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The Pay-Productivity Gap: An Engineering Perspective

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Abstract

The pay-productivity gap has been and continues to be a subject of much debate in the literature as well as in the popular press, raising a number of questions. For example, why have wages not kept pace with recent increases in productivity in Western industrialized democracies? Is this a new phenomenon, or are there precedents? In this paper, we examine these and other related questions. We show that the pay-productivity gap is as old as economics itself, having a history dating back to the early 19th century (Allen, 2007). Further, we argue that the "gap" itself can ultimately be attributed to 1) an erroneous understanding of the role of labor in modern material processes (production functions) and 2) a mis-specified formal model of such processes. More specifically, with the introduction of the steam engine, labor went from a source of energy/force/work to what was essentially a supervisory input overseeing machinery, resulting in a decoupling of the labor input from physical productivity. Subsequent increases in machine productivity were as such totally unrelated to labor, yet measured output per unit of labor increased. Firms had no reason to increase wages on the legitimate grounds that the supervisory input which labor had become was not responsible for the increase. Recent developments in automation and control technology have reduced the demand for labor without affecting output thus increasing measured output per unit of labor.

Keywords

Pay-Productivity Gap, Energy Rents, Bargaining

1. Introduction

The pay-productivity gap has been and continues to be a subject of much debate in the literature as well as in the popular press, raising a number of questions (Fleck, Glaser, & Sprague, 2011; Ravikumar & Shao, 2016). For example, why have wages not kept pace with productivity in Western industrialized democracies? Is market failure to blame? Is this a new phenomenon, or are there precedents? In this paper, we examine these and related questions. We show that the question of the pay-productivity gap is as old as economics itself, having a history dating back to the early 19th century (Allen, 2007). Further, we argue that the "gap" itself can ultimately be attributed to (*i*) an erroneous understanding of the role of labor in modern material processes (production functions) and (*ii*) related to (*i*), a mis-specified model of such processes. More specifically, with the introduction of the steam engine, labor went from a source of energy/force/work to what essentially was a supervisory input overseeing machinery, resulting in a decoupling of conventionally-defined labor from physical productivity[1]. Subsequent increases in machine productivity were as such totally unrelated to labor, yet measured output per unit of labor increased. Firms felt no reason to increase wages on the legitimate grounds that the supervisory input which labor had become was in no way responsible for the increase.

The paper is organized as follows. To begin with we examine the current pay productivity gap, which is then followed by a short history of the gap in 19th century Great Britain and 20th century America. This will be achieved by combining data with observations culled from the writings of period political economists. This will be followed by the presentation of a consilient theory of production, based on the two universal factor inputs, energy and organization, which will be used to analyze in detail, the question of (*i*) labor productivity (*ii*) the corresponding property rights, and (*iii*) the pay-productivity gap from a theoretical point of view. It will be argued that the key decoupling in so far as labor was concerned occurred when inanimate steam and water power replaced labor as the source of force/power/energy in material processes, setting up what would result in the centuries-old pay-productivity gap. This is then followed by a discussion of the many attempts on the part of political economists to address the problem of income distribution in a world in which labor and capital are not physically productive factor inputs. It is felt that this literature is extremely relevant today as we now face what are essentially the same questions.

2. The Pay-Productivity Gap: Present and Past

Over the course of the last two decades, conventionally-defined labor productivity in U.S. manufacturing has increased monotonically, while real wages have remained virtually flat, raising a number of questions, notably why have wages failed to follow productivity? Not only has it raised questions about outcomes (i.e. higher wages), but also about the underlying process, namely about the workings of the labor market. According to basic microeconomic theory, higher productivity should lead to higher profits as firms bid for workers, which in turn, leads to higher nominal and real wages.

[1]The unconvinced are invited to view "How It's Made" videos on YouTube, asking yourself what does labor do in each of the videos?

Referring to Figure 1, we see that from roughly the mid-1970s, pay and productivity in the U.S. appear to diverge, with the latter increasing at a faster rate than the former. Prior to that (1948-1979), both series were highly collinear, with productivity rising 108.3 percent and hourly compensation, by 93.4 percent. However, from 1979 to 2025, productivity increased by 90.2 percent, while hourly compensation increased by 33. In short, productivity has growth 2.7times as much as pay. Interestingly, this was not a U.S.-only phenomenon, as similar results were reported throughout the G20 countries as shown in Figure 2, where a similar gap was opened.

