The trouble with production theory

Bernard C. Beaudreau [Université Laval, Québec, Canada]

Abstract
The edifice that is modern economics sits atop two pillars, namely consumer theory and producer theory. In turn, the latter sits atop what is perhaps the most important footing in all of economics namely production theory. After all, economics is the science of wealth, and since wealth is the result of material processes, it stands to reason that production theory stands at the very core of economics. Recently, "post-real" macroeconomics has been barraged with criticism (Romer 2016, Syll 2016), mostly directed at the "imaginary shocks" that lie at its core. In this paper, we argue that while "post-real" macroeconomics suffers from a number of shortcomings, the veritable problem is one that extends beyond macroeconomics to virtually all of economics, namely an archaic, simplistic, increasingly irrelevant, and scientifically misspecified approach to modeling wealth-producing material processes – in short, neoclassical production theory. It is shown that when more appropriate models of production are employed, most if not all the puzzles and paradoxes that plague economics disappear, as do imaginary shocks.

JEL Codes O40, O47, O57, Q43

Keywords production theory, process engineering, consilience

1. Introduction

The edifice that is modern economics sits atop two pillars, namely consumer theory and producer theory. In turn, the latter sits atop what is perhaps the most important footing in all of economics namely production theory. After all, economics is the science of wealth, and since wealth is the result of material processes, it stands to reason that production theory stands at the very core of economics. Recently, "post-real" macroeconomics has been barraged with criticism (Romer 2016, Syll 2016), mostly directed at the "imaginary shocks" that lie at its core.' In this paper, we argue that while "post-real" macroeconomics suffers from a number of shortcomings, the veritable problem is one that extends beyond macroeconomics to virtually all of economics, namely an archaic, simplistic, increasingly irrelevant, and scientifically misspecified approach to wealth-producing material processes – in short, neoclassical production theory.

Our basic argument is relatively simple and straightforward: neoclassical production theory is scientifically and empirically incorrect and a source of systemic irrelevancy. The evidence is there for all to see. Consider for example, the following facts.

i. Real business cycle analysis is based on imaginary shocks at a time when any and all shocks should be identifiable and quantifiable. After all, economics is not sub-atomic particle physics.
ii. Growth theory is also based on imaginary shocks, namely total factor productivity (TFP), which suffer from the same shortcomings.

iii. General Purpose Technology-based growth theory is based on shocks that while historical accurate have spawned the "electricity paradox" as well as the "information paradox."
iv. Neoclassical production theory violates the basic laws of mechanics according to which only force/energy can be physically productive. As labor is essentially supervisory in nature and capital is not a source of energy, it stands to reason that the notions of labor productivity and capital productivity sit in violation of basic physics.
v. Production theory is a misnomer, as what economics regards as theory is little more than simple and multiple correlations, with no underlying theory whatsoever.
vi. Material processes as modeled by economists and by process engineers are completely orthogonal. Notions such as the marginal product of labor, or capital have no equivalents in engineering or applied physics.

We will stop here. Our point is simple, namely that nothing can be right in economics if its most important cornerstone is not right. And that cornerstone is our understanding of the material processes that generate wealth.

This raises the obvious question of "how did this happen." Why is it that after over two centuries and a half of discourse, production remains the poor cousin of economics? How did a branch of moral philosophy which has sought and continues to seek knowledge and understanding degenerate into the realm of the metaphysical and imaginary, riddled with paradoxes and puzzles? After all, we are talking about material processes which are understood in all other fields of science (e.g. photosynthesis) with no exception.

In this paper, it will be argued that a combination of factors conspired to prevent economics from developing a scientifically accurate and relevant theory of production, consistent with the material process sciences in general. To illustrate these factors, the discussion will revolve around a comparison of the evolution of economics on the one hand, and thermodynamics on the other, two fields of scientific endeavor that were born of the steam engine and the ensuing industrial revolution (Berg 1980, Beaudreau 1998). We will show that repeated, unsuccessful attempts at closing the widening gap between the two left the door wide open for the metaphysical, the imaginary and the increasingly irrelevant. We also argue that this mattered little when growth was robust, but when the music died (i.e. when productivity growth slowed down), the profession found itself at a loss, one whose effects continue to be felt to this very day.

2. How we got here

In this section, we examine how production theory, over the years and decades, became increasingly irrelevant. This is accomplished by drawing a parallel between production theory in economics and the branch of physics known as thermodynamics, both of which were spurred on by the introduction of the Watts-Boulton rotary steam engine. It will be argued that despite a promising start, economics got side-tracked by non-production related issues, notably income distribution and the business cycle, while thermodynamics was free to evolve to the point of generating a set of laws that continue to hold today.[1] It will be shown that

[1] Lindenberger and Kummel (2002) make a similar argument, pointing out that: "the problem of the physical generation of wealth was coupled inseparably to the problem of the physical distribution of

despite a common starting point, the two diverged quickly with the result that by the end of the 19th century, production as formalized in economics was virtually orthogonal to production as formalized in applied physics and engineering. Interestingly, this duality found its way into the writings of a number of prominent figures in the 19th century.

Consider the following quotation, taken from Chapter 15 of Volume 1 of Karl Marx's Das Capital, entitled Machinery and Modern Industry.

