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The Solow Residual or What Happens When Moral Philosophers Try Their Hand at Natural Philosophy

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Abstract
Material processes are well understood in all of the fields of natural philosophy, that is, in all applied physics-based fields (e.g. biology, Astronomy). However, this is not the case in economics where they remain an enigma, the Solow residual perhaps the best testimony. This paper argues that this unfortunate and unacceptable state of affairs owes in large measure to the fact that moral philosophers, from Smith to Romer, were and are ill-equipped to understand the laws that govern modern production processes, forcing them to develop alternative principles and laws, principles and laws which contravene those of natural philosophy and principles and laws which are the principal cause of what Moses Abramovitz referred to as our measure of ignorance, namely the Solow residual.

Introduction

From the enlightenment to the 19th century, the realm of knowledge consisted of moral philosophy which dealt fundamentally with the behavior of human beings, and natural philosophy which dealt with the behavior of material/physical processes/systems. David Hume and Adam Smith are examples of the former, while Newton, Leibniz and Fourier are examples of the latter. Physical systems consist of material processes which are energy based.[1] The transformation of raw materials is one such process, involving energy whether it be muscle based, or inanimate in nature (coal, oil, hydro, nuclear, etc.).

The industrial revolution witnessed the introduction of a new energy source, one that would increase the operating speed/velocity of existing material processes and thus increase productivity manifold, namely the steam engine (atmospheric, reciprocating and turbines). For example, artisan-operated looms were replaced by steam-powered ones, operating at greater speeds, and for longer periods (24/7). At work were the laws of physics, notably the law of kinetics according to which the velocity or speed of material processes was increasing in the square root of energy consumption. Put differently, energy consumption increased at the square of process velocity or speed. Ultimately, the result was levels of material wealth never before seen or experienced.

According to natural philosophy, specifically classical mechanics, thermodynamics and kinetics, neither capital (simple and complex tools) nor workers, not being sources of force/energy, are physically productive. In fact, workers were relieved of their age-old role of powering material processes with the widespread introduction of the Boulton-Watt reciprocating steam engine. As Alfred Marshall would point out in 1890, the workers of the pre-industrial period (i.e. those whose brawn

[1] Most of modern calculus (differential and integral) owes to the study of force/energy, as does classical mechanics. In short, natural philosophy is, in essence, the study of force/energy.

powered material processes) had metamorphosed into machine operatives. This is illustrated poignantly in contemporary process engineering textbooks where capital or tools define material processes and labor is, for all intents and purposes absent.

What Happens When Moral Philosophers Try Their Hand at Natural Philosophy?

Unfortunately for us all, natural philosophers were, for the most part, uninterested in the wealth of nations and more specifically, in the introduction of the steam engine in 1769. For at least two reasons. First, their interest was focused on celestial interests (planetary motion) and on motion (Isaac Newton) and second, steam as a force was poorly understood (thermodynamic laws were still a century away). As a result, the task fell on moral philosophers, the first of whom was Adam Smith who in 1776 penned "An Inquiry into the Nature and Causes of the Wealth of Nations" which is the first attempt by either a natural or moral philosopher to understand the laws of motion of industrial material processes.

As it turned out, the study of wealth-related material processes would over the next two centuries, with a few exceptions, be the exclusive domain of moral philosophers. Which is ironic as the subject matter was unequivocally one of natural philosophy. This paper chronicles the study of material processes by moral philosophers from Adam Smith to Paul Romer. It focuses on the evolution of what is referred to in the literature as production theory and its dynamic equivalent, growth theory highlighting the various constructs that were introduced over time. It will be shown that owing to their limited knowledge of the laws and concepts of natural philosophy, they would go on to elaborate a new set of laws, ranging from the law of diminishing marginal product of labor and capital to the Solow residual.

