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Why Has Growth Theory Been a Failure?

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Abstract
Why has growth theory been a failure? By growth theory, it should be understood the various approaches to economic growth, from Edward Dension's work in the 1950s and 1960s, to that of Robert Solow and Paul Romer. In short, why has the residual approach to growth been unsuccessful both empirically and policy wise, the latter being evidenced by the failure of policy worldwide to restore growth to its post-WWII levels. Drawing from the science of material processes, it argues that the core approach to modeling material processes in economics (i.e. neoclassical production theory) is orthogonal to those found in the material sciences in general, as well as to the basic laws of physics (classical mechanics, thermodynamics, kinetics), resulting in puzzles and paradoxes, the most celebrated of which is the Solow residual, the focus of growth theory for the past four decades. When a consilient approach is invoked, they virtually disappear, ushering in a new era, one in which growth is shown to be analogous to growth in other material sciences.

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1. Introduction

The slowdown in productivity growth in the mid-to-late 1970s (a.k.a. the Productivity Slowdown) constituted and continues to constitute the greatest challenge ever undertaken by the economics profession, the latter being defined as academic, government and professional economists. While the Great Depression was, in many ways, a more catastrophic event, it did not unleash a tsunami of research the way the Productivity Slowdown has. This owed to a number of factors including the primitive state of macroeconomics at the time, the lack of sophisticated analytical and empirical tools, and the glaring lack of data, resulting in work that was more speculative (as to the causes) than in what could be referred to as serious or scientific work. All of this had changed by the 1980s, when theory, empirical methods and data had evolved considerably.

Yet, despite the progress, the results have been, to put it mildly, disappointing. The evidence is there for all to see. Despite four decades of throwing virtually all the profession has at the problem, after pulling out all the stops, after holding no punches, the problem of economic growth remains whole. Perhaps the most telling piece of evidence is the abject failure of policy. Western industrialized nations have reinvented themselves, slashing government, signing free trade agreements, subsidizing research to the tune of trillions, rewriting the tax code with the wealthy and the corporate in mind, transforming universities into technical colleges, and yet, nothing—in fact, growth rates continue to decline. In short, the past four decades of growth have been an unqualified failure both on the theoretical front and in policy circles.

This paper asks the obvious question why? Why has growth theory been a failure? After all, growth *per se* is understood in virtually all other material sciences. Take, for example, the plant sciences where it has been understood for centuries, or in cellular biology. In short, there is no other material science where growth is not understood today, except in economics. In this paper, it will be argued that the main reason lies with the orthogonality of economic growth models to the physics of material processes in general. In other words, the lack of consilience with the laws of the universe is largely to blame. On a more upbeat note, once the basic principles of classical mechanics, thermodynamics and kinetics are incorporated into the analysis, it can be shown that the myriad puzzles and paradoxes disappear. Put differently, once the economics profession embraces the elements of basic science, it will join the rest of the material sciences in having understood growth.

The paper is organized as follows. To begin with, we present a consilient theory of growth in the material sciences, the energy-organization framework. This will then be followed by a critical review of production theory and of growth theory, starting with Adam Smith. The upshot is that most of what today constitutes the basis of the theory of production/growth violates basic physics. That this be the case is highlighted by the presence, over the course of the past two centuries, of discordant voices and approaches.

2. The Energy-Organization Framework

In virtually every material process-based field/discipline, the process of growth is not only well understood, it has been and is systematically reduced to its thermodynamic and/or kinetic equivalent (biology, ecology, demography). In short, growth is either a function of growth in energy availability/use—whether it be within a stationary or non-stationary environment—or an increase in second-law efficiency. The quintessential example is photosynthesis where the growth of biomass is a function of solar radiation/light, the latter being the force that acts on biomass to produce carbohydrates/sugars.

Table 1: Material Processes, Energy and Organization Inputs

Material Process	Energy Input	Organizational Input
Chemical Processes	Heat	Kettles, Laddles
Manufacturing Processes	Kinetic Energy	Simple and Complex Tools
Photosynthesis	Solar Radiation	Molecular Structures and Raw Materials
Mitochondria	Glucose Molecule	Structure of Raw Material

In fact, essentially all material sciences focus on growth and hence have developed analytical frameworks to describe and understand it. Take, for example, biology, specifically plant biology which has modeled growth in terms of photosynthesis, where solar radiation powers a series of chemical reactions which result in the production of glucose. As in all other material sciences, energy is the essential factor input. Unlike material processes as studied by engineers, there are no tools (simple or complex) involved. Similarly, unlike cell growth where the set of instructions is contained in the organism's RNA or DNA, there is no specific set of instructions nor of supervision. Table 1 presents a list of material processes and the work-energy and non-work-energy-based factor inputs.