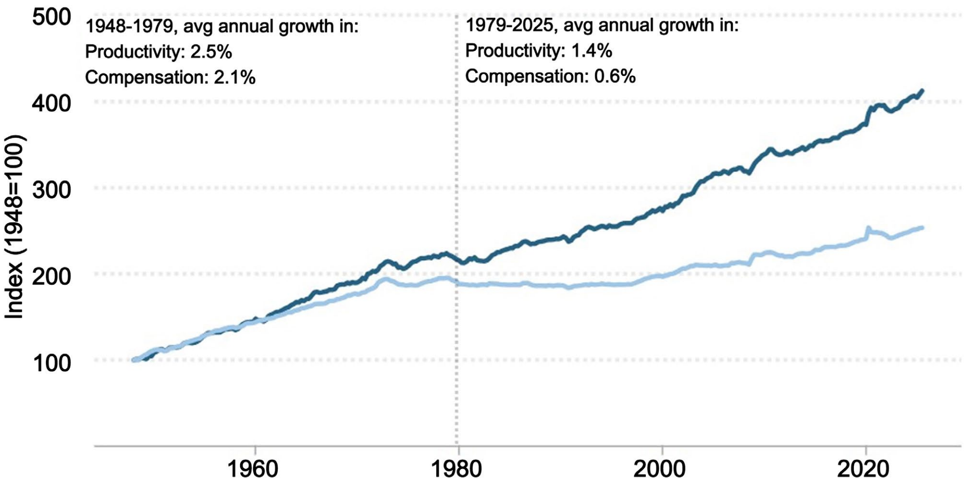

Figure 1. Pay-productivity gap 1948-2025. Source: Economic Policy Institute (2026).

Figure 2. Pay-productivity gap G20 1999-2013. International Labor Organization (2013).

This raises a number of questions, ranging from why, to whether such occurrences are new—that is, not having any precedents? In the next section, we address the latter question.

2.1. Past Gaps

As it turns out, pay-productivity gaps have a long history in the industrial age—that is, from the late 18th century onwards. For example, in 1820, British industrialist and social reformer Robert Owen, in his *Report to the County of Lanark*, attributed the slowdown in economic activity to the failure of wages and thus purchasing power to rise in response to the introduction of scientific power (i.e. the steam engine) as a leading cause of the downturn.

The failure of industrialization, Owen explained, owed to its inherent inability to create the wherewithal to execute the requisite trades, namely money income. Potential output chronically exceeded actual output. In fact, not only did higher productivity not lead to greater wealth, but it led to falling wages and a general worsening of living conditions, a paradox according to Owen. Consider, for example, the following passages taken from the *Report on County of Lanark*, where he extols the effects of "scientific improvements and arrangements."

It is well known that, during the last half century in particular, Great Britain, beyond any other nation, has progressively increased its powers of production, by a rapid advancement in scientific improvements and arrangements, introduced, more or less, into all the departments of productive industry throughout the empire. The amount of this new productive power cannot, for want of proper data, be very accurately estimated; but your Reporter has ascertained from facts which none will dispute, that its increase has been enormous;—that, compared with the manual labour of the whole population of Great Britain and Ireland, it is, at least, as forty to one, and may be easily made as 100 to one; and that this increase may be extended to other countries; that it is already sufficient to saturate the world with wealth and that the power of creating wealth may be made to advance perpetually in an accelerating ratio (Owen, 1821: p. 246).

It must be admitted that scientific or artificial aid to man increases his productive powers, his natural wants remaining the same; and in proportion as his productive powers increase he becomes less dependent on his physical strength and on the many contingencies connected with it... That the direct effect of every addition to scientific, or mechanical and chemical power is to increase wealth; and it is found, accordingly, that the immediate cause of the present want of employment from the working classes is an excess of production of all kinds of wealth, by which, under the existing arrangements of commerce, all the markets of the world are overstocked (Owen, 1821: p. 247).

Getting in the way of increased wealth and welfare, however, was the problem of underincome—that is, insufficient income relative to potential wealth. Society's capacity to produce had increased; income and expenditure had not.

Having taken this view of the subject, your Reporter was induced to conclude that the want of beneficial employment for the working classes, and the consequent public distress, were owing to the rapid increase of the new productive power, for the advantageous application of which, society had neglected to make the proper arrangements. Could these arrangements be formed, he entertained *the most confident expectation that productive employment might again be found for all who required it; and that the national distress, of which all now so loudly complain, might be gradually converted into a much higher degree of prosperity than was attainable prior to the extraordinary accession lately made to the productive powers of society. Cheered by such a prospect, your Reporter directed his attention to the consideration of the possibility of devising arrangements by means of which the whole population might participate in the benefits derivable from the increase of scientific productive power; and has the satisfaction to state to the meeting, that he has strong grounds to believe that such arrangements are practicable. His opinion on this important part of the subject is founded on the following considerations:*

First—It must be admitted that scientific or artificial aid to man increases his productive powers, his natural wants remaining the same; and in proportion as his productive powers increase he becomes less dependent on his physical strength and on the many contingencies connected with it.

