrassing error. It assumes that income indicates contribution to production. For a century, this error has led economists to conclude that natural resources are unimportant. They see that the natural resource sector earns a tiny fraction of all income. And so they infer that we could get rid of this activity and still retain the vast majority of 'economic output'.

Unfortunately, the real world doesn't work like that. Income doesn't tell us about the importance of resource flows. It never has and it never will. As long as we think that it does, we're headed down a dangerous path. Let's not let the delusions of neoclassical economics seal our fate. The planet deserves better.

Acknowledgments

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Notes

Data and code for all figures are available at the Open Science Framework: https://osf.io/ehxmp/

Agriculture share of US national income:

- 1839–1899: Historical Statistics of the United States Bicentennial Edition, Table F238-249
- 1900–1928: Historical Statistics of the United States Bicentennial Edition, Table F250-261
- 1929–present: Bureau of Economic Analysis Tables 6.1A–D. (Table 6.1A isn't available online. You can get it here).

Labor productivity of US agriculture is from Historical Statistics of the United States Millenial Edition, Table Da1143-1171.

US price of electricity:

- 1902–2000: Historical Statistics of the United States Millenial Edition, Table Db235 (residential electricity)
- 2001–present: Bureau of Labor Statistics, CPI series CUSR0000SEHF01

US production worker wages are from MeasuringWorth.com

US oil and gas energy production is from:

- 1919–1948: Historical Statistics of the United States Millenial Edition, Table Db155-163.

- 1949–present: Energy Information Agency Table 1.2

Energy consumption by the US oil and gas sector is from Guilford et al. (2011) Table 6 (direct energy use).

US oil and gas employment is from:

- 1919: Census of Mineral Industries 1958, Table 1
- 1929–present: Bureau of Economic Analysis Tables 6.8A–D, persons engaged in production. (Note that Table 6.8D is discontinuous with 6.8A–C because of the transition from SIC to NAICS classification. I splice 6.8D by indexing it to 6.8C.

Eurozone energy production and consumption (by the energy sector) is from the Eurostat energy balance tables. Eurozone labor hours are from Eurostat table nama _10 _a64 _e.

Calculations

Corn has about 90 kilocalories of energy per 100g. There are 4184 joules in a kilocalorie, giving 376,560 joules per 100 g of corn. That's 3765.6 joules per gram.

Norway's energy sector produces about 100 GJ of energy per labor hour. That's 100 billion joules. Translating to corn, we divide 100 billion joules by 3765.6 joules per gram. That gives 2,655,6193 grams, which is about 27 metric tons. So for every hour of work, a Norwegian energy-sector worker produces (transforms) the energy equivalent of 27 tonnes of corn.

Let's compare that to the corn produced by US farmers. In 1800, it took US farmers about 344 hours (on average) to produce 100 bushels of corn. A bushel of corn is roughly 25 kg. So pre-industrial US farmers produced about 7 kg of corn per hour — 0.007 tonnes. In contrast, it takes modern US farmers about 3 hours to produce 100 bushels of corn. That translates to about 0.8 tonnes per hour.

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