It is argued that if like in all other material sciences, the laws of natural philosophy were invoked and respected, most of what is known today as production theory would unfortunately be invalidated. The paper is organized as follows. To begin with, the paper chronicles the writings of moral philosophers from the early 19th century to the present. This is then followed by a scientific rejoinder, consisting of a physics-based approach to production. Lastly, it presents the various discordant voices regarding classical and neoclassical production theory over the past two centuries.

Material Processes as Seen by Moral Philosophers

This section examines material processes as seen by prominent 19th and 20th century moral philosophers. Table 1 begins with a listing of the 19th century stalwarts along with a description of their training/education. What is immediately obvious is the extent to which not one had any training in natural philosophy, with moral philosophy being the dominant major/area of specialization. It bears reminding that moral philosophy consisted, in large measure, of the fields of rhetoric, logic, philosophy, morals, ancient and modern languages and history. While Thomas Malthus was the only ecclesiastic -that is, member of an official church - all were trained as such – that is, as ministers/priests.

Table 1: 19th Century Moral Philosophers/Political Economists: University and Major

Moral Philosopher/Political Economist	*University*	*Degree*
Adam Smith 1723-1790	University of Glasgow	Classical and Contemporary Philosophy
David Hume 1766-1834	University of Edinburgh	Moral Philosophy
Thomas Malthus 1766-1834	Jesus College, Cambridge	English, Latin and Greek

Karl Marx 1818-1883	Bonn University	Law and Philosophy
John Stuart Mill 1806-1873	Schooled by James Mill, father.	Classics
William Stanley Jevons 1835-1882	University College School	B.A. and M.A. in Moral Sciences
Alfred Marshall 1842-1924	St-John's College, Cambridge	Mathematics, Philosophy, Metaphysics, Theology and Ethics
Francis Edgeworth 1845-1926	Trinity College, Dublin	Classics, Ancient and Modern Languages
John Bates Clark 1847-1938	University of Zurich, University of Heidelburg	German Historical School

Table 2: 20th-Moral Philosophers/Economists

Moral Philosopher/Economist	*University*	*Degree*
Paul Samuelson 1915-2009	Chicago and Harvard	B.A., M.A., and PhD Economics
Milton Friedman 1912-2006	Rutgers, Chicago	B.A., PhD Economics
Franco Modigliani 1912-2003	New School of Social Research	B.A., PhD Economics
Robert Solow 1924-2023	Harvard	B.A., PhD Economics
Robert Clower 1926-2011	Oxford	B.A., PhD Economics
Robert Lucas 1937-2025	Chicago	B.A. History, PhD Economics
Edward Prescott 1940-2023	Carneige-Mellon	B.A. Operations Research, PhD Economics
Robert Gordon 1940-	Harvard, MIT	B.A., PhD Economics
William Baumol 1922-2017	London School of Economics	B.A., PhD Economics
Paul Romer 1955-	Chicago	B.A., PhD Economics

Table 2 presents the same listing of prominent 20th-century economists. Again, what stands out is the dearth of training outside the field of political economy, which as argued was an offshoot of moral philosophy. Another way of seeing 20th century economists is as second-generation moral philosophers, the main distinguishing feature was the extensive and intensive use of optimization techniques borrowed from thermodynamics (e.g. Lagrangians, Hamiltonians, Euler and Bellman Equations). The core of their training was (and remains to this day) firmly rooted in the work of 19th century moral philosophers/political economists (i.e. those listed in Table 1).[2]

Early 19th-Century Moral Philosophers

Considered to be the first political economists, the research methodology of early 19th century moral philosophers consisted mostly of observation. A good example of this is Adam Smith's description of a pin factory he had visited. The factory in question employed 10 workers and produced 48,000 pins per day. If each of the ten workers had done all the steps themselves, each worker could only produce only 10 or 20 pins per day. He was also a frequent visitor to Matthew Boulton's Soho Manufacture in Birmingham where he witnessed first hand the effects of what he would later refer to as fire power, but which was in actual fact the steam engine.

[2] On a personal note, this describes to a tee, my own training in economics.