> "Mathematicians and mechanicians, and in this they are followed by a few English economists, call a tool a simple machine, and a machine a complex tool. They see no essential difference between them, and even give the name of machine to the simple mechanical powers, the lever, the inclined plane, the screw, the wedge, etc. As a matter of fact, every machine is a combination of those simple powers, no matter how they may be disguised. From the economic standpoint this explanation is worth nothing, because the historical element is wanting. Another explanation of the difference between tool and machine is that in the case of a tool, man is the motive power, while the motive power of a machine is something different from man, as, for instance, an animal, water, wind, and so on. According to this, a plough drawn by oxen, which is a contrivance common to the most different epochs, would be a machine, while Claussens circular loom, which, worked by a single labourer, weaves 96,000 picks per minute, would be a mere tool. Nay, this very loom, though a tool when worked by hand, would, if worked by steam, be a machine. And since the application of animal power is one of man's earliest inventions, production by machinery would have preceded production by handicrafts. When in 1735, John Wyatt brought out his spinning machine, and began the industrial revolution of the 18th century, not a word did he say about an ass driving it instead of a man, and yet this part fell to the ass. He described it as a machine to spin without fingers.
>
> All fully developed machinery consists of three essentially different parts, the motor mechanism, the transmitting mechanism, and finally the tool or working machine. The motor mechanism is that which puts the whole in motion. It either generates its own motive power, like the steam-engine, the caloric engine, the electromagnetic machine, etc., or it receives its impulse from some already existing natural force, like the water-wheel from a head of water, the wind-mill from wind, etc. The transmit-ting mechanism, composed of fly-wheels, shafting, toothed wheels, pullies, straps, ropes, bands, pinions, and gearing of the most varied kinds, regulates the motion, changes its form where necessary, as for instance, from linear to circular, and divides and distributes it among the working machines. These two first parts of the whole mechanism are there, solely for putting the working machines in motion, by means of which motion the subject of labour is seized upon and modified as desired. The tool or working machine is that part of the machinery with which the industrial revolution of the 18th century started. And to this day it constantly serves as such a starting-point, whenever a handicraft, or a

---

wealth." The latter, we maintain, was in turn coupled inseparably to the problem of the business cycle. For example, Marx's interest in the question of distribution was motivated, in large measure, by his interest in the business cycle. This was also the case in the early 20th century where, for example, Paul Douglas' work on production was motivated ultimately by the business cycle.

> manufacture, is turned into an industry carried on by machinery" (Marx 1867, 261).

Clearly, Marx was familiar with both the principles of classical mechanics and the developing field of thermodynamics. Not only was he familiar with these branches of physics, but he ascribed much importance to motive power, to the steam engine, the caloric engine, and to the electromagnetic machine.[2] This stands in stark and obvious contrast with the first seven chapters of *Das Kapital* and the brunt of Marxist thought where the labor theory of value holds sway, notably that labor is the sole source of all value. In short, the labor theory of value is nothing more than classical production theory writ large. Hence, we have an example of the fundamental dichtomy that characterized the 19th century, namely the growing chasm and struggle between production as modeled in economics and production as modeled in the physical sciences.

Widening this chasm was a set of issues that were divorced from the question of production. Among these were (i) the business cycle and (ii) the question of income distribution. Without delving into the details, the labor theory of value was the key element of Marx's theory of surplus value and the ensuing policy prescriptions. A theory of value based on Chapter 15 of *Das Kapital* would have pre-empted all of Marx's substantive analysis, positive and normative. In fact, one could go as far as to argue that it would have pre-empted virtually all of radical economics.

Put differently, Marx's labor theory of value can be viewed as an intellectual ruse intended to justify a set of beliefs and principles regarding income distribution and the business cycle – specifically, the role of the rising rate of surplus value in precipitating the business cycle. He knew only too well that the steam engine had relegated labor to a supervisory role, and that material processes were, by then, powered primarily by motive power.

He was not alone. In the period before Marx (BM) and after Marx (PM), writers ignored the obvious, preferring to promulgate theories of material wealth that were increasingly orthogonal to classical mechanics and the developing field of thermodynamics. Consider the following cases. In the BM period, we consider the case of Adam Smith, who in the Wealth of Nations, attempted to analyze his friend Matthew Boulton's Watt steam engine. In the PM period, we consider the case of William Stanley Jevons who provided the classics' response (i.e. the establishment's response) to Marx's claim to the effect that capital was unproductive and hence profits and all forms of payments to capital were a form of theft.

2.1 Adam Smith and the Wealth of Nations

Before addressing the question proper, a few facts bear noting. First, Adam Smith, James Watt and Matthew Boulton were acquaintances. Second, James Watt had perfected his version of the Newcommen atmospheric steam engine in 1769, seven years before Smith published his magnum opus, the *Wealth of Nations*.

It is our view that the Wealth of Nations was, in large measure, a response to the steam engine and the enormous potential that it brought to bear on the British economy. And

[2] That he included the "electromagnetic machine" in 1867 should be seen as a testimony to his perspicacity and knowledge of the underlying engineering and physical principles of industrial material processes in the 19th century.

nowhere is this more evident than in Chapter 1 where he examined the question of labor productivity. In a nutshell, productivity had increased due (i) specialization (ii) lower downtime due to multiple tasks and (iii) machinery (Smith 1776). The latter were tools that had until then been powered by human muscle but were now powered by “fire power”. Basing most of his observations on Matthew Boulton’s Hockley Brook factory powered by Watt steam engines, Chapter 1 could well have been entitled “The Effects of Fire Power on Labor Productivity and Wealth.”

This raises the question, why did Smith nest “fire power” in a discussion of labor productivity? After all, fire power had rendered labor’s motive power (i.e. brawn) redundant. The reason, we believe, had to do with the politics of “fire power”. Workers throughout Great Britain feared for their future as machines would replace artisanal weavers, spinners, metal workers, etc. By portraying machinery (fire power) as the friend and not the foe of conventional labor, he hoped to increase its acceptability.

The upshot, however, was disastrous for economics as it sired classical production theory where output was modeled as a function of labor and labor alone. Paradoxically, at a time when labor had been reduced to a supervisory role, it was elevated to the role of sole factor input – productive factor input, that is. However, in Smith’s defense, the steam engine in the 1770s was as much an enigma to Newtonian physicists as it was to moral philosophers of the day.

