Energy Architecture and Economic Growth

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One of the concerns within the Association, as expressed in its meetings around the world, is how to create economic growth, not just for developed OECD countries but for developing countries as well. Energy is central to economics and therefore to economic growth as much of history can attest. One way to understand such history is by using dialectic reasoning, or energy dialectics, where alternative options present themselves during a disputation but where a final resolution, or synthesis, creates a solution. For example, Carl Marx laid out in his Dialectic Materialism examples of history, such as the post Dark Age tension between the landed gentry (the thesis) and the peasants (the antithesis), and how such opposing sides ultimately created a dialectic resolution, such as capitalism (the synthesis). Then within that synthesis was a new dialectic between the capitalists (the thesis) and the workers (the antithesis) that would create the new synthesis of socialism, but may have actually created unions and unionization as the final resolution. Perhaps Carl Marx was not the consummate economist, but it is an interesting take on history nonetheless. It shows how a dialectic can affect the economy. In turn an energy dialectic, as explained in Reynolds (2021), of a transition from two potential and sometimes countervailing energy resources into a new energy resource synthesis can likewise be used to explain economic resolutions and indeed help explain economic growth.

By way of illustration, in the early 1800s, the method of lighting included using whale oil in lamps. Then as whales were over-hunted and the supply of whale oil followed a pattern of production exactly like that of M. King Hubbert's (1956) logistics curve, as explained in Bardi (2007), then the price of whale oil started increasing. This Hubbert pattern for whale oil was due to the rate of hunting being much higher than the rate of regeneration of whales and thus the information and depletion effects (see Reynolds) dominated. This meant that there were two main options for lighting during the mid 19th century energy dialectic. The one lighting option was whale oil for kerosene-type lamps, the source of which was the more serviceable but also the more increasingly expensive energy, and the other option was a simple wood fire for heat and light. A wood fire though was awkward to use for plain lighting and could not be easily carried to functional locations.

Another option at the time was called camphine, Kovarik (2013) and PBS (2008), which was an alcohol and turpentine concoction that was said to be 10 times more prevalent than whale oil, although at about a 25% lower Btu (joule) content per gallon (liter) and at a much lower price, which suggests it was not a perfect substitute for whale oil. Plus, there was emerging town-gas made from coal-to-gas. But the final energy dialectic synthesis that came to be the predominant choice was crude oil from far down in the ground when Edwin Drake conducted oil well drilling with his deep well in 1859. Interestingly, as in other energy dialectics, the new energy synthesis helped economic growth tremendously. The U.S. GDP per capita growth rate for the 100 years before 1859 according to Maddison (2004) statistics was 1.5% per year, but for the 100 years after 1859, it was 4% per year, a greater than 90% increase in the economic growth rate.

1. Energy Architecture and Economic Growth

The normal reasoning about economic growth is that it is only about technology of and by itself, but energy architecture may also play a role that is often missed. Energy architecture has to do with the physical characteristics of a particular energy resource. One such characteristic, as explained by Smil (1991), is high power density concentrations of energy emitting from a relatively small area of extraction. Considering the effects of energy characteristics, though, there is no reason to expect a-priori that the 100 years before 1859 should have been any less or any more progressively productive than the 100 years after 1859 as far as overall U.S. economic growth per capita is concerned, unless technology works with energy architecture to create more or less potential. The predominant U.S. energy resource before 1859, as far as overall growth was concerned, was that of coal and wood, while after 1859 it was that of liquid petroleum. A solid versus a liquid.

Although lighting was the main issue surrounding the 1859 energy dialectic synthesis of crude oil, considered to be the 3rd great energy dialectic, nevertheless, coal was the most ubiquitous energy resource for growth related transformation during the previous economic epoch. But now consider the differences in energy architecture between coal and crude oil. For example, one type of energy architectural characteristic is the placement concentration of an energy resource. Coal can often have more Btus per acre than crude oil, roughly 500,000 MMBtus/Acre (250,000 Gigajoules per hectare). That is a coal mine when looking straight down from the ground level can pack more Btus per acre than crude oil can, not when comparing the East Texas oil field to that of an Indiana coal mine, but when comparing much of West Virginia to much of West Texas. So if that is the case, then why would oil be responsible for a greater than 90% increase in the growth rate of the U.S. if oil in general has less Btus per acre?