Second—That the direct effect of every addition to scientific or mechanical and chemical power is to increase wealth; and it is found, accordingly, that the immediate cause of the present want of employment for the working classes is an excess of production of all kinds of wealth, by which, under the existing arrangements of commerce, all the markets of the world are overstocked.

Third—That, could markets be found, an incalculable addition might yet be made to the wealth of society, as is most evident from the number of persons who seek employment, and the far greater number who, from ignorance, are inefficiently employed, but still more from the means we possess of increasing, to an unlimited extent, our scientific powers of production.

Fourth—That the deficiency of employment for the working classes cannot proceed from a want of wealth or capital, or of the means of greatly adding to that which now exists, but from some defect in the mode of distributing this extraordinary addition of new capital throughout society, or, to speak commercially, from the want of a market, or means of exchange, co-extensive with the means of production (Owen, 1821: p. 248).

Jean-Charles Léonard Simonde de Sismondi, the Swiss political economist, made the pay-productivity gap the cornerstone of his dynamic theory of the business cycle, with wage income lagging behind output growth. He attributed the gap itself to incentives, namely that firms have no incentive to increase wages in response to technological change.

Le vendeur n'a pas par lui-même aucun moyen d'étendre son débit, qui ne réagisse sur ses confrères; il leur dispute une quantité donnée de revenu qui doit remplacer son capital; et plus, il réussit en garder pour lui même; moins il en laisse pour les autres. Il ne dépend nullement du producteur d'augmenter les revenus de la société, ou du marché qu'il sert de manière qu'ils puissent s'échanger contre une augmentation de produits… Entre commerçants, on regarde comme une mauvaise action de se séduire réciproquement ses pratiques; mais la concurrence *que chacun exerce contre tous ne présente point une idée aussi précise; et un commerçant n'a pas moins d'empressement d'étendre son débit aux dépens de ses confrères qu'à le proportionner a l'accroissement des richesses, lorsque celles-ci lui offrent l'échange d'un nouveau revenu. Jusqu'ici dans l'un ou l'autre cas, la découverte d'un procédé nouveau a causé une grande perte nationale, une grande diminution de revenu, et par conséquent, la consommation* (Simonde de Sismondi, 1827: p. 345)[2].

Thomas Malthus, in Principles of Political Economy Considered with a View to their Practical Applications, also made reference to the problem, viewing it as a problem of distribution, distribution in this case referring to the creation of income, and not the functional distribution of income.

We have seen that the powers of production, to whatever extent they may exist, are not alone sufficient to secure the creation of a proportionate degree of wealth. Something else seems necessary in order to call these powers fully in action. This is effectual and unchecked demand for all that is produced. And what appears to contribute most to the attainment of this object, is, such a distribution of produce, and such an adaptation of this produce to the wants of those who are to consume it, as constantly to increase the exchangeable value of the whole mass... In the same manner, the greatest stimulus to the continued production of commodities, taken altogether, is an increase in the exchangeable value of the whole mass, before a greater value of capital has been employed upon them. (Malthus, 1820: p. 361)

Fast forward to the 1920s, another period of major technological change (Bresnahan & Trajtenberg, 1995), one in which the question of the pay-productivity gap reappeared, almost with a vengeance. Perhaps the most publicized admission of the existence of a pay-productivity gap was that of Detroit industrialist Henry Ford, who in response to the pay-productivity gap at the Ford Motor Company, chose to double wages in January 1914 and pleaded with his fellow industrialists to do likewise. Invited to the White House by President Herbert Hoover in 1932 to discuss the depression, he pointed to the need for:

...increasing the purchasing power of our principal customers—the American People...this can be done in two ways: first, by putting additional value into goods or reducing prices to the level of actual values; and second, starting a movement to increase the general wage level. Nearly everything in this country is too high priced. The only thing that should be high priced in this country is the man who works. Wages must not come down, they must not even stay at their present level;

[2]The seller has no means of expanding his sales by himself, except by affecting his competitors; he is disputing a given amount of income that must replace his capital; and moreover, he succeeds in keeping some for himself; the less he leaves for others. It does not depend at all on the producer to increase society's income, or on the market he serves, in such a way that they can be exchanged for an increase in products... Among merchants, it is considered bad practice to try to lure each other's clientele; but the competition that each exerts against all does not present such a precise idea; and a merchant is no less eager to expand his sales at the expense of his colleagues than to align them with the increase of wealth, when the latter offers him the exchange of a new income. Up to this point, in either case, the discovery of a new method has caused a great national loss, a large decrease in income, and consequently, consumption (Simonde de Sismondi, 1827: p. 345).

they must go up (Fisher, 1930: p. 25).