Beaudreau (1998) outlined a consilient approach to understanding material processes and growth in general—that is, across disciplines. The energy-organization (hereafter EO) approach models material processes in terms of two universal factor inputs, namely broadly-defined energy and broadly defined organization, the former being physically productive, while the latter being organizational. In keeping with basic mechanics and thermodynamics, energy and energy alone does work, the implication being that all other factors are organizational in nature.

$$W(t) = \eta[T(t), S(t), I(t)]E(t) \quad (1)$$

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 organizational in nature, affecting second-law efficiency, shown here as η.[1] Better tools (i.e., Watt's external condenser, the Boulton-Watt dual-action steam engine, 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 (Beaudreau and Lightfoot 2015). Equation 1 provides a simple description of the EO approach to material processes, with $E(t)$ being the energy input and η being the thermodynamic concept of second-law efficiency. This can be seen as a measure of energy productivity, which in this case, is a function of the relevant organizational variables, including tools ($T(t)$, supervision $S(t)$, and information ($I(t)$).[2] Beaudreau (1998) maintained that this simple model was universal in scope, being applicable to all material processes.

The EO approach to growth is as simple as it is straightforward, namely that growth of the output is an increasing function of growth of the energy input as well as growth/innovations in η, second-law efficiency. The key as far as we are concerned is the universality of Equation 1. Any and all growth processes in the material sciences is/are predicated on growth in the energy input, and, the case that concerns us here, growth in the organizational context. For example, in the case of wealth-related material processes, growth requires an increase in energy as well as an equivalent increase in tools and supervision—conventional capital and labor.[3]

This raises the question of input productivity or, put differently, the contribution of factor inputs to output and growth. In keeping with basic mechanics and thermodynamics, the only physically productive factor input is energy/force. All others are organizational inputs, which define the material process, but are not productive in the traditional sense.[4] Put differently, they increase with output, but are not the

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[1] One could argue that they are organizationally productive in the sense that they affect the "quality" of the material process which has a bearing on second-law efficiency—that is, the productivity of energy.

[2] While all are ultimately energy based, the corresponding energy has no bearing on output. For example, labor or supervision is energy-based (workers or control devices). Information, specifically information transmission,

storage and retrieval, is also energy based.

[3] In artisanal material processes, the energy input is provided by human beings, specifically by human muscles. See Beaudreau (1998) for a detailed taxonomy of material processes and energy inputs.

[4] For more on the role of tools in material processes, see Alting (1994) and Beiser (1983).

ultimate cause.[5] 1921 Chemistry Nobel prize laureate-turned economist Frederick Soddy captured the essence of material processes—animate and inanimate—in the following parable.

> At the risk of being redundant, let me illustrate what we mean by the question "How do men live?" by asking what makes a railroad train go? In one sense or another, credit for the achievement may be claimed by the so-called "engine-driver," the guard, the signalman, the manager, the capitalist, the share-holder,-or again, by the scientific pioneers who discover the nature of fire, by the inventors who harnessed it, by labour which built the railroad and the train. The fact remains that all of them, by their collective effort 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 another manifestation of continued liveliness, is, with few and unimportant exception, "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. (Soddy 1921, 4)

In the next section, the EO framework will be used to examine critically, both production and growth theory, from Adam Smith to Robert Solow.

3. A Critical Overview of Production and Growth Theory

Growth theory, defined as the systematic analysis of growth and growth rates, is a relatively recent development, dating back to the post-WWII period. Previously, growth was assumed to be part of production theory, where factors contributing to increased GDP were enumerated. The analysis was mostly descriptive but couched in either a classical or neoclassical framework. In this section, we examine both the history of production theory as well as its scientific validity.

Our starting point is Adam Smith's *An Inquiry into the Nature and Causes of the Wealth of Nations,* published in 1776. Our focus is Chapter 1, where he presents what would become the classical theory of wealth. In short, output or wealth was an increasing function of the labor input, with the latter's productivity being governed by specialization-induced factors, including (*i*) learning-by-doing, (*ii*) reduced wasted time changing tasks and (*iii*) the use of machinery. These factors would affect labor productivity, and thus affect output.

With the benefit of hindsight, this was a somewhat odd way to model the introduction of the steam engine, which he referred to as fire power. In actual fact, the steam engine would relieve workers of work in the physical sense, as they would now become organizational inputs, overseeing steam engine-powered material processes. Yet, he would ascribe the increased output (productivity) to labor, arguing that specialization (code for industrialization) would make workers better off, and not worse off as many at the time maintained. From that point on, the phenomenal growth in Great Britain's wealth (i.e., the wealth of the nation) would be tied to growth in the work performed by coal.

Yet ironically, coal would be absent from the analysis for centuries. Which begs the question, why? We contend that the reason lies with Smith's ultimate purpose, namely of (*i*) convincing workers of the advantages of specialization and thus of the steam engine and (*ii*) making a case for free trade which

[5] In most material processes, organizational inputs are minimal (e.g. photosynthesis).

would increase the "extent of the market" and thus accelerate specialization. In other words, it had nothing to do with the current "scientific" endeavor of understanding material processes. Put differently, classical production theory was more propaganda than hard science.