The end result was the classical theory of production based largely on labor in short, output was an increasing function of the labor input. The latter's productivity, he argued, was increasing in specialization. His account of the workings of specialization (Chapter 1 *of The Wealth of Nations*) focused on (i) increased efficiency in performing a single task (ii) less time wasted changing tasks and (iii) the effects of machinery or fire power. Labor was viewed as the sole productive factor input, a view that would characterize the writings of all classical moral philosophers, including Frederick Engels and Karl Marx. In fact, the labor theory of value constituted the cornerstone of radical political economy

Revisionist 19th-Century Moral Philosophers

Radical political economy had a tsunami of an effect on classical thinking. After all, its cornerstone (i.e. the labor theory of value) was classical in origin. If labor was the source of all value, then it would only stand to reason that it and it alone would be entitled to the spoils. Profits or anything less than the full amount was akin to theft, of illegal appropriation on the part of the owners of the means of production, raising the question of how to justify, in a meaningful manner, profits, or roughly 30 percent of output being diverted?

Their response was swift. Less than five years after the publication of *Das Kapital* in 1867, classical political economists responded by simply decreeing capital to be physically productive, not unlike labor. The new classical, or neoclassical view was now that both labor and capital were physically productive and thus entitled, legally-speaking, to a share of the spoils.

Late 19th Century Moral Philosophers

By late 19th-century moral philosophers, it should be understood the likes of William Stanley Jevons, Alfred Marshall and Francis Edgeworth. Their methodology was three-fold in nature, consisting of (i) a reaction to radical thought (ii) the language of the emerging science of thermodynamics and (iii) a desire to formalize the analysis. Ironically, while they were the first moral philosophers to borrow from the realm of natural philosophy, notably from the field of thermodynamics where they focused on its form, namely language, and not on its content. The laws of thermodynamics were ignored, however, its form, namely differential calculus, became its language. The result was neoclassical consumer and producer theory.

Post-WWII Moral Philosophers

The post-WWII methodology consisted, primarily, of a call to the data, a call that would reveal the weakness ,of the neoclassical approach, namely that labor and capital, the two inputs, could explain, at best 50 percent of post-WWII growth. Needless to say, this came as a shock to the emerging field of economic growth.

The obvious explanation was technology, the black box of neoclassical production theory. And so was born, modern growth theory. Assuming a twice-differentiable, constant-return-to-scale production function, growth would be modeled as the sum of the weighted inputs growth-rates, and what was an error or fudge factor, namely the Solow residual. This remains the essence of modern growth theory. While the number of inputs has increased (KLEM and KLEMS production functions) and the residual has been rechristened as total factor productivity (tfp), this is where things stood until the 1980s when a new class of models made their appearance, namely those of new, endogenous growth theory.

As it turned out, the residual wasn't a problem, that is until it disappeared. Throughout the 1950s and 1960s, theorists attempted to get a handle on what was driving the residual, without making any inroads. A good example is Edward Denison's pioneering work on U.S. economic growth. The productivity slowdown, however, changed everything. Their work, while interesting, was deemed to be inconclusive and in need of revision. The residual would now be the subject of inquiry, of formal inquiry. Technology, which had until then been seen as parametric, would now be endogenized. The result was Romer-type and Schumpeter-type growth models, known collectively as new growth theory.

Unfortunately, despite the flurry of activity which resulted, complete with Nobel prizes, growth remained and remains a mystery, a mystery that it was in the past, and the mystery it would become for the next four decades. Today, this is where the profession finds itself in so far as growth is concerned, namely still in the dark. This, however, has not stopped governments around the world from pursuing growth-enhancing (hoped for) policies, based on some of the notions found in this literature, but to no avail, leading some of the leading members of the profession to question its very relevance. According to Paul Krugman:

> My own sense is that NGT 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.
>
> But it's still amazing, for someone who remembers the excitement of the time, how completely it has all vanished from the economics landscape. Krugman (2013), p. 3.