Another high-profile case was that of University of Chicago economics professor, Thorstein Veblen, who argued that managers had failed to raise wages or reduced prices (increased real wages) in response to productivity increases, likening their behavior to a form of sabotage. As it turned out, the pay-productivity gap was commonplace in the 1920s literature, with the likes of Paul Douglas, Rexford Tugwell, Robert Brookings, and numerous others attributing the Great Depression to the failure of wages and purchasing power in general to increase in step with productivity gains in the 1920s. **Table 1** presents real wage and productivity data for the 1920s, culled from the U.S. Department of Commerce's Historical Statistics of the U.S. We see that throughout this period, wages lagged behind productivity gains, prompting a number of reactions on the part of scholars, industrialists and government officials. We see, for example, that Thorstein Veblen referred to managerial sabotage, and called for the end to the for-profit economy and the establishment of the Technate, where engineers would replace businessmen.

Table 1. Real wages and productivity, U.S. manufacturing 1920-1929.

Year	Nominal Wage	CPI	Real Wage	Productivity Index	Wage Index
1920	0.44	54.60	0.84	100.00	100.00
1921	0.51	54.50	0.93	115.31	111.27
1922	0.48	50.10	0.95	130.62	113.92
1923	0.52	51.30	1.01	125.62	120.53
1924	0.54	51.20	1.05	133.75	125.41
1925	0.54	51.90	1.04	142.50	123.72
1926	0.54	51.10	1.05	145.31	125.25
1927	0.54	50.00	1.08	148.75	128.42
1928	0.56	5.80	1.10	155.31	131.08
1929	0.56	50.60	1.10	162.50	131.59

Source: U.S. Department of Commerce (1975).

2.2. The Pay-Productivity Gap in the Policy Debate

Given its preponderance in the 1920s and 1930s, it should come as no surprise to learn that the pay-productivity gap had reached the policy realm, underlying the key policy measures in the Great Depression. As it turned out, the pay-productivity gap was the cornerstone of both the Hoover and Roosevelt Administrations' responses to stagnation in the late 1920s and depression in the 1930s. Herbert Hoover's Associative State called on firms to raise wages in response to greater productivity, while Roosevelt's National Industrial Recovery Act of 1933 and National Labor Relations Act of 1935 both called for across-the-board wage increases in the hope of closing the alleged wage-productivity gap.

In the next section, we examine the many potential causes of what appears to be an anomaly, at least according to the standard view. However, in order to gain additional insights into the very nature of labor's role in material processes, the energy-organization approach to production (Beaudreau, 1998) is presented. Unlike the standard approach, it borrows from mechanics and thermodynamics to focus on the underlying nature of labor's part in production processes, the idea being that it should shed light on engineers' and managers' decision-making process.

3. Analytical Framework: The EO Approach to Modeling Material Processes

3.1. A Consilient Model of Production

We begin by presenting the Energy-Organization (*EO*) approach to modeling material processes (Beaudreau, 1998). Drawing from material process sciences (engineering, biology), it models wealth in terms of two universal factor inputs, namely broadly-defined energy and broadly-defined organization. Both are necessary conditions in all material processes whether it be in biology, chemistry, engineering or economics. The model is formalized in terms of Equation (1) where W, E, K, and L refer to wealth, energy, capital (tools) and labor (supervision), respectively[3].

$$W = \eta[K, L]E \tag{1}$$

$\eta[K, L]$ corresponds to the broadly-defined organization input, while E corresponds to the broadly-defined energy input. While E is sometimes referred to as energy consumption *per se*, technically it refers to available work or negentropy. As energy cannot be created nor destroyed, it follows that energy is not consumed *per se*, but rather overall entropy is increased. Second-law efficiency (i.e. η) is assumed to be increasing in capital (tools) and labor (supervision). For the sake of discussion, it will be assumed that the latter are qualitative and not quantitative variables. That is, second-law efficiency is increasing in the quality of tools and the quality of supervision[4]. A good example of the latter is James Watt's external condenser that increased the steam engine's efficiency (i.e. η) by 600 percent[5].

L, labor (supervision) is assumed to be information-based, consisting of collecting, storing, and retrieving process-related information, and using it as part of an operating protocol/algorithm. This can be carried out/performed by what 19th century British economist Alfred Marshall referred to as "machine operatives," that is, workers, or by computer-based automated control systems/devices.

We may now pass to the effects which machinery has in relieving that excessive muscular strain which a few generations ago was the common lot of more than

[3]These are used instead of capital and labor in keeping with the engineering and applied physics literature.

[4]At the aggregate level, both T and S are quantitative variables. That is, aggregate output is increasing in aggregate, economy-wide tools and equipment, and supervision.