The next major development was neoclassical production theory, which dates back to the 1870s, when William Stanley Jevons published the *Theory of Political Economy.* In essences, it was a response to the radicals (e.g., Marx, Engels) who maintained that profits were a form of theft given that labor was the only productive factor input. The radicals were, in actual fact, classical in their views on production as output was an increasing function of labor. Capital's role was obscure, being nested in labor productivity.

Thus, by a simple wave of a wand, or flick of a pen, capital entered the production function and was assigned a marginal, average and total productivity, thus legitimizing profits and fending off the growing radical challenge. Again, as was the case with Smith and Classical production theory, Jevons' neoclassical framework was not the result of a quest to understand the science of material processes but rather, a retort to the radicals. Instead of falsifying the Classical view according to which labor was physically productive, he—and other neoclassical writers—added another non-physically productive factor input to the analysis of the origins of wealth.

The next milestone was the work of Charles Cobb and Paul Douglas in the mid-1920s. In 1928, the two published the first set of estimates of the neoclassical production function, specifically, the labor and capital output elasticities. Assuming a twice differentiable, homogenous of degree one production function, they obtained values of 0.75 and 0.25 for labor and capital's output elasticities, respectively. Their production function also included a scaler, A, which they argued captured technology. This was a momentous development as it lent credibility to the underlying theory as well as provided hard numbers.

Again, like Smith and Jevons, Paul Douglas' motives were not so much scientific as they were political. In actual fact, he alongside numerous others in the Progressive movement in the U.S. believed that productivity growth had outstripped wage growth. To justify his position, he felt that hard data would be required. In short, he sought to prove the existence of law or regularity according to which wage income should, at all times, represent 75 percent of national income, a task he would spend the rest of his academic career pursuing.

Fast forward to the post-Great Depression and post-WWII period when the issue of macroeconomic dynamics would become front and center. According to British economist Roy Harrod, the Keynesian model was an incomplete description of the business cycle and of the economy as it was static. To his way of thinking, the analysis should be dynamic and include growth. Thus was born what would become known as the Harrod-Domar growth model. To accomplish this feat, he started with a fixed-proportions, capital-labor production function. This would lead to a model of equilibrium growth which required that s/v be equal to n, or s, the ratio saving to income, divided by the v, capital-output ratio, be equal to n, the rate of growth of the labor force. Implicitly, Harrod and Domar assumed that capital and labor were both productive and the source of wealth.

The razor's edge problem and Harrod's claim that Western industrialized economies were inherently unstable and prone to crises, led Robert Solow and Trevor Swan to reformulate the Harrod-Domar model by assuming a variable v, which, not surprisingly eliminated the problem. The result was the Solow-Swan growth model. Again, with the benefit of hindsight, what was a response to a macroeconomic problem or query, would go on to constitute the core model of economic growth. Put differently, like Smith and Jevons, these writers had not set out explicitly to uncover the scientific underpinnings of wealth creation but rather, were intent on resolving an outstanding conundrum. The resulting account of growth (i.e., growth theory) was simply a by-product.

The upshot of this short history of production and growth theory is straightforward, namely that what constitutes the core of production and growth theory was, in actual fact, a by-product of a series of contributions motivated by anything but uncovering the underlying scientific principles of material processes. Smith, the pamphleteer, wanted to sway public opinion, Jevons wanted to rescue capitalism, Douglas wanted to give teeth to the Progressive agenda, Harrod wanted to prove instability while Solow wanted to refute the latter. Not surprisingly, the final product left and leaves much to be desired.

This raises the obvious question, what, if anything, does contemporary growth theory explain? By contemporary growth theory, it should be understood, the view that labor, capital and a residual are the cornerstones of growth. Given that both labor and capital are organizational factor inputs and thus, non-physically productive, it stands to reason that from a physical productivity point of view, contemporary growth theory explains virtually nothing as the third element is the residual, which as its very name implies, is non-explanatory. Labor isn't physically productive, nor is capital, making for a situation in which neither of the three cornerstones is able to account for growth.

We would, however, be amiss to maintain that the past two centuries have been a bust. After all, there have been attempts at a more scientific understanding of production and growth. We now turn and examine some of these.

4. Missed Opportunities

The past two centuries have witnessed the evolution of material sciences, from its origins in Newtonian physics, to classical mechanics, to thermodynamics and finally, to kinetics (translational, rotational, chemical). Originally known as natural philosophy—as opposed to moral philosophy—the material sciences soon broke off into a number of subfields, including applied physics, mechanics, engineering and the fields of chemistry and biology. All, however, were grounded in the laws of mechanics, thermodynamics and kinetics.