Material Processes as Seen by Natural Philosophers

Neoclassical moral philosophers, from Stanley W. Jevons to Paul Romer, hold that wealth is an increasing function of labor, capital and a technology scaler. Labor and capital are assumed to be physically productive as evidenced by such concepts as the marginal productivity of labor and the marginal productivity of capital. In more recent work, the laws that govern productivity are extended to inputs such as information and services.

This begs the question: how do applied physicists and engineers view these notions? How do they stack up against the laws of classical mechanics, thermodynamics and kinetics? The short answer is that they don't. According to classical mechanics, capital, defined as simple and complex tools, are not physically productive, not being a source of energy/force. Hence, the very concept of the marginal productivity of capital stands in violation of classical mechanics. According to classical mechanics, simple and complex tools are viewed as providing mechanical advantage, but are not physically productive as they are not a source of energy/force.

A similar argument applies to information, which according to contemporary moral philosophers is physically productive, having an output elasticity in the order of 6 percent (references). Such a view has no equivalent in natural science, where information is seen as definitional and not physically productive. More and/or better information acts on output via second-law efficiency, or to put it more simply, on the efficiency of energy use. James Watt's external condenser is an example of better information increasing the energy efficiency of a ton of coal.

Consider next the labor input which as shown above, was one of the first inputs to be examined by moral philosophers (Smith, Ricardo, Mill, Marx). By the mid-to-late 19th century, the marginal productivity of labor had become the key element in all of moral philosophy's view of wealth creation. The classical model of wealth creation is labor-centric, having just labor as the prime input. This would become Marx's casus belli and the foundation of radical political economy, not to mention the socialist and communist doctrines. Interestingly and ironically, labor is completely absent from the current process engineering and manufacturing engineering textbooks. Despite being the cornerstone of past and present analysis, labor is deemed to be irrelevant to process engineers – with good reason, it is a supervisory or organizational input, having no bearing on physical outcomes. Late 19th-century moral philosopher Alfred Marshall acknowledged this new reality, referring to labor as "machine operatives."

This leads us to the obvious conclusion that the principles that underlie to the point of defining moral philosophy-based neoclassical production theory stand in violation of basic natural philosophy – or basic science. Put differently, labor and capital cannot explain wealth as neither is physically productive. Combined with the standard Solow residual, it would stand to reason that current production theory cannot explain anything. Put differently, two non-physically productive factors and an accounting residual do not a theory of wealth or growth make.

Today, material processes in the known universe are widely understood, except in economics. They are, for the most part, based on the laws of classical mechanics, the laws of thermodynamics and the laws of kinetics. Historically, the laws of classical mechanics predate early political economy by roughly a century. The laws of thermodynamics, however, were discovered in the mid-19th century, and the laws of kinetics,

The Dissenting Moral and Natural Philosophers

At no time in its 250 year history did mainstream moral philosophers-turned political economists invoke the basic scientific laws that governed material processes. However, we would be amiss to argue that none dabbled with/flirted with elementary physics in their writings. In this section, we present a series of incursions by moral philosophers into the realm of natural science as well as the reverse, namely incursions by natural philosophers into the realm of moral philosophy.

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 variations). Clearly, Marx had devoted a considerable amount of time to 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).

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 issue 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.

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. There were also incursions by natural philosophers into the realm of moral philosophy.

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 polymath Charles Babbage in 1832. In *On the Economy of Machinery and Manufactures*, he provided perspicacious 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.

Frederick Soddy's 1921 *Cartesian Economics*

Another early 20th century dissenter was 1921 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.

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].

Howard Scott's Technocracy

In little time, this incongruity reached academia, specifically Columbia University where a group of engineers, known as the *Technocracy 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.

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 outsiders, was met with great resistance from moral philosophers. 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:

> 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."

Economic Growth from the Point of View of Natural Philosophy

Given that wealth creation is a material process, it stands to reason that its study would be consistent with the laws of classical mechanics, thermodynamics and kinetics. More to the point, wealth should be modeled as an increasing function of power usage. This is an inarguable fact. Anything less would be a violation of the laws of physics.