[5]Thermal efficiency of the Newcomen engine stood at 0.3 percent, while that of Watt's at 2 percent.

half the working men even in such a country as England…in other trades, machinery has lightened man's labours. The house carpenters, for instance, make things of the same kind as those used by our forefathers, with much less toil for themselves… Nothing could be more narrow or monotonous than the occupation of a weaver of plain stuffs in the old time. But now, one woman will manage four or more looms, each of which does many times as much work in the course of a day as the old hand loom did; and her work is much less monotonous and calls for much more judgment than his did (Marshall, 1890: p. 218).

The model is sufficiently general to allow for energy and information deepening, which by definition consists of an increase in the energy/tool and information/tool ratios, respectively. Historically, energy deepening has been associated with machine speed-ups whereby applying more energy (high-pressure steam, kwhs), tools produce more output per unit of time, while information deepening has been associated with more and better process and sub-process-based information (Beaudreau, 2017).

3.2. Is Neoclassical Distribution Theory Consistent with the Physics of Material Processes?

As distribution theory was/is founded on neoclassical production theory, which itself was based on Adam Smith's ill-fated, unscientific attempt at analyzing the role of the steam engine on labor productivity, confounded by a off-the-cuff response on the part of William Stanley Jevons and Alfred Marshall to Engel and Marx's allegations over the legitimacy of profits in the former (Adam Smith's world), the question of whether neoclassical distribution theory is consistent with the physics of material processes arises. In other words, is the cornerstone of modern economics, the neoclassical production function, consistent with the laws of classical mechanics and thermodynamics? In its basic version (two factors), it maintains that both capital and labor are physically productive. In its extended version (KLEMS), it maintains that capital, labor, energy, material and services are all physically productive, and moreover, substitutable (Berndt & Wood, 1975).

The idea that all factors are physically productive is firmly embedded in the neoclassical approach to production and distribution as well as the question of income distribution in general[6]. A good example is the current debate over IT (Jorgenson & Stiroh, 2000) where it is assumed—without any doubt or debate—that like all other factors, information is physically productive, complete with an estimable output elasticity. For example, William Lehr and Frank Lichtenberg, using government data, estimated a computer output elasticity of 0.06 (Lehr & Lichtenberg, 1999).

Unfortunately, these practices, while convenient, cannot be justified on scientific grounds—by which it should be understood on the basis of classical mechan-

[6]Over time, it has become common practice for the user to literally throw any and all possible factor inputs into the production function, and attribute physical productive status to it. Interesting examples include the inclusion of highways, computers, and materials as factors of production.

ics and applied physics. As shown in the previous section, according to the latter, energy and energy alone is physically productive, all other inputs being necessarily organizational in nature[7]. As labor has not been a source of energy/force since the Paleolithic era (i.e. that is, in general), it stands to reason that neoclassical distribution theory is not, nor will never be consistent with the physics of material. processes. Table 2 presents a list of what are the corresponding violations of the principles of basic physics and mechanics. In short, all non-energy inputs are not physically productive, but are essential to the organization of material processes. In a sense, they are organizationally productive.

Table 2. Neoclassical production theory violations of basic physics/mechanics.

Factor Input	Violation
Labor	Labor is essentially a supervisory input, overseeing machines. Not physically productive.
Capital	Consists of simple and complex tools, provides mechanical advantage, is not physically productive.
Managers	Organize material processes, higher form of supervision. Not physically productive.
Information	Not a source of energy. An input in the overall supervisory technology.
Robots	Set of tools that replace operator held power tools. Not a source of energy, hence not physically productive.

3.3. What Would a Physical Productivity Standard Look Like?

These findings lead us to the obvious question, namely what would a pure physical productivity-based income distribution standard look like? The answer to this question is self-evident. Like Engel and Marx who had identified labor as the only factor input and hence the only legitimate claimant to output, in this case, energy is the only physically-productive input, and as such, would be the only legitimate claimant to output.

All other factors, being organizational inputs, would not be entitled to a share of the output. Clearly, this would raise an important incentive problem. If all other inputs were excluded from the plunder, then they would have no interest in participating. This leads us to an important conclusion, namely that a pure productivity standard is inconsistent with production as we know it.

The EO approach to understanding material processes has important implications for what are traditionally known as productivity indexes. Specifically, given that energy and energy alone is physically productive, it stands to reason that there is only one true productivity index, namely energy productivity, which is equiva-

[7]Interestingly, the related fields of industrial relations and industrial psychology also assume, for the most part, that labor is physically productive, and hence wages should reflect the value of what is, in essence, the property of labor—that is, his/her work. The field of industrial relations appears to be of two minds in so far as the role of labor and wages are concerned. There is the Cornell ILR stream which is decidedly neoclassical in its approach, and the other, more conventional stream which focuses on collective bargaining, almost at the expense of markets.

lent to the concept of second-law efficiency in thermodynamics. However, given the presence of numerous, non physically-productive factor inputs (organizational), it is nonetheless useful to have measures of what we refer to as factor product indexes, or Product per Factor Indexes. These are a measure of overall output per unit factor input, without the connotation of physical productivity. Table 3 presents three of these, although the list could be lengthened to include other organizational factor inputs, such as managers, engineers, superintendents, etc.