While mainstream thought in general ignored these developments, there were exceptions, some more notable than others. In this section, we present a handful of these, ranging from Charles Babbage's 1832 masterpiece "On the Economy of Machinery and Manufactures," to 1923 Nobel Prize laureate (Chemistry) Frederick Soddy's bold attempt to rewrite production theory, "Cartesian Economics'." The upshot is simple, namely that not all political economists were impervious to the developments in the material sciences. However, as we shall argue, many chose to ignore them for ideological/political reasons.

4.1 Charles Babbage's On the Economy of Machinery and Manufactures 1832

Perhaps the earliest attempt at invoking basic science as a guide to understanding industry was that of Charles Babbage in 1832. In *On the Economy of Machinery and Manufactures,* he provided detailed scientific descriptions of the new technology. Consider, for example, the following excerpt where classical mechanics is used to illustrate the contribution of wind, water, and steam.

> Of those machines by which we produce power, it may be observed, that although they are to us immense acquisitions, yet in regard to two of the sources of this power, the force of wind and of water, we merely make use of bodies in a state of motion by nature; we change the directions of their movement in order to render them subservient to our purposes, but we neither add to nor diminish the quantity of motion in existence. When we expose the sails of a windmill obliquely to the gale, we check the velocity of a small portion of the atmosphere, and convert its own rectilinear motion into one of rotation in the sails; we thus change the direction of force, but we create no power....The force of vapour is another fertile source of moving power; but even in this case it cannot be maintained that power is created. Water is converted into elastic vapour by the combination of fuel. (Babbage 1832, 15)

Interestingly, he devoted a whole chapter to speed or what he referred to as "velocity." Chapter 4, entitled "Increase and Diminution of Velocity," showcased using industry-specific examples the role of increased machine speed as a key feature of mechanization.

> In turning from the smaller instruments in frequent use to the larger and more important machines, the economy arising from the increase in velocity becomes more striking. In converting cast into wrought iron, a mass of metal, of about a hundred weight, is heated almost to white heat and placed under a heavy hammer moved by water or steam power. This is raised by a projection on a revolving axis; and if the hammer derived its momentum only from the space through which it fell, it would require a considerably greater time to give a blow. But it is important that the softened mass of red-hot iron should receive as many blows as possible before it cools, the form of the cam or projection on the axis is such, that the hammer, instead of being lifted to a small height, is thrown up with a jerk, and almost the instant after its strikes a large beam, which acts as a powerful spring, and drives it down on the iron with such velocity that by these means about the double the number of strokes can be made in a given time. (Babbage 1832, 26)

Whereas previous writers referred to specialization, Babbage provides a detailed account of the role of power in material processes in general, and the role of steam power in U.K. manufacturing. Further, he perspicaciously was the first to formalize the role of rotary motion/power in material processes, alluding to the importance of velocity or put differently, machine speed. To Babbage, science mattered. Unfortunately, Babbage did not matter to political economy as evidenced by his absence from the overall record.

4.2 Frederick Soddy's 1921 Cartesian Economics

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 1921, 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.

4.3 F.G. Tryon

To many observers in the early 20th century, the U.S. was in the midst of an industrial revolution, one to which the economics profession appeared to be oblivious. F.G. Tryon 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 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 [Tryon (1927),281].

4.4 Technocracy as Described by Howard Scott

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.[6]

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 were in need of a major overhaul. The latter would be grounded in thermodynamics in general and in energy in particular. In short, while perhaps not fully aware of 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 the scientific underpinnings of material processes in economics.

For example, in *Introduction to Technocracy,* by Howard Scott, published in 1933, the first 10 pages contained a rendition of basic applied physics, thermodynamics and kinetics. This would then constitute the basis of the new science of wealth, one based on the laws of physics.

> The eighteenth century say the introduction of the powered machine, which was first conceived as an extension of the hand operations of craftsmen. The close of the nineteenth century witnessed the machine process occupying a dominant place in the technological scheme and reshaping men's habits and methods of thinking., The turn of the century marked the introduction and the accelerating rise, under guidance of science of the modern, continuous technological processes of production. In this new industrial order, the machine was no longer conceived as an extension of the hand tool; it became a moving mechanical element in a sequence of events, the course and rate of which had been arranged and ordered in strict accordance with the exact quantitative calculations of science. Men in the fields of scientific inquiry and technological research, the same as those directly engaged in technological employment, gradually ceased to think in terms of workmanlike efficiency of a given cause working to like effect: they began to think in terms of process. (Scott 1933, 8)

As mentioned, the driving force 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. The movement offered both a detailed diagnosis of the problem as well as a series of corrective measures/reforms (an energy monetary standard, guaranteed income). It, 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 depression.