2.2 William Stanley Jevons and the theory of political economy

Perhaps the most influential of 19th century iconoclasts – in large part, much in spite of himself, – was Willam Stanley Jevons, the father of neoclassical production theory. In the *The Theory of Political Economy* published in 1874, he outlined what was to become neoclassical production theory, namely that wealth is an increasing, continuous, twice-differentiable function of homogenous labor and capital. A lesser known, but equally important contribution, was his *The Coal Question An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal-Mines*, published in 1865 in which he addressed the question of Great Britain’s dwindling coal reserves. In the opening salvo, he declared:

> “Day by day it becomes more evident that the Coal we happily possess in excellent quality and abundance is the mainspring of modern material civilization. As the source of fire, it is the source at once of mechanical motion and of chemical change. Accordingly it is the chief agent in almost every improvement or discovery in the arts which the present age brings forth. It is to us indispensable for domestic purposes, and it has of late years been found to yield a series of organic substances, which puzzle us by their complexity, please us by their beautiful colours, and serve us by their various utility.
>
> And as the source especially of steam and iron, coal is all powerful. This age has been called the Iron Age, and it is true that iron is the material of most great novelties. By its strength, endurance, and wide range of qualities, this metal is fitted to be the fulcrum and lever of great works, while steam is the motive power. But coal alone can command in sufficient abundance either the iron or the steam; and coal, therefore, commands this age – the Age of Coal.

> Coal in truth stands not beside but entirely above all other commodities. It is the material energy of the country – the universal aid – the factor in everything we do. With coal almost any feat is possible or easy; without it we are thrown back into the laborious poverty of early times" (Jevons 1865, 14).

Paradoxically, some nine years later (i.e. in 1874), coal or energy was completely absent from what is largely considered to be his magnum opus, namely *The Theory of Political Economy*, where capital is included in the production function and, more importantly, is assumed to be physically productive. In short, both labor and capital are assumed to be physically production and more importantly, are substitutable (Jevons 1874). One could argue that internal validity (i.e. *vis-a-vis* the debate over the role of capital in wealth) is what prevented Jevons from incorporating energy into the corpus of neoclassical analysis.

3. Growing dissidence

By the end of the 19th century, material processes as seen in economics and in thermodynamics were completely orthogonal, having little more than the dependent variable in common (i.e. output / wealth). Enter the second industrial revolution and the accompanying massive increase in energy consumption that resulted from the shift from shafting and belting to electric unit drive (Devine 1983, Sonenblum 1990), and you get the equivalence of an ecclessiastic philosophical crisis pitting engineers against economists. In this section, we examine the growing dissidence from outside – and to a certain degree, from within – of economics.

The second industrial revolution with its emphasis on a new power transmission technology that allowed for energy deepening – greater energy consumption per unit capital – brought out the glaring differences between economists and engineers over the underlying nature of material processes. As firms converted their cumbersome shafting and belting power drive technology to electric unit drive and cities, counties and states offered low-cost, grid-delivered electric power, productivity soared (Devine 1983, Sonenblum 1990, Beaudreau 1998). However, as neoclassical production theory ignored energy, these epoch-defining innovations failed to appear on the radar.[3] Moreover, as electric unit drive was less capital intensive than belting and shafting, investment expenditure actually fell as a result, making detection even less probable. .

The failure of the nation's leading economists to acknowledge the presence of what would be an epoch-defining change in material processes led to a chorus of criticisms, largely from statisticians and engineers. To them, the U.S. was in the midst of an industrial revolution, one to which the economics profession appeared to be oblivious. F.G. Tyron of the Institute of Economics (Brookings Institution) was among the first to point to the incongruity between production processes as modeled in economics and those observed in early 20th century America.

> "Anything as important in industrial life as power deserves more attention than it has yet received by economists. The industrial position of a nation may be gauged by its use of power. The great advance in material standards of

[3] In fact, it was only with the introduction of the notion of a general purpose technology (GPT) in the 1980s that the integral role of electricity in the second industrial revolution was formally acknowledged.

> life in the last century was made possible by an enormous increase in the consumption of energy, and the prospect of repeating the achievement in the next century turns perhaps more than on anything else on making energy cheaper and more abundant. A theory of production that will really explain how wealth is produced must analyze the contribution of this element of energy.
>
> These considerations have prompted the Institute of Economics to undertake a reconnaissance in the field of power as a factor of production. One of the first problems uncovered has been the need of a long-time index of power, comparable with the indices of employment, of the volume of production and trade, of monetary phenomena, that will trace the growth of the factor of power in our national development" (Tyron 1927, 281).

One year later (i.e. in 1928), Woodlief Thomas of the Division of Research and Statistics of the Federal Reserve Board published an article in the *American Economic Review* entitled "The Economic Significance of the Increased Efficiency of American Industry," in which he attributed the "striking changes" in American industry to power-related developments:

> "Large-scale production is dependent upon the machine process, and the increasing use of machinery and power and labor-saving devices has accompanied the growth in size of productive units. The growing use of power in manufacturing, for example, is reflected in the increase in horsepower of installed prime movers. This does not tell the whole story, moreover, for owing to increased use of electricity, the type of power used is now more efficient requiring less fuel and labor for its production. Out of a total installed horsepower in factories of thirty-six million in 1925, twenty-six million or 72 percent was transmitted to machines by means of electric motors, as compared with 55 percent in 1919, 30 per cent in 1909, and only 2 per cent in 1899. Between 1899 and 1925 horsepower per person employed in factories increased by 90 percent and horsepower per unit of product increased by 30 percent. Power has been substituted for labor not only through machines of production but also in the form of automatic conveying and loading devices" (Thomas 1928, 130).

In little time, this incongruity reached academia, specifically Columbia University where a group of engineers, known as the Technocacy Alliance outrightly rejected mainstream approaches to understanding wealth (essentially neoclassical production theory), arguing that they ignored mechanics, thermodynamics, process engineering and with the then state of the art regarding material processes in general.[4]

Foremost in the minds of the "dissidents" was the fact that while America's capacity to produce wealth was increasing, actual wealth appeared to be stagnant, prompting various calls to action. One such call came from the engineering department at Columbia, where Walter Rautenstrauch and Howard Scott launched the Technocracy movement. In short, it contended that mainstream economics in general and production theory in particular were irrelevant, not to mention incomplete and unscientific, and was in need of a major overhaul.