Table 3. Product per factor indexes (PFI).

Index	Definition
Energy PFI	W/E
Labor PFI	W/L
Capital PFI	W/K

As such the PFI index should be seen as a neutral, non-causal measure of product per unit factor input. Admittedly, this is a new way of looking at measures of factor output, one that stands at odd with the conventional view that all factor inputs are somehow physically productive and contribute to the final product. However, it is nonetheless consistent with the implicit view of productivity and product found in the engineering literature where the labor input is altogether absent/ignored.

4. The Decoupling of Traditionally-Measured Labor Productivity from Actual Labor Productivity

In the contemporary pay-productivity gap literature, it is often alleged that wages were decoupled from productivity in the early 1980s, when the two diverged, the latter increasing faster than the former (see Figure 1 and Figure 2). In this case, the introduction of factory automation and ICT-based control technology reduced the demand for human-based supervision, thus increasing the labor product per factor index (Labor PFI). We, on the other hand, are of the view that the phenomenon of decoupling occurred in the early hours of the industrial revolution when labor was stripped of its traditional role as a source of force/work/energy and became a supervisory input. From that point on, it would never be physically productive again earning the moniker "machine operative" from Alfred Marshall in his 1890 magnum opus, Principles of Economics, and also from the London Board of Trade in the early 20th century.

This, we believe, explains in whole or in part the reason why most firms have been and continue to be less inclined—or not inclined at all—to raise wages in response to higher conventionally-defined labor productivity. Put simply, most if not all increases in the productivity in the 19th and 20th centuries were unrelated to and as such not in any way connected to the labor input. Take, for example, machine speed-ups, where operating speeds were/are increased. In this case, machine operatives (i.e. labor) simply oversee faster machines, with no discernable change to their technique. Further, given that most firms are constrained on product markets, it stands to reason that higher productivity would actually decrease the demand for supervision, thus making a wage decrease more likely. Recently, the introduction of automated control devices has reduced the need for and hence demand of machine operatives, leading to an increase in the labor product per factor index (see Figure 1).

5. Why Wages Shouldn't Follow Productivity: The Scientific Reasons

This leads us to our first important finding, namely that from a purely scientific point of view, there is no reason why wages, which are a form of remittance to machine operatives/supervisors, should increase with productivity. For over two centuries, labor has no longer been a source of force/work/energy and as such cannot claim to be responsible for the physical creation of wealth, nor for their increases. From a legalistic point of view (i.e. the canons of property law), the increased productivity in question should be attributed to its rightful owners, namely the very source/cause of the increase, the energy deepening. Neither labor nor capital have a legitimate claim to it, at least according to the laws of mechanics/physics.

Similarly, we are of the view that the current debate is, like the 19th and 20th century debates enumerated above, the unfortunate consequence of a legacy/vestige of a theoretical misspecification/misunderstanding of the role played by labor in modern material processes, as well as a victim of the classical and neoclassical belief (erroneous) that labor is physically productive. Once this erroneous and misleading assumption is dispensed with, the problem disappears.

6. Wages and Profits as Energy Rent Sharing or How the Existing Functional Distribution of Income Can Be Understood?

This then raises the important question, namely if labor (capital) is not physically productive, then how are we to understand the current functional distribution of income where workers take home roughly 60 - 70 percent of national income, and capital, the rest? Is this not incongruous? As it currently stands, the owners of energy appropriate roughly between four and eight percent of output, while labor and capital appropriate the rest. Contrast this with a pure physical productivity standard where the reverse would be the case. One way of seeing the former is in terms of bargaining, specifically that the owners of labor and capital have, over the course of the past two centuries, appropriated something we refer to as energy rents, which are by definition equal to the difference between the value of energy's physical productivity and the cost/price of energy[8]. We could refer to this as the

[8]For more on the bargaining approach see, Pissarides 2000, Duffy and Papageorgiou 2000, Bentolila and StPaul 2003, Blanchard 2006, Guscina 2006 and Bental and DeMougin 2005. Our approach differs in so far as the underlying fundamentals are concerned. This literature typically assumes that labor and capital are physically productive thus violating the laws of physics.

energy rent pie, which is divvied up between the owners of the organizational inputs. For example, the owners of labor appropriate 50 - 60 percent, and the owners of capital, 30 percent and managers, the rest.