The point is that the Solow residuals reported in the post-WWII period cannot exist in such a world, thus raising the question, is there any evidence of this? In 1982, German physicist Reiner Kummel, in a paper published in Energy, showed that if energy is properly included in a neoclassical-like production function (LINEX), the post-WWII Solow residuals and productivity slowdown could be explained by energy, specifically, electric power use. High post-WWII growth in electric power usage explained all output growth, and a decrease in the rate of growth of electric power usage in the 1970s explained the slowdown in growth. Beaudreau (1995) showed similar results by using output elasticities obtained by estimating a Cobb-Douglas function defined over capital, labor and electric power for U.S. manufacturing, directly as opposed to indirectly which is the standard. He found an output elasticity of 0.64 which is decidedly greater than previous estimates in the 0.04-0.06 range.

More recently, Beaudreau (2017,2020) invoked the laws of kinetics to show that most of output growth over the past two centuries owed to increases in the speed/velocity of the myriad material processes that together constitute an economy. The steam engine-driving belting and shafting and the steam engine-driving individual electric motors (i.e. electric unit drive) increased process speeds (relative to artisanal techniques), thus increasing hundreds-fold, the wealth of the world.

Having shown that speed and acceleration could account for the phenomenal growth of the post-WWII period, he argued that the upper limits (of process speeds) were reached in the 1960s and 1970s, making further increases unfeasible. For example, he points to airplane speed as a metaphor, where speeds increased throughout the post-WWII period, only to peak in the 1960s (and have actually decreased since).

The Productivity Slowdown according to Natural Philosophy

The data show a marked decrease in the rate of growth of electric power usage during and after the 1970s, raising the question of why. Why did it suddenly fall, bringing with it productivity and output growth? The general view (Kummel….Beaudreau) was that the OPEC-engineered oil embargoes (1973 and 1979) and the ensuing energy crises had put an end to centuries of energy deepening. This view, however, fell out of favor as real energy prices returned to their pre-OPEC crises levels, and yet, energy use growth has been anemic to non-existent. As mentioned above, the reason appears to be rooted in kinetics and the end of what Beaudreau referred to as the “age of speed."

Why Were/Are the Material Sciences Ignored?

Our findings so far raise a number of interesting questions. One such question is why dialogue with what are closely related fields was and is virtually 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 first-hand understanding of the very material processes underlying growth been shut out, not so much as even consulted? In this section, we present a non-exhaustive list of 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.

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 classical mechanics as a field was in its infancy and thermodynamics was altogether 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 discipline, 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.

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 in 1867 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 where 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.