[4] While the Technocracy movement went through a number of iterations, organization-wise, our analysis will refer to the movement in general.

The latter would be grounded in thermodynamics in general and in energy in particular. In short, while not knowing it, the Technocrats were attempting to steer economics back on to a course similar to that taken by thermodynamics in the 19th century, one based on a the scientific underpinnings of material processes in economics.

Implicit in the Technocracy movement was a biting indictment of economics in general and production theory in particular. All material processes known to man were energy based, except in economics. There could be and would be no compromise. Neoclassical economics was rejected outright as scientifically irrelevant.

Driving the Technocracy movement was the view that energy-related innovations (electric unit drive in particular) had increased America's ability to produce without a concomitant increase in income and expenditure, leading to stagnation, unemployment and a full-blown depression. Technocracy offered both a diagnosis of the problem and a series of corrective measures/ reforms (an energy monetary standard, guaranteed income). The movement, however, lost much of its appeal with the rise of Keynesian economics, which provided a less radical fix. In short, animal spirits replaced the energy shock as the cause of the downturn.

Such boldness, especially from non-practitioners, was met with great resistance from the profession. For example, University of Chicago economics professor Aaron Director, in a pamphlet entitled, the Economics of Technocracy, seriously doubted its usefulness, arguing that mainstream economics and production theory was better suited to analyze the issues it sought to address. To begin, he summarized Technocracy in terms of six points:

i. The importance of energy: Through the expenditure of energy we convert all raw materials into products that we consume and through it operate all the equipment that we use." This, of course, has always been familiar to us, except that it was stated in terms of work, and not of energy. The great merit of the latter term is the possibility of dragging in the Law of Conservation of Energy and this marrying physics to the social mechanism.
ii. Energy can be measured, and the unit of measurement is always the same, while the dollar varies from time to time.
iii. The chief distinction between our society and that of all previous societies is the much greater amount of energy which can be generated. This has always been recognized by the designation of our civilization as the machine era.
iv. With every increase in the amount of mechanical energy the need for labor decreases.
v. The present depression marks the end of an era, since the increase in mechanical energy has at last become so great that, regardless of what happens, the need for human labor will rapidly decline.
vi. Does it follow, therefore, that the price system must break down, and that only he engineers can run a mechanical civilization (Director 1933, 8).

In short, according to Director, Technocracy offered nothing new, and, more importantly, was riddled with the most elementary of oversights and errors. Energy was nothing new, and, as such, presented no particular challenge to mainstream political economy. Technological progress, in this case, electric drive, increased, in a commensurate fashion, actual output and income, wages and profits. The causes of the Great Depression, he argued, lie elsewhere, notably in the war, the resulting debts, and tariffs without being more specific.

Another early 20th century dissenter was British Nobel-prize laureate chemist Frederick Soddy, who after his pioneering work with Ernest Rutherford on atomic transmutation turned his attention to economics, largely in response to the alleged "misspecification" of production theory, more to the point, to the absence of energy from the analysis. The gist of his critique can be found in the following allegory:

> "At the risk of being redundant, let me illustrate what I mean by the question, How do men live? by asking what makes a railway train go. In one sense or another the credit for the achievement may be claimed by the so-called engine-driver, the guard, the signalman, the manager, the capitalist, or share-holder, or, again, by the scientific pioneers who discovered the nature of fire, by the inventors who harnessed it, by Labour which built the railway and the train. The fact remains than all of them by their united efforts could not drive the train. The real engine-driver is the coal. So, in the present state of science, the answer to the question how men live, or how anything lives, or how inanimate nature lives, in the sense in which we speak of the life of a waterfall or of any other manifestation of continued liveliness, is, with few and unimportant exceptions, By sunshine. Switch off the sun and a world would result lifeless, not only in the sense of animate life, but also in respect of by far the greater part of the life of inanimate nature. The volcanoes, as now, might occasionally erupt, the tides would ebb and flow on an otherwise stagnant ocean, and the newly discovered phenomena of radioactivity would persist. But it is sunshine which provides the power not only of the winds and waters but also of every form of life yet known. The starting point of Cartesian economics is thus the well-known laws of the conservation and transformation of energy, usually referred to as the first and second laws of thermodynamics" (Soddy 1924, xi).

In short, according to Soddy, energy is the cornerstone of all human activity, including production. Labor, capital, information, technology etc. are all accessory inputs, necessary for but not the actual source of wealth. Despite much promise, the proposed Cartesian economics, based on the laws of basic physics (mechanics and thermodynamics) failed to make inroads into mainstream economics.

The fallout for engineering-based models of material processes is there for all to see. Energy would be absent from production theory, growth theory and economics in general until the 1970s. Interestingly, Edward Denison's encyclopedic view of the sources of growth (Denison 1962) ignored energy altogether, as did Zvi Griliches and other pre-1970 growth economists. There was, however, an exception, namely Roumanian economist Nicholas Georgescu-Roegen who in The Entropy Law and the Economic Process," provided an alternative account of production, one that he referred to as the flow-fund model of production. A "fund" factor is either labour power, farm land or man-made capital providing a useful service at any point in time; a '"stock" factor is a material or energy input that can be decumulated at will; and a "flow"' factor is a stock spread out over a period of time. The fund factors constitute the agents of the economic process, and the flow factors are used or acted upon by these agents.[5]

[5] Georgescu-Roegen contributed in a non-negligible way to the development of ecological economics where the economy is modeled in terms of entropy. While these models are consilient with basic physics and thermodynamics, they fail to address the issues raised by conventional economics, focusing for the

Despite its breadth, the “flow-fund model of production” suffered from a number of short-comings. For example, the question of physical productivity was not adequately addressed as he implicitly assumed that capital and labor were physically productive. Further, both the breadth of his work (addressing such questions as sustainability) and the theoretical errors that were well documented, combined to cast a shadow on the flow-fund model as an accurate description of material processes, and on physics-based models of material processes. In other words, the controversy surrounding his use of entropy to describe not only energy but materials, and the myriad debates that ensued served to obfuscate his main contribution, namely that energy powered all known material processes.[6]

4. The straw that broke the camel’s back: the productivity slowdown

Like a jilted lover, lady energy took her revenge in the 1970s with two crises, 1973 and 1979. Having ignored energy for the good part of two centuries, the profession now was faced with the task of understanding/analyzing the fallout. The problem was that production theory was devoid of energy. In fact, energy was no more than an intermediate input (U.S. Survey of Manufacturers), hence not productive.