In other words, the current distribution can be understood as resulting from bargaining on the part of non-energy-based factor inputs. This is not unlike John K. Galbraith's view of income distribution in the 20th century as resulting from a form of bargaining between large corporations and large unions, the latter being referred to as "countervailing power" to the rise of large, vertically-integrated conglomerates. It is also consistent with Robert Owen's view of the role of the commune in income distribution, as well as with the Technocrats view of the role of the Technate in income distribution.

In Beaudreau (1998, 2005), I argued that income distribution in a world in which energy and organization are complementary inputs is best understood using cooperative bargaining theory. Accordingly, the owners of energy and organization bargain over their respective share of the product (i.e. payoff set) Theoretically, the distribution of income is the solution to this game. Since broadly-defined organization is a *sine quo non* of production, it is clear that energy's overall share of the product cannot be total (i.e. equal to one). Put differently, a pure energy standard is ruled out by the presence of organization. The difference will be appropriated by the owners of organization (i.e. the designers of and owners of the production processes, and the owners of the supervisory input).

6.1. Bargaining without Outside Options

We begin by defining the bargaining problem. The owners of energy and organization (e.g. the owners of energy (E), tools (T), and the supervisory inputs (S), bargain over wealth (W)], the output, in this case, manufacturing value added. Define s_E, s_T, s_S, where [$0 \le s_i \le 1$, $\sum_{i=E,T,S} s_i = 1$], as the energy, tools, supervisor and designer/owner factor income shares, respectively. Also, assume that α_i where $i = E$, T, and S, defines factor i's bargaining power [$0 \le \alpha_i \le 1$, $\sum_{i=E,T,S} \alpha_i = 1$]. Lastly, assume that factor i's utility is an increasing linear function of income. More specifically, $U_i = U_i[s_i W]$ $\forall$ $i = E, T, S$.

This provides a general framework in which to study income distribution. In the absence of outside options, the simple bargaining problem is given by Equation (2), where the s_i's are chosen to maximize the product of utilities.

$$\max_{\{s_i\}} S = \prod_{i=E,K,L} \left[U_i\left[s_i W\right]\right]^{\alpha_i} \tag{2}$$

For example, if we assume that $\alpha_i = \frac{1}{3}$, then it is clear that the solution to this problem is given by $s_i = \frac{1}{3}$ for all $i = E, K, L$.

As shown in this example, in a world devoid of outside options and in which preferences are identical, income distribution will be largely determined by each factor's bargaining power. That is, if the economic value of energy, tools, supervisors and production processes is nil, then their share of the overall income (output) pie will be determined by each factor's bargaining power. For example, the greater is lower-level supervisors' bargaining power, the greater is its share of the pie, so to speak.

6.2. Bargaining with Outside Options

The presence of outside options alters considerably the bargaining problem. For example, suppose that the owners of electric power can sell each kilowatt hour at a price of 7 cents. It stands to reason that, at the very least, the owners' share of manufacturing output must be equal to or greater then the corresponding market value of the power. Define ξ_i such that $\xi_i > 0$ to be factor *i*'s outside option. The bargaining problem becomes:

$$\max_{\{s_i\}} S = \prod_{i=E,K,L} \left[U_i \left[s_i W \right] - \xi_i \right]^{\alpha_i} \tag{3}$$

subject to:

$$s_i W(t) - \xi_i > 0 \forall i = E, K, L \tag{4}$$

In this case, a bargain will be struck if and only if, at the very least, the various factor inputs receive their outside options; otherwise, negotiations will break down, in which case production will not occur. It therefore follows that Equation (4) must hold for all $i = E$, K, and L.

6.3. The Determinants of Outside Options and Bargaining Power

Among the determinants of the resulting bargaining solution are (*i*) each factor's outside option, and (*ii*) each factor's bargaining power. This leads us to examine the determinants of outside options and bargaining power. For outside options to have any meaning, there must exist alternative uses for energy, tools, and upper and lower-level supervisors. For example, the owners of electric power could consume their kilowatt hours instead of devoting them to generating value added. The owners of tools (capital) could opt for consumption over investment. Lastly, the owners of upper and lower-level supervisory skills could devote their time to leisure activities. In a world in which the number of firms exceeds one, the owners of these factor inputs could, theoretically, bargain with another firm. The point of the matter is that outside options are conditioned by each factor's set of alternative activities.

For all bargaining problems with more than one solution (i.e. the perfectly competitive bargaining solution, defined by a strict equality for Equation (2)), bargaining power plays a crucial role in the resulting income distribution. For example, the more bargaining power the owners of supervisory inputs have over the owners of electric power, the greater will their share of the product be.