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:

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

> 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.
>
> Energy can be measured, and the unit of measurement is always the same, while the dollar varies from time to time.
>
> 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.
>
> With every increase in the amount of mechanical energy the need for labor decreases. 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.
>
> Does it follow, therefore, that the price system must break down, and that only the engineers can run a mechanical civilization. (Director 1933, 8)

He then proceeded to re-examine, using standard neoclassical analysis, each of these points. In keeping with the 19th century tradition of equating energy with machinery, the shock was cast in terms of “technical progress,” and not of energy deepening. This was then followed by a Ricardian-inspired analysis of the effects of “technical progress” on costs, wages and prices.

Competition, he argued, was a sufficient condition for full employment.

> On the other hand, the technocrats maintained that a more scientific utilization of existing equipment would result in a much larger product: “It is only necessary to insist that the number of engineers in industry far outweigh the number of economists, and if these engineers are to run industry in the future, they should be competent to point out methods of improving efficiency. It is not enough to hide behind a barrage of words. It should be patent to the most critical observer that the one thing which the individual enterprise under competitive conditions does strive for is to reduce its cost, regardless of the consequences on employment.’ (Director 1933, 16)

Having concluded that “technical progress is not incompatible with full employment,” he proceeded, in Chapter VII, to debunk the view that the Great Depression was the result of energy-based technological change. This, metaphorically speaking, is where the gloves came off. First, he, in the tradition of Say and Ricardo, ruled out underincome. Output, he argued, is identically equal to income, whether in the form of money or in kind.

> If there were no commercial banking system, the national income would be distributed for consumption goods and the production of additional equipment in accordance with the desires of the community. The output of industry is equal to the income of the laborers employed in it and of the property owners whose capital is invested in it. Clearly, if entrepreneurs borrowed funds directly from the income receivers, they could

> not continue to produce capital equipment in excess of the amount which income receivers were willing to save. (Director 1933, 21)

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, more importantly, presented no particular challenge to mainstream political economy. Technological progress, in this case, electric drive, increases, in a commensurate fashion, income, wages and profits. The causes of the Great Depression, he argues, lie elsewhere, notably in “the war, the resulting debts, and tariffs.”

4.5 Nicholas Georgescu-Roegen’s The Entropy Law and the Economic Process 1971

Nicholas Georgescu-Roegen’s *The Entropy Law and the Economic Process* (1971) is another example of basic science at the core of economics. Its premise is straightforward, namely that thermodynamics is based on two laws: The first law states that energy is neither created nor destroyed in any isolated system (a conservation principle). The second law of thermodynamics – also known as the entropy law – states that energy tends to be degraded to ever poorer qualities (a degradation principle).

Georgescu-Roegen argued that the relevance of thermodynamics to economics stems from the physical fact that man can neither create nor destroy matter or energy, only transform it. The usual economic terms of production’ and ’consumption are mere verbal conventions that tend to obscure that nothing is created and nothing is destroyed in the economic process – everything is being transformed

He recognized that capital as defined in economics was not physically productive. Rather, that role was assumed by energy. In Georgescu-Roegen’s terminology, energy may have the form of either a stock factor (mineral deposits in nature), or a flow factor (resources transformed in the economy); but never that of a fund factor (man-made capital in the economy). Hence, in response to Robert Solow’s 1974 claim that capital could be substituted for energy, he argued that such a substitution is physically impossible.

Unfortunately, his message was lost on production theory which remained unfettered (i.e., neoclassical). While entropy, or the degradation of matter is today recognized, especially in ecological economics, the role of negentropy in production continues to be ignored.

4.6 Karl Marx’s Das Kapital 1867

Karl Marx’s *Das Kapital,* published in 1867, is today considered to be a classic in 19th century political economy, having laid out the bases for the labor theory of value, the rate of surplus value and Marxian economics in general. Starting from classical production theory where wealth is an increasing function of the labor input, he went on to elaborate a theory of the laws of motion of capitalism based on technological change, declining wages and rising profits. Capitalism, he argued, contained the seeds of its own destruction. Policy-wise, the implications were straightforward: profits were a form of theft and justice could only be done if surplus value was returned to its rightful owners (and only productive factor input).

The bulk of these ideas are found in the first few chapters of Das Kapital. However, in Chapter 15, entitled *Machinery and Modern Industry”,* he provided an altogether different account of production, one based on classical mechanics, and one that could very well rival any engineering manual of the day. In short, he described, at length, the steam engine and force in general as the motive power and force behind industrial production. 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 Claussen's 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 transmitting 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 manufacture, is turned into an industry carried on by machinery. (Marx 1867, 261).

One wonders how and indeed why the writer who penned these words and thoughts could go on to defend the labor theory of value and all that it implies (i.e., its many derivatives). Clearly, Marx had devoted a considerable amount of time understanding the physics of material processes, specifically focusing on classical mechanics. In short, he understood the role of power, as well as the notions of simple and complex machines.

All of this, however, was inconsequential as it was summarily ignored, sacrificed on the ideological altar of distribution issues and concerns. Had he taken his analysis to its logical conclusion, he would have concluded that neither labor (supervisory input) nor capital (tools) were physically productive, and that only energy/force/power was. Distribution would involve sharing the final output, not on productivity grounds, but on the basis of a bargaining process (i.e., bargaining power).