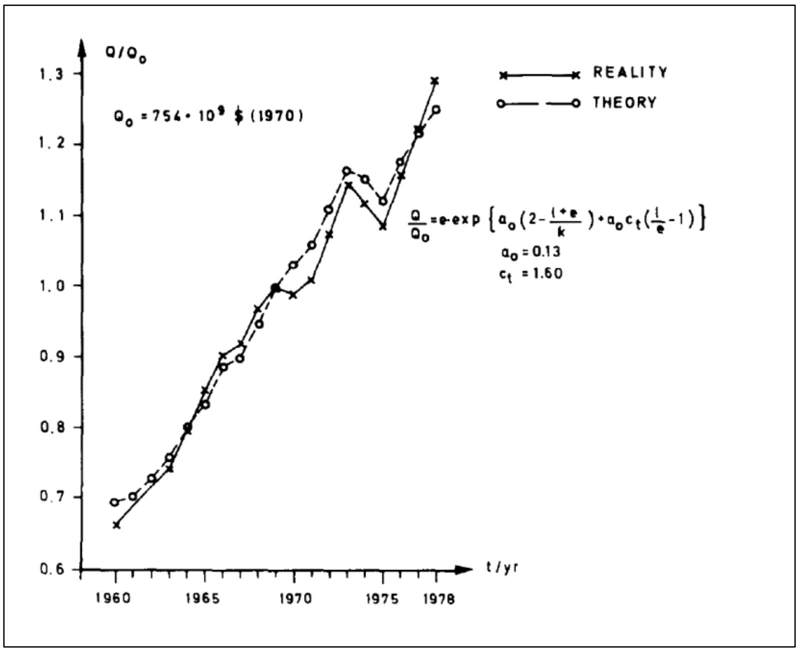
Ernst Berndt and David Wood, in 1975, began to fill this void with the KLEMS production function, where energy, materials and services were added to capital and labor. The energy output elasticity was estimated at 4-6%, leading them to conclude that energy was a relatively unimportant factor input. The energy crises, they reasoned, would affect output via the respective cross-elasticities, specifically the energy-capital cross-elasticity.

The Berndt-Wood estimates would go on to frame the debate over the role of the energy crises in the productivity slowdown. In short, most agreed that a quadrupling of the price of energy and the myriad energy shortages and embargoes were non-issues. There was, however, one exception, German physicist Reiner Kummel who argued the contrary, showing that productivity and growth tracked energy use/consumption (Kummel 1982). In short, the rate of growth of energy use/consumption had de facto slowed down, resulting in lower productivity and growth. Using an estimation technique known as LINEX, he reported an energy output elasticity of 0.58, significantly higher than that of Berndt and Wood (1975), one that was more in keeping with classical mechanics and thermodynamics. Beaudreau (1995) reported a similar elasticity of 0.53 for U.S. manufacturing (1950-1984), confirming Kummel’s findings.

most part on sustainability and environmental degradation. Questions such as the role of labor and capital in material processes are not addressed, with the result that it is largely ignored in mainstream economics.

[6] Interestingly, Paul Samuelson described his work as perhaps the most important contribution of his era. Yet, energy and entropy continued to be absent from his work, acting as a metaphor for the role of entropy, namely important but ignored in formal analysis.

Figure 1 Actual and predicted growth of U.S. GDP 1960-1978



Source: Kummel (1982)

These findings did little to change the narrative. In short, energy continued to be regarded as a non-issue and an intermediate input. Moreover, production theory continued to be devoid of energy. Capital, labor and the Solow residual continued to garner virtually all of the attention.

Physics and the material sciences had made an incursion into economics via energy, but one that was short-lived and of no lasting consequence. Part of this had to do with the very manner in which it entered the equation, namely as an appendage to the traditional factors, capital and labor. In the KLEMS approach, capital, labor, energy, materials and services are all assumed to be physically productive. Even Kummel, who is a theoretical physicist, viewed capital and labor as physically productive, in violation of the laws of classical mechanics.[7] As Marx and Soddy had pointed out, motive power drives modern material processes, with labor and capital as passive (i.e. non-physically productive) inputs.

In the next section, we present the few attempts were made at consilient economics-material sciences approaches to modeling production. That is, models that are consistent with basic physics and address the issues raised by economists. It bears reminding that while both process engineers and economists study material processes, they do so for different reasons. The latter do so to better understand the wealth creating process, while the former do so to improve efficiency, or solve bottlenecks.

[7] Kummel's LINEX production function is typically specified as follows: $q_{CDE} = q_0 k^{\alpha_0} l^{\beta_0} e^{\gamma_0}$, where k is the capital input, l, the labor input, and e, the energy input.

5. Consilient models of production

As evidenced by the perspicacity of his insights into the fundamental nature of material processes in the industrial era, Karl Marx would have to be considered one of the earliest writers to present a "consilient" account/model of the wealth-creating process. Others include the Technocrats, with their emphasis on energy and its primordial role in material processes. However, neither Marx nor the Technocrats offered an analytical model of material processes, comparable in nature to the classical or neoclassical production function.

$$W(t) = n[T(t), S(t), I(t)]E(t) \tag{1}$$

Beaudreau (1998) presented the consilient energy-organization approach to modeling material processes, where he identified to universal factor inputs, namely broadly-defined energy and broadly-defined organization. Drawing from process engineering, he argued that the former was physically productive while the latter was organizationally productive.[8] Equation 1 presents the gist of the model, where W (t) is output, E(t) is energy consumption and η is second-law efficiency. The latter, in turn, is a function of S(t) the supervisory input, T (t), tools, and I(t) information. In keeping with basic physics, the latter three factor inputs are not physically productive, but rather are organizationally productive affecting second-law efficiency. Better tools (i.e. James Watt's external condenser, electric unit drive) increase energy efficiency by minimizing losses. As η is bounded from above, it stands to reason that organizational innovations will have limited effect on output and output growth.