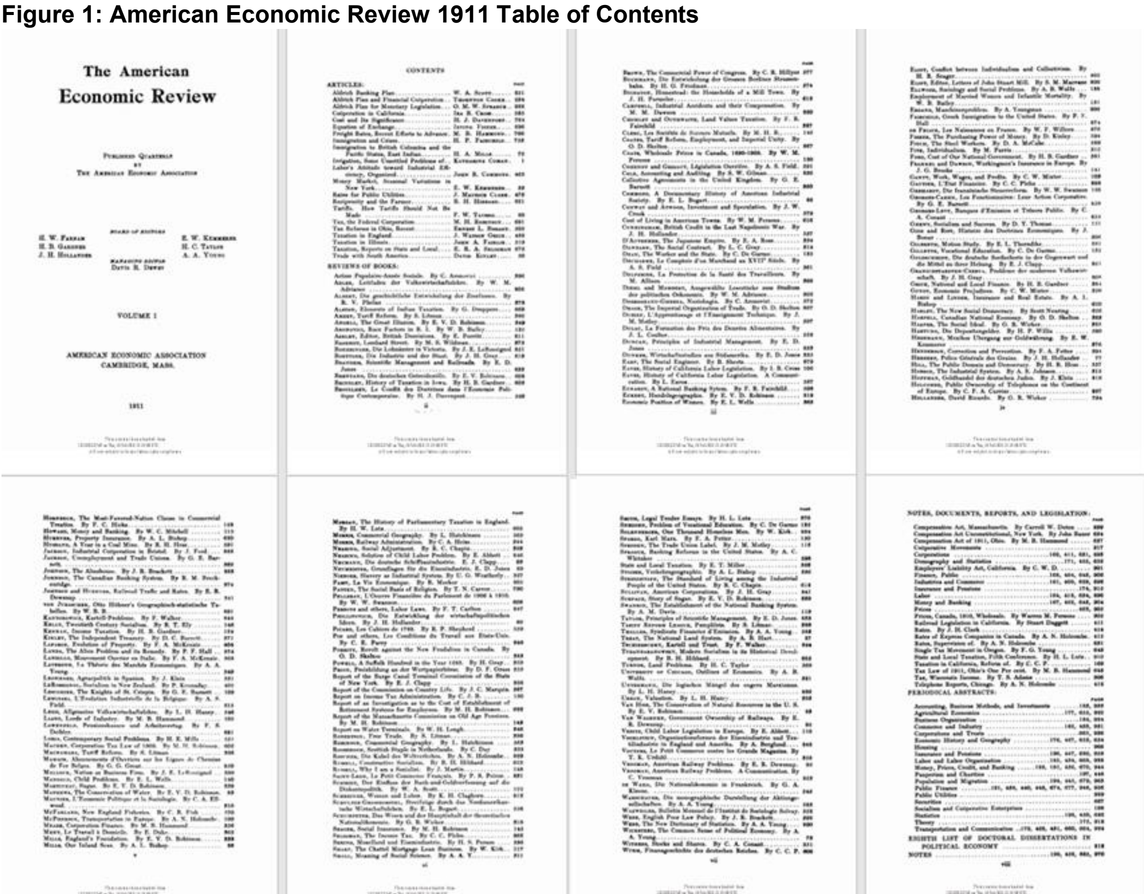
Moreover, this had a rather pernicious effect on first principles. Specifically, the profession reverse engineered, as it were, the results of GE analysis to first principles—consumer and producer theory. Simple max $U(x)$ and max $\pi(q)$ became the standard in microeconomics, thus pre-empting any and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

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 and religiously-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.[3] 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


The American Economic Review

VOLUME I

AMERICAN ECONOMIC ASSOCIATION
CAMBRIDGE, MASS.

1911

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

[3] As Benjamin Friedman has pointed out, the origins of the American Economic Association were firmly rooted in 19th century moral philosophy/religion (See Friedman 2024).

(dynamic optimization, duality etc.), its 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.

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.

Conclusion

All in all, it can be concluded that despite what were valiant attempts, moral philosophers' quest over the past two and one-half centuries to understand what are natural philosophy-based phenomena, namely the creation of wealth and its growth, has been a failure, and this on two fronts, namely in so far as the development of realistic models of production, and second, their eschewal of outside natural philosophers' attempts to inject the laws of the natural world into the analysis of wealth and growth.

Moses Abramovitz, one the leading moral philosophers in the field of economic growth, in a moment of clarity – or an epiphany of sorts - referred to the Solow residual as a "measure of ignorance." The findings of this paper lead us to qualify this statement as follows, namely that the Solow residual is "a measure of moral philosophers' ignorance of the very laws that govern material processes as set out by natural philosophers." This has resulted in the current state of affairs in which material processes and growth are understood in virtually all other fields, except economics.

While this will appear to most to be a harsh, even damning judgement of the economics profession as a whole, it is not. If anything, it is a wake-up call. After all, economics is first and foremost about wealth, and because wealth is a material process, it stands to reason that it has to be understood as such. Inventing concepts and notions that violate the laws of physics is no way to lay the scientific foundations of the applied material science that is economics. The on-going failures of the profession to understand past, present and future growth stands as a stark reminder of the need for a major reset.

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