4.7 William Stanley Jevons' The Coal Question and The Theory of Political Economy

As pointed out, Karl Marx sacrificed science and consilience on the ideological altar of distribution, with the known consequences and results. Clearly, the world would have been better off had science mattered to him. Another such case is that of William Stanley Jevons who today stands as the key architect of modern neoclassical economics. In 1865, he published a short book entitled *The Coal Question; An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal Mines.* As the title suggests, Jevons was very much concerned about what was an obvious concern in the case of the finite resource that was coal, namely its eventual exhaustion. Clearly, he viewed coal as one of, if not the key factor input in the industrial revolution and thus, of the industrial era. Consider his opening lines:

> 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).

To Jevons, coal or energy was the mainspring of modern civilization, being the source of fire, mechanical motion and chemical change. Clearly, at this point in his career, science mattered. As he put it, “coal in truth stands not besides but entirely above all other commodities.” Fast forward to 1872, five years after the publication of Marx's *Das Kapital* which had stood classical economics, especially distribution, on its head, and the publication of his magnum opus, *The Theory of Political Economy* which would go on to define modern neoclassical economics. Surprisingly, but not unexpectedly, coal/energy is conspicuous by its very absence. Seven years later, coal had gone from hero to zero. Wealth was an increasing function of labor and capital, period. More importantly, capital was decreed to be physically productive, thus not only contravening classical mechanics, but providing a pat response to the growing radical movement. Clearly, by then science no longer mattered as ideological considerations took precedence over intellectual integrity.

5. Why Were Advances in Material Sciences Ignored?

Why is it that dialogue across what are related fields is, for all intents and purposes, non-existent in economics? Why haven't process engineers teamed up with growth theorists to understand the intricacies of past (and hopefully future) growth? Why have the very people who have a firsthand understanding of the very processes underlying growth been left out, not even consulted? In this section, we present a number of non-mutually-exclusive reasons, from the early history of the discipline, to the ideology and propaganda of the 19th century, to the medium of diffusion of results (journals as opposed to books), to the creation of a Nobel prize.

5.1 Tabula Rasa

The first reason we advance has to do with the very history of the discipline, namely that it predates its tributary disciplines. Economics has a history that dates back to the mid-18th century, a time when thermodynamics was non-existent. Moreover, early work such as Adam Smith's "An Inquiry into the Nature and Causes of the Wealth of Nations" was about the newly-discovered, Watt steam engine. As such, when Smith was confronted with the daunting task of describing the effects of the steam engine on wealth, he had to resort to primitive notions, couching his analysis in what was a Paleolithic, labor-centric view of production, one that focused on labor. This became known as the classical theory of production, with a single factor input, namely labor. Chapter 1 of the Wealth of Nations enumerates the various ways in which specialization (code for the adoption of the steam engine) increases labor productivity.

From a purely Newtonian point of view, this was a breach, as the steam engine had, for all intents and purposes, replaced labor as the source of work, transforming it into a mere organizational factor input, overseeing the workings of machinery—-what Alfred Marshall would, a century later, refer to as machine operatives. That this be the case is not surprising as Smith, a moral philosopher, was not a natural philosopher (i.e., schooled in Newtonian physics). Not helping matters was the fact that steam as a force was not well understood—in fact, not understood at all. It would take a century before thermodynamics, the science of heat, would do so.

However, economics or political economy could not wait. The introduction of the steam engine and its widespread adoption in the 19th century with all the associated problems and challenges, obviated the need for a science, however imperfect or unscientific. Among the most pressing problems was the business cycle and the apparent failure on the part of England to make a successful transition to the new, higher GDP in response to the steam engine. Rather than greater wealth, the steam engine ushered in periods of higher unemployment and misery.

5.2 The Labor Theory of Value and the Problem of Existence and Stability of Equilibria

This, however, raises an interesting question, namely that while it is true that economics predates the fundamental fields, why were their insights not incorporated at a later date? In other words, why did economics not evolve, why did it not update itself? The answer, we argue, lies with two developments, namely the rise of radical economics in the early-to-mid 19th century with Karl Marx as its main proponent, and second, the resulting allegation that private market economies were inherently unstable (i.e., Harrod Instability), and more importantly, contained the seeds of their own destruction. Both of these were instrumental in the widening divide between economics and fundamental science, notably thermodynamics.

Karl Marx's magnum opus, *Das Kapital* published in1867 was a turning point of sorts, as it turned classical production theory on its head. If labor was the only productive factor input, then it stood to reason that the owners of labor were the only ones entitled to the spoils. In short, profits were a form of theft. This followed from the fact that capital was not physically productive. The classical response was swift, coming with the publication of William Stanley Jevons' *The Theory of Political Economy* in 1872 were capital was simply decreed to be productive. Using the language of thermodynamics, it was decreed to be physically productive, complete with a marginal productivity, thus justifying profits as legitimate, both physically and legally, The result was neoclassical production theory based on two, non-physically-productive factor inputs.