Using data from U.S., German and Japanese manufacturing, he showed, like Kummel (1982), that productivity and growth tracked energy consumption, and more importantly, that the productivity slowdown coincided with a marked decrease in energy consumption growth, which in turn, coincided with the energy crisis. Table 1 reports the relevant growth rates for manufacturing value added Q, electric power EP, labor L and capital K, as well as the relevant fixed-weight aggregate input index (AI) for three time intervals: 1950–1984, 1950–1973, and 1974–1984. We see that virtually all growth in output in the pre- and post-productivity slowdown periods (i.e. before and after1973) is accounted for by growth in the inputs, with energy being the main driver.

In addition to rationalizing the productivity slowdown in terms of energy consumption growth, the energy-organization approach offers a simple, yet compelling account of the "information paradox," namely that information is a non-physically productive organizational factor input whose effect on second-law efficiency was not only punctual in nature, but theoretically limited – in the limit, zero.[9] In other words, because information is a non-physically productive input, it follows that the information paradox is not a paradox at all, but rather a manifestation of this simple fact.

[8] Process engineers typically consider two inputs, namely energy and information. See Alting (1994).

[9] This corresponds to the case in which second-law efficiency has reached its theoretical maximum, leaving little room for further information-based improvements. See Beaudreau and Lightfoot (2015) for further details.

Table 1: Output and input growth rates: U.S., German and Japanese manufacturing

US			
	1950-1984	**1950–1973**	**1974–1984**
USV A	2.684	3.469	0.121
USAI*	2.674	3.472	0.310
USEP	4.052	5.371	0.246
USN	0.662	0.900	-0.091
USK	3.694	3.614	3.4008
Germany			
	1963–1988	**1962–1973**	**1974–1988**
GERV A	2.462	6.522	1.486
GERAI*	2.433	5.190	1.080
GEREP	2.894	5.883	1.366
GERN	-0.785	0.592	-0.938
GERK	2.945	5.620	1.406
Japan			
	1965–1988	**1965–1973**	**1974–1988**
JAP V A	3.826	8.844	3.099
JAP AI*	3.566	9.856	1.538
JAPEP	3.559	11.320	0.965
JAPN	-0.082	2.297	-0.367
JAPK	7.520	13.536	5.182

* $\hat{\beta}_1 \frac{\dot{ep}(t)}{ep(t)} + \hat{\beta}_2 \frac{\dot{l}(t)}{l(t)} + \hat{\beta}_3 \frac{\dot{k}(t)}{k(t)}$, where $\hat{\beta}_i$ the estimated output elasticities, are taken from Beaudreau (1995).

Source: Beaudreau (1998).

6. The potential fallout from abandoning poor science by field

Consilent approaches to understanding material processes have important implications not only for growth, but for virtually all of the current fields and sub-fields of economics. This owes, in large measure, to the key role wealth and material processes play in each. In this section, we examine three such fields, namely labor economics, capital theory and finance and lastly, income distribution.

6.1 Labor economics

The role of what is commonly referred to as the labor input in modern (read: industrial) material processes has been the subject of vigorous debate from the very beginning. After all, the Watt-Boulton rotary steam engine had rendered human force/brawn redundant, relegating labor to a supervisory role, one that could be easily accomplished by women and even children. It was clear to most writers that labor was no longer physically productive, but organizationally necessary as machines were prone to stoppages and breakdowns.

As it no longer supplied the force driving tools (simple and complex), its claim on the spoils was increasingly under siege. Theoretically, there was no reason it should benefit from the resulting energy deepening (i.e. greater use of force) and greater productivity. From a strict "productivity" point of view, its contribution had been diminished, which would/could justify a lower wage.

Classical and neoclassical production theory, however, continued to put labor at the center of its analyses of material processes. The latter went as far as to attribute three-quarters of output to what had become a supervisory input – what Alfred Marshall referred to as "machine operatives."[10] Physically unproductive tools and equipment (i.e. capital) were assigned a secondary role, contributing to one-quarter of output. Ironically, energy, the only truly physically productive input, was ignored.

This brings us to consilient models of material processes and their implications for labor economics. The first implication is definitional and descriptive, namely accurately describing the role of modern-day labor in production processes. In short, labor is a supervisory input, and one whose role in production is currently under siege from ICT-based control devices. In other words, Marshall's machine operatives are being replaced with automated control systems. In time, there is reason to believe that labor as we know it today will disappear, bringing with it, the end of human supervision. In his 1995 best-selling book, the End of Work, Jeremy Rifkin makes a similar argument. However, it should be pointed out that his choice of title is misleading as work will continue unfettered, it being the product of the continuous application of force.[11] A more appropriate title would have been The End of Human Supervision of Material Processes.

6.2 Capital theory and finance

The role of tools (simple and complex) in material processes has not only been the subject of great debate, it has spawned some of the most notable schisms in economics. Is capital productive, and if so, what is the extent of its contribution? The classics viewed it as a complement to labor, but not productive in and of itself – consistent with classical mechanics. As pointed out above, this led to the first schism in economics when Karl Marx declared, on the basis of classical production theory, that profits were a form of theft, given that capital was not physically productive. To remedy the situation and restore legitimacy to capitalism, the neoclassical writers simply decreed it to be physically productive, thus entitled to a share of the output.