It has to do with a different energy architecture characteristic which is the energy source *state grade*. A state of a physical substance is whether it is a liquid, a gas or a solid or, as in the case of solar power, an energy field. Clearly a liquid state in energy terms is more useful than a solid state, but where a gaseous state is much less useful due to the lack of storability of a gas compared to a solid or liquid. In terms of storage, natural gas has 1000

Btu's per cubic foot at room pressure (35 Megajoules per cubic meter), and still only 177,000 Btus per cubic foot at 3000 pounds per square inch (200 atmospheres) compared to oil's 1 million Btus per cubic foot at room pressure. Coal is storable simply laying on the ground at about 500,000 Btus per cubic foot depending on the type of coal. And that is a storability that can last not just a day or a week but over the course of seasons and even for a couple of years or more.

The coal versus oil economic growth aspect of the 3rd Energy Dialectic, though, has to do with how useful a liquid is in comparison to a solid which has to do with internal combustion engines (with oil) versus external combustion engines (with coal). Liquid fuels can be used in small droplet quantities at a time within internal combustion engines which are then lighter in weight and more powerful in force per pound of engine than external combustion engines. A two cylinder internal combustion chainsaw might weigh only 10 pounds (4.5 KG), but a two cylinder external combustion coal-fired steam locomotive might weigh 10 tons. Even commensurate comparisons show the advantage of a liquid fuel. A Caterpillar 797f mining dump truck can carry 400 short tons 40 miles per hour with 4000 horse power. It weighs about 280 tons. While a steam locomotive could get up to 4000 horse power, but where its ability to stop and start are not as good and it where it is forced to be four times as heavy as the weight it pulls. So a locomotive pulling 400 short tons would need to weigh 1600 tons and stay on a track with water refilling stations every so often.

The least useful state is a field state, such as wind and solar power entail, because it lacks cheap, easy storability and also reduces the physical processes available to be used. For example, renewables can last a day or a month in some battery forms, but cannot easily or cheaply last a season or more. Solar is not useful with an internal or external combustion engine, where as such combustion engines, or even steam driven turbines, can produce electricity to compete with solar and where the energy source itself is quite storable. These kinds of mechanical engineering reasonings tend not to be emphasized in much energy economic analyses, but they need to be carefully looked at when determining economic potential of any given energy resource. The high quality potential of oil is a lot of what is behind the fact that the 100 years after 1859 were so much more successful than the 100 years before 1859. The crux of the growth enhancing aspect of these two energy resources, then, was that crude oil had greater potential to bring about economic growth inducing technological change due to its energy architecture of being a liquid energy resource rather than a solid.

2. An Energy Growth Comparison of Technologies

To put the energy architecture versus pure technology debate another way, consider the technology available for having a 21st century smart-grid application in everybody's household, i.e. a smart house or smart home automation or domotics. Such a technology can help gain demand side power variations in order to better match demand with the variable supply side electric power sources, or even match one demand entity with counter demand side entity variations. Such a smart home technology should be just as innovative and growth enhancing as say adding a separate condensing cylinder on an 18th century atmospheric steam engine, unless there is more to growth than merely technology.

Consider the two technologies: a 21st century smart-grid application in everybody's household or an 18th century separate condensing cylinder on an atmospheric steam engine. The second technology was useful in reducing the size of steam engines even as it increased the steam engine's power. This innovation led to a steam engine on a rolling platform such as a steam locomotive and bigger more powerful steam ships. That in turn engendered the ability to leverage the use of economies of scale in factories and the optimal location of such factories outside of high cost, inner-city land toward locations of low cost land areas outside of the city and often near a coal or iron ore mine. Such changes added tremendously to economic growth potential.

21st century smart gride home domotics tries to make the running of appliances occur at different times of day in order to reshuffle the time of day that a need for electric power on the demand side occurs and which can therefore make renewables, or base load nuclear power, more cost effective. Still, the domotics technology has much less ability to leverage economic growth since it is more about fixing renewables' inherent energy architecture deficiencies, specifically its lack of storability, than about creating growth potential energy leveraging. Not that renewables are not an important substitute to oil as oil supplies become constrained (see Reynolds), but the potential for creating new economic growth with renewables will be more limited in comparison to past energy changes which were generally to higher grade energy architecture characteristic resources. With renewables, it is all about government regulations to search for economic growth as opposed to past energy transitions where government regulations in regard to energy were about keeping people safe during the robust economic growth that materialized.