This, we maintain, *de facto* stifled progress in the field as it provided the long-sought legitimization of profits not as a form of theft, but as being earned or merited. Any and all critiques were dismissed outright, as they constituted a clear and present threat to the established order.

Another factor that *de facto* stifled progress was the problem of equilibrium, specifically system-wide, macroeconomic or general equilibrium. One of the key predictions of radical economics was the inevitability of overall, systemic collapse. According to Karl Marx, capitalism contained the seeds of its own destruction. Given the recurrent downturns in U.K. GDP throughout the 19th century, some greater than others, this became a going concern. Clearly, the onus was on classical and neoclassical economists to prove, mathematically or otherwise, that private market economics could reach a full-employment equilibrium, one that was unique and most importantly, stable. From the late 19th century onwards, the quest to prove that such an equilibrium existed would occupy the thoughts of leading figures such as Leon Walras and Vilfredo Pareto.

However, as their work makes clear, the task was far from obvious. In short, to arrive at such a proof, the starting point had to be simple, namely excess demand functions that were analytical. And this required a simple model of consumer and producer behavior. This would continue to be the case in the 20th century when new methods from topology would be used (Brouwer and Kakutani's fixed-point theorems).

As has been the case in all highly-formalized work involving advanced optimization techniques, the starting point had to be as simple as possible. This, we argue, has contributed to stifling even further, the emergence of more consilient models of consumer and producer behavior. Put differently, mathematical elegance and tractability pre-empted more realistic approaches to consumer and producer behavior. A case in which formalization acted and continues to act as a constraint on progress.

Moreover, this had a rather pernicious effect on first principles. Specifically, the profession reverse engineered, as it were, the results of GE analysis to first principles—consumer and producer theory. Simple max $U(x)$ and max $\pi(q)$ became the standard in microeconomics, thus pre-empting any and all refinements. After all, anything other would negate GE analysis and results.

5.3 The Decline of Pamphlets/Treatises/Volumes and the Rise of Scholarly Journals

For most of its history, the findings in economics were diffused through either pamphlets or books. In fact, most of that which today constitutes the core curriculum in modern economics originated in pamphlets or books, not in journal articles. While this to most will appear or seem irrelevant or inconsequential, we believe that it has an important bearing on the evolution of economics. Specifically, journal articles are not, in general, conducive to Kuhnian-like paradigm shifts in thought, owing in large measure to the length and purview of the contents. In short, journal articles are more conducive to the propagation of, the refinement of, and the testing of the canons of the field/science. For example, in economics, articles on consumer theory seek to validate, refine, or extend the basic utility maximization model. To my knowledge, there is not one article that single-handedly changed the course of a field or the profession itself.

Historically, economic journals evolved from being a combination of book reviews and short articles/comments to exclusively devoted to the latter. Take, for example, the *American Economic Review,* founded by a group of politically-minded scholars, which in its early years devoted more space to book reviews as it did to articles. Figure 1 shows the contents of the inaugural volume of the *American Economic Review.* What is particularly noteworthy is the fact that of the seven pages of content, six and one-half are book reviews, the other half being articles. In other words, it accorded more importance, in so far as the advancement of the field was concerned, to new ideas/concepts than it did to refinements of existing ones. The same was true of the *Journal of Political Economy* whose inaugural number contained 36 book reviews and 24 articles.

Figure 1: American Economic Review 1911 Table of Contents

This changed in the post-WWII period when the focus shifted away from book reviews, over to journal articles exclusively. One could argue that this was the result of two developments, namely the rise of Keynesian macroeconomics and the publication of Paul Samuelson's *Foundations of Economic Analysis*, both of which served to provide the field with a pseudo-scientific set of laws. Both became the reference and thus starting point in work for years to come. Interestingly, neither had anything to do with fundamental science, despite the highly mathematical nature of *Foundations of Economic Analysis.*

This shift had the unfortunate effect of stifling progress in what could be referred to as economic fundamentals. Today, consumer theory remains largely unchanged as does the theory of the firm. While economics has witnessed the introduction of new, more sophisticated analytical techniques (dynamic optimization, duality etc.), the core has remained largely unchanged. Few leading journals are prepared to take risks, with the result that little progress has been observed. Add to this the fact that the gatekeepers (i.e., the editors) have a stake in the existing paradigm and you get a form of sclerosis, where journals essentially reproduce existing knowledge.

5.4 A Nobel Prize in Economics

Perhaps the crowning achievement of the economics profession in so far as its scientificity is concerned was the creation in 1968 of a Nobel prize in economic sciences. For one, it *de facto* consecrated economics as a bona fide science, distinct from all other social sciences (moral philosophy), thus dissipating any and all doubts as to its "scientific" status. However, examining in detail the various laureates and their contribution, what stands out is the lack of connection with the other scientific Nobel prizes—that is in physics, chemistry and medicine.