Consilient approaches to production invariably invoke the laws of classical mechanics with regard to capital. Put differently, tools and equipment are not, per se, physically productive, providing mechanical advantage.[12] This has important implications for capital theory and

[10] Interestingly, the British from Marshall on, referred to labor as "operatives," and not workers, the implication being that labor "operated" machinery, and did not "work" in the traditional sense.
[11] As odd as it may sound, workers stopped working with the introduction of inanimate power / energy / force, metamorphisizing into what was a supervisory input.
[12] Mechanical advantage is a measure of the force amplification achieved by using a tool, mechanical device or machine system. Ideally, the device preserves the input power and simply trades off forces against movement to obtain a desired amplification in the output force. The model for this is the law of

finance as both are based on the notion/belief that capital is productive and hence can legitimately lay claim to a share of the spoils. In its absence, the theory breaks down, raising the question how should the owners of tools and equipment be remunerated? What share of output should they receive? One thing however is obvious, namely that they, no more than labor, are entitled to energy's productivity.

6.3 Income distribution

As can be surmised, the implications of consilient models of material processes for the distribution of income are far-reaching. The neoclassical approach based on labor and capital physical productivity is rendered null and void as neither of these two factor inputs is physically productive. While the question of alternatives is beyond the scope of this paper, we can nonetheless speculate as to possible replacements.

Were we to invoke a pure productivity standard, it is clear that all output would revert to the owners of the sole physically productive factor, namely energy. However, such a standard would not be incentive compatible for labor and capital. Another possibility would be to provide labor and capital with their reservation factor payment so as to entice participation. Put differently, the owners of energy would share in the spoils in order to ensure that organization be present. A third possibility would be for the owners of energy to share what Beaudreau (1998) referred to as "energy rents," defined as the difference between the value of energy's physical product and its cost.[13] Accordingly, the greater part of the wages that are now paid to labor would consist of energy rents, as would the greater part of profits paid to capital. Such a view is implicit in David Lloyd George's view of wages noted in Coal and Power in 1924:

> "Those people are best paid and most prosperous that make use of the resources of science.....the average level of earnings must depend on production and production increases as the use of power per head of population increases" (Lloyd George 1924).

As such, variations in income shares over time (Piketty 2014) can be seen as resulting from changes in the bargaining game over energy rents. As Piketty has shown, capital's share increased in the 1920s and from the 1980s onwards. The former can be attributed to the energy deepening in the form of electric power in the 1920s, while the latter can be attributed to ICT-based factory automation, both of which allowed the owners of capital to appropriate a larger share of the associated energy rents.

---

the lever. Machine components designed to manage forces and movement in this way are called mechanisms. An ideal mechanism transmits power without adding to or subtracting from it. This means the ideal mechanism does not include a power source, is frictionless, and is constructed from rigid bodies that do not deflect or wear. The performance of a real system relative to this ideal is expressed in terms of efficiency factors that take into account friction, deformation and wear (https://en.wikipedia.org/wiki/Mechanicaladvantage).

[13] 13Lindenberger and Kummel (2002) made a similar argument in what is a different context. Specifically, they pointed out that: "If wealth had been distributed according to the "marginal productivity theory", labor would have received only a share of national income much smaller than the observed 70%. But apparently, in the past most of the value added by energy was attributed to labor. The underlying mechanism of distribution was that of wage-negotiations in which free labor unions, powerful during times of high employment, regularly succeeded in winning wage increases according to the growth of productivity, i.e. increased production due to increased and more efficient energy utilization. This way most of the population in the industrialized countries benefited from the wealth generated by the production factors capital, labor, and energy.

7. The fault, dear Paul, lies not in our stars, but in ourselves, that we are underlings

In his analysis of post-real macroeconomics, Paul Romer raised an extremely important question, namely why has poor science (i.e. imaginary shocks) been tolerated (Romer 2016)? The main reason, he argued, lies with the sociology of science, with the presence of steep dominance hierarchies in macroeconomics, controlled by a few gatekeepers or kingpins.

While we believe that this is part of the reason, we believe that it is incomplete. We believe that the principal reason the profession has tolerated (in the sense of not rejecting) and continues to tolerate and reinforce constructs like imaginary shocks has to do with the current state of production theory where residuals have become the "acceptable" norm. In short, it has to do with the primitive yet universally accepted accounts of production, accounts that continue to be orthogonal to the material sciences in general.

As the Solow residual is universally accepted, the notion that it varies over time, and in some cases, takes on negative values, is not as much of a stretch as one would think. In other words, existence and variability conspired to provide legitimacy to the notion of a systemic "negative" productivity shock. The "kingpins" or "gate keepers" got away with it because they appealed to something that is second nature to the current generation of economists, namely the Solow residual, and variability over the spectrum of real numbers. Today, the Solow residual is as much a part of growth theory and economic theory in general as are the traditional factor inputs, capital and labor. Put differently, Kydland and Prescott would not and could not have gotten away with "imaginary shocks" had they not been part of the intellectual landscape that is present day economics.

8. Conclusions

It is our view that until the economics profession gets production right, nothing can be and will be right in economics. For over two centuries, we have failed to heed the advice of physicists, production engineers, engineers in general, even chemists, preferring to promulgate models that while convenient and self-serving, are nonetheless theoretically misspecified and stand in violation of the basic laws of physics.

Economics is the only field within the material sciences in which growth is still shrouded in mystery. We submit that the reason has to do with the lack of consilience or pluralism. Instead of rendering our models consistent with those used elsewhere in the material sciences, we have created a world onto ourselves in which the laws of physics are suspended or even worst, violated. It therefore comes as little surprise that applied fields like macro or economic growth rely on imaginary concepts.

It is our view that a revolution of sorts is required in the field of production theory. However, we hasten to add that in actual fact it would be less of a revolution, and more of an acknowledgement of over a century of parallel thinking and theorizing. While the fallout will be great for labor economics, capital theory and finance and income distribution, we feel that we have no choice. Either we continue to be irrelevant, or we begin the long and arduous task of rendering our formalizations of material processes consistent with those found in the material sciences (i.e. consistent with basic physics), and in so doing, of putting economics on the track of scientific legitimacy and respectability.