This raises the question of bargaining power *per se*. What determines bargaining power within the firm (i.e. among the owners of energy, tools, the supervisory input and the conceivers of production processes)? Unfortunately, while formal bargaining models provide much insight into the process of income distribution in the presence of rents, it provides little in the way of an exact bargaining solution.

Throughout 19th and 20th centuries, increasing energy use and the resulting energy rents led to calls on the behalf of labor to share in the plunder, so to speak. While machine operatives were not in any way responsible for the increase in output, they, their representatives, and/or members of governments nonetheless manifested a desire to share in them, one based on a number of criteria, from morality/justice to demand-related issues (i.e. increasing aggregate purchasing power). **Table 4** presents a list of what are bargaining-related approaches to the sharing of what were/are energy rents, ranging from the Technocrats' and a guaranteed energy-based income (paid out in energy certificates), to John Kenneth Galbraith's notion of "countervailing power" in regard to the rise of the large multinational corporation, largely responsible for the rise in energy rents in the 1910-1940 era.

Table 4. Related bargaining-based approaches to factor shares.

Source	Process
Owen (1827)	Labor Certificates
Scott (1933)	Universally-Distributed Energy Certificates
Long (1934)	"Share the Wealth Movement"
John Kenneth Galbraith (1967)	Countervailing Power in Wage Negotiation
Post-WWII Tripartite Collective Bargaining in Europe	Strict Bargaining Approach to Wages
Pissarides (2000)	Bargaining Approach to Wage Determination.
Beaudreau (1998, 2005)	Energy Rent-Based Approach to Factor Shares.

6.4. Classical Production Theory and the Labor Theory of Value as Attempts to Influence Labor's Bargaining Power

The introduction of inanimate energy-powered machinery (steam powered, electricity powered) described above came with its share of challenges, especially when it came to the distribution of the resulting spoils. Early political economists were confronted with an important paradox, namely a manifold increase in output/productivity, coupled with a diminished role of labor. To most, it was painfully obvious that labor's role in production had been considerably reduced, to the point of being menial—tasks that could be accomplished by women and children. This new normal was problematic for two reasons, namely that (*i*) it resulted in a highly unequal distribution of income with labor being increasingly marginalized (like today), and (*ii*) given that profits were/are a residual factor payment, money income would not increase with wealth, resulting in a problem of effective demand. In other words, because firms do not remit a salary to the owners of capital, an increase in productivity not accompanied by an increase in wages (wage income) will not raise money income, resulting in a form of stagnation.

The list of writers that grappled with this problem is long and exhaustive, including Adam Smith, Robert Owen, Thomas Malthus to name but a few (See Table 4). For example, Smith's approach was ingenious, namely arguing indefatigably that fire power raised labor productivity, thus making a case for higher wages. In Chapter 1 of the Wealth of Nations, he argued that the introduction of machinery and the resulting specialization increased labor productivity by (*i*) concentrating on a single task, (*ii*) reducing the downtime from going between tasks, and (*iii*) the complementary nature of fire-powered machinery. In short, Smith was sugar-coating what was a cataclysmic shift in labor's role in material processes from a source of force/work/energy and supervision, to that of mere machine operatives.

Smith's attempt at revaluating the role of labor in material processes was, as we shall show, a defining feature of early political economy, and as it turns out, early production theory. Clearly, the steam engine had reduced labor's role to that of mere supervision. However, given the role of labor in society at the time, as well as its role as the principal determinant of effective aggregate demand, it was imperative that it should not be marginalized. The downsize was to attribute a disproportionate amount of attention to the role of labor in material processes, as evidenced by classical production theory which focused on one single factor input, namely labor. This made for a situation in which, ironically, the steam engine, was excluded.

Industrialist Robert Owen made a similar plea, arguing that labor was the key factor input and as such, was entitled to an important share of the spoils, knowing full well that its role had been greatly diminished by the introduction of steam-powered machinery. Foremost among his concerns was the question of aggregate demand, arguing that the increased productivity from the introduction of "scientific power" had not translated into increased money income and increased aggregate demand, which was the basis for his radical solution, namely the replacement of the market mechanism with that of worker communes, where money would be replaced by worker certificates in an amount equal to potential output. These certificates would then be distributed on an egalitarian basis. The point of the matter is that Owenite communism was, in large measure, a reaction to the pay-productivity gap.

Owen's writings inspired others including German political economist Karl Marx whose response was the labor theory of value and another form of communism. Put differently, the labor theory of value, in addition to being based on classical production theory (i.e. that of Smith), was a ruse intended as a formal justification for his theory of income distribution. It is our view that Marx, like Smith and Owen, was painfully aware of the reduced role of labor in material processes, but chose to elevate labor to the role of supreme factor input to justify/rationalize his solution to the problem of distribution. Evidence of this