With domotics, let's say you need your clothes washed. So you use the smart grid and the smart electrical household to run the washing machine. That may mean that you have to fill the washing machine with your clothes and let it sit until the low cost part the electric utility day occurs, and thus everyone else in the household has to in turn wait for your cycle to complete to do their laundry. Then in the middle of the night or possibly in the middle of the working day with solar, the laundry gets done and it sits getting moldy until you can finally put the clothes in the dryer, or if in Europe it will wait until you get a chance to put it out on the line. Then you have to wait for the dryer cycle to go before you can get it out and fold it and, as well, everyone else who may need drying, might have to wait. Now maybe all that consternation is worthwhile to the consumer because of the money or carbon that is saved. Nevertheless, a close examination of consumer utility changes vise-a-vise cost reductions could find it less cost effective than meets the eye. In the meantime such forced exertions don't seem to leverage much in the way of new economic growth but only work to alleviate the energy architecture deficiencies of renewables.

Using the second technology, an 18th century separate condensing cylinder, means that train travel is possible. So with train travel, you can buy a train ticket, from say London to Leeds, which sounds like an appealing consumer utility increasing purchase, for travel, for experience of travel and for business. On the other hand, back in the 21st century, taking care to put in domestic laundry, dishes or water at appropriate times of the day to catch appropriate times of energy usage doesn't sound like quite the same eye-catching consumer opportunity. The 18th century train ticket can either be bought or not bought, the saving of money occurs by not buying and the expenditure of money occurs in the buying but with an overall increase in utility. The 21st century spending of money with having a smart grid home network is in the not using of energy or in the using of energy at a specific time of day a deterioration of consumer utility but at a savings.

Therefore, once the smart home computer is in place, you are forced to spend time and thought to attain its advantage even though you will have the help of an annoying computer, affectionately called by someone's name to make it sound better than it is, a good marketing ploy. It's no longer a one time decision to either go to Leeds or not to go, instead it becomes an everyday burden of whether you'll save money or not. It can become habit forming like remembering to turn off the lights or remembering to turn down the heat (or up the cooling) but it seems like taking care of weeds where if you don't to it, you sit looking at the weeds although you are resting.

3. Helping with Reductions in Carbon Emissions

Now because of global climate change, there may well be a need to use demand side management in order to help reduce carbon emissions, and as such, many will want to live with such demand side accommodations. That makes it important to specify the smart grid as a necessary evil rather than a great Smithian solution to a non-problem of elevating consumer utility of using electric power at a reasonable price. However, there is another need behind the electric systems usage which is how expensive petroleum will become once shale oil production goes voluminously downward and once OPEC+ members with the most market power realize that they can make more money selling less oil rather than more oil. Non-U.S. shale-oil has a "Loki" problem of substitutes in production. Electric demand side systems, from zoom to hybrid cars to plug in electric buses, may have to substitute for petroleum based systems even if the current energy dialectic synthesis turns out to be nuclear power rather than pure renewables, and where nuclear power has both elements of a solid and a field energy resource which enhances its storability.

Another interesting problem with demand side power management is how to implement putting in place energy efficiency applications. For example, in developing countries it is often challenging to get villagers to use improved biomass cook stoves, or even propane stoves, rather than using traditional stoves or open fires for cooking even though newer efficient stoves can save a lot of fuel over the course of months and years and can actually give a return on investment of as much as 10% to 100% per year. And yet there is a reluctance to buy such stoves even with low cost payment options available. This suggests that many energy consumers of daily energy utilization apparatuses have a very high internal rate of return that makes them very risk averse to buying energy saving equipment. Even in rich countries, the purchases of energy efficient refrigerators or washing machines can be hampered by this very same risk averse, high internal discount rate problem. That suggests that having external entities, such as the power company, come into homes and offer to replace old or inefficient appliances with a payment plan within their utility bill could help. It would induce more demand side electrical power management than simply relying on consumer sovereignty of and by itself. The power company could actually pay consumers for a power audit and switch out plan with adjustments made on power use billing rather than consumers paying for it.

Nevertheless, climate change will happen, and cities like New York or Utqiagvik (formerly Barrow) Alaska will inevitably have to choose between a Zuiderzee strategy of putting levies and ocean walls between a city and the ocean or a Dunkirk strategy of out and out abandoning the city. Also with COVID or further virus evolutions there may also be a need, like in the Middle Ages during plagues, to set up worker and family enclaves where new people and travelers have to undergo a quarantine to enter or leave such an area. But such enclaves can at least undergo better smart grid coordination to enrich demand side energy management including reductions in home to work commuting.

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