It is our view that had economics heeded the advice of the dissenters in the 1930s, it would have sparred itself much turmoil, including post-WWII growth theory based on the imaginary Solow residual, post-productivity slowdown RBC macroeconomics, also based on the imaginary Solow residual, and 30 years of post-productivity growth theory (Romer, Lucas, Aghion and Howitt) that has failed to understand these very shocks. Further, we feel that until we acknowledge the basic fact that material processes in economics are analogous to those found in the material sciences in general, and we incorporate this fact in the modeling of production pro-cesses, economics will continue to be stricken with paradoxes, puzzles and imaginary constructs, not to mention irrelevancy.

References

Alting, Leo (1994) *Manufacturing Engineering Processes*. New York, NY: Marcel Decker Inc.

Beaudreau, Bernard C. (1995) "The Impact of Electric Power on Productivity: The Case of U.S. Manufacturing 1958–1984," *Energy Economics*, 17(3), 231–236.

Beaudreau, Bernard C. (1998) *Energy and Organization: Growth and Distribution Reexamined*. Westport, CT: Greenwood Press.

Beaudreau, Bernard C. and Douglas Lightfoot (2015) "The Physical Limits to Economic Growth by R and D-Funded Innovation," Energy, 84.

Beiser, Arthur (1983) *Modern Technical Physics.* Menlo Park, CA: The Benjamin/Cummings Publishing Company.

Berg, Maxime (1980) *The Machinery Question and the Making of Political Economy*. Cambridge: Cambridge University Press.

Berndt, Ernst and David Wood (1975) "Technology, Prices and the Derived Demand for Energy," *Review of Economics and Statistics*, 57(3), 259–268.

Denison, Edward F. (1962) *The Sources of Economic Growth in the United States and the Alternatives Before Us*. New York, NY: Committee for Economic Development.

Denison, Edward F. (1985) *Trends in American Economic Growth 1929–1982*. Washington, DC: The Brookings Institution.

Devine, Warren D. (1990) "Electricity in Information Management: The Evolution of Electronic Control," in Schurr, Sam. H. et al. (eds.), *Electricity in the American Economy*. Westport CT: Greenwood Press.

Director, Aaron (1933) *The Economics of Technocracy*. Chicago, IL: University of Chicago Press.

Georgescu-Roegen, Nicholas (1971) *The Entropy Law and the Economic Process*. Cambridge, MA: Harvard University Press.

Griliches, Zvi (1994) "Productivity, R and D, and the Data Constraint," *American Economic Review*, 84(1), 1-23.

Jevons, W.S. (1865) *The Coal Question, Chapter 1*. London: MacMillan and Co.,

Jevons, W.S. ([1874]1965) The Theory of Political Economy, Augustus M. Kelley, Bookseller, New York.

Kummel, Reiner (1982) "The impact of energy on industrial growth," *Energy* 7 (2): 189-201

Kummel, Reiner, Dietmar Lindenberger, and Wolfgang Eichhorn (1998) "The Productive Power of Energy and Economic Evolution," *Indian Journal of Applied Economics, Special Issue on Macro and Micro Economics*.

Dietmar Lindenberger and Reiner Kummel, (2002) "Thermodynamics and Economics," *Post-Autistic Economics Review*, 14, June 24.

Lloyd-George David (1924) *Coal and Power*. London: Hodder and Stoughton.

Marx, Karl, (1906) "Machinery and Modern Industry," in Marx, Karl, *Das Kapital* (Chapter 15), New York, NY: The Modern Library.

Piketty, Thomas (2014) *Capital in the 21st Century*. Cambridge, MA: Harvard University Press.

Rifkin, Jeremy (1995) *The End of Work*. New York, NY: Putnam Publishing Group.

Romer, Paul (2016) *The Trouble With Macroeconomics*, Stern School of Business, New York University. https://www.law.yale.edu/system/files/area/workshop/leo/leo16romer.pdf

Rosenberg, Nathan (1972) *Technology and American Economic Growth*. Armonk, NY: M.E. Sharpe.

Rosenberg, N. (1983) "The Effects of Energy Supply Characteristics on Technology and Economic Growth," in Schurr, S. et al. (eds.) *Energy, Productivity and Economic Growth*. Cambridge, MA: Oelgeschager, Gunn and Hain.

Smith, Adam (1990) "Of the Division of Labour," (Book I, Chapter 1), *An Inquiry into the Nature and Causes of the Wealth of Nations*, Chicago, IL: Encyclopaedia Britannica, 1–12.

Soddy, Frederick (1924) *Cartesian Economics, The Bearing of Physical Sciences upon State Stewardship.* London: Hendersons.

Sonenblum, Sidney (1990) "Electrification and Productivity Growth in Manufacturing," in Sam H. Schurr, Calvin Briwell, Warren D. Devine Jr. and Sidney Sonenblum, eds. *Electricity in the American Economy: Agent of Technological Progress*. Westport, CT: Greenwood Press.

Syll, Lars Palsson (2016) "Paul Romers assault on post-real macroeconomics", *Real-World Economics Review*, 76, 30 September, pp. 43-54. http://www.paecon.net/PAEReview/issue76/Syll76.pdf

Thomas, Woodlief (1928) "The Economic Significance of the Increased Efficiency of American Industry," *American Economic Review*, 18, 122–138.

Tyron, F.G. (1927) "An Index of Consumption of Fuels and Water Power," *Journal of the American Statistical Association*, 22, 271–282.

U.S. Department of Labor, (1967) *Productivity and Technological Change in the Petroleum Refining Industry.* Department of Labor Statistics, Washington, DC.

Author contact: bernard.beaudreau@ecn.ulaval.ca

SUGGESTED CITATION:
Bernard C. Beaudreau, "The trouble with production theory", *real-world economics review*, issue no. 77, 10 December 2016, pp. 85-102,
http://www.paecon.net/PAEReview/issue77/Beaudreau77.pdf