In many instances, prizes given in medicine could well have been given in chemistry or physics, and vice-versa, a testimony of the universal nature of science (fundamental and applied). For example, the 1997 prize in Medicine, awarded to Paul Boyer for his research on ATP could well have been awarded in chemistry or physics for that matter.

Despite the fact that wealth creation is a material processes, like all other material processes in the known universe, no such collegiality exists in economics. Not one of the prizes in economics could have been awarded in the other three scientific categories. One could argue that this is evidence that science does not, *de facto,* matter.

6. What Economics Would Look Like Were the Material Sciences Integrated in a Meaningful Way

Over the course of the past one hundred years, omissions or oversights in neoclassical economics have, for the most part, been rectified with what I shall refer to as addenda—that is, parametric add-ons to the basic utility and production functions. A good example is the long list of additions to consumer theory, including things like altruism, framing effects, warm glows, reciprocity and identity. In production theory, the list includes management, information, energy, materials, services, highways, etc. In both cases, the essence of the analysis has remained the same. What has changed are the relevant parameters and variables.

The results have been less than convincing. Take for example Ernst Berndt and David Wood's KLEMS production function which added energy, materials and services to the traditional factor inputs of labor and capital. While a step in the right direction, especially with regard to the energy input, it is nonetheless anti-scientific as it imparts no known laws or physical theories of production, making for a situation in which all five are assumed to be physically productive and thus, on an equal footing. Clearly, this is a violation of two hundred years of applied physics/engineering. Furthermore, the upshot is that energy, the only physically-productive input, is relatively unimportant, having an output elasticity of 0.04.

In this section, we provide examples of how science can shed light on a number of puzzles in contemporary economics. We start with the Information Paradox as formulated by Nobel laureate Robert Solow. Accordingly, it maintains that we see computers and IT everywhere but in the productivity statistics, the idea being that despite their prevalence, computers seem not to affect productivity and wealth, as originally thought. Physics, however, tells us that information is not a source of energy and, as such, cannot do work. The only possible effect is on second-law efficiency, specifically more or better information can reduce losses, thus increasing useful work. This follows from basic physics.

Another example is the productivity slowdown. Basic physics tells us that productivity is work (value added) relative to energy input. It therefore stands to reason that if productivity growth has slowed down, then energy growth has also slowed down. In other words, the rate of increase of the energy input has slowed, which is exactly what we observe. The question is then why? Reiner Kummel pointed to the OPEC-engineered energy crises in the 1970s, which coincided exactly with the timing of the productivity slowdown. In recent work, I pointed to the underlying kinetic limits of material processes (Beaudreau 2020). Specifically, increasing machine speeds were the hallmark of the industrial revolutions. However, the age of forever increasing speeds came to an end in the late 1960s, early 1970s, touching off the productivity slowdown. In short, we had reached our kinetic limits.

7. Summary and Conclusions

This paper asked and attempted to answer the question, why has growth theory been a failure? Starting from the premise that wealth creation is a material process and that material processes in general are known to obey the laws of physics, the various theories of production and growth were examined critically, and found to be lacking. In fact, production theory and its derivative, growth theory, were found to violate the laws of physics. We showed, however, that over the course of the past two centuries, there have been exceptions in the form of numerous attempts on the part of both economists and non-economists to provide a consilient approach to understanding growth.

Thus, in conclusion, growth theory has failed, not for lack of good-will and effort. The past forty years have witnessed a veritable *blitzkreig* of activity on the part of the profession. All, however, has been for naught as the underlying foundations were, put bluntly, wrong. Nothing good could come of it, and, not surprisingly, nothing has. As Paul Krugman put it in his 2013 New York Times Op-Ed column entitled "The New Growth Fizzle":

> My own sense is that New Growth Theory never really had the elements needed to turn it into an intellectual success story; too much of it involved making assumptions about how unmeasurable things affected other unmeasurable things. It took off, briefly, partly because the subject is so important, and people wanted to be able to say something about it; meanwhile, business-cycle macro was then, as it is now, a deeply disputatious area riven by politics, and people were eager to talk about something else. In short, it was an intellectual bubble that eventually deflated of its own accord (Krugman 2013).

In closing, it is worthwhile noting that the steam engine engendered two (at least) scientific fields of inquiry, namely economics and thermodynamics, the latter being the science of heat/steam. Fast forward two hundred years and we find one of the two being mired in controversy and riddled with paradoxes and the other becoming one of the cornerstones of modern science, having spread its tentacles throughout virtually every scientific field. Why the difference? Because one respected

Newtonian physics while the other took it upon itself to reinvent the underlying physics of material processes, making a series of wild and erroneous assumptions, resulting ultimately in the failure that is there for all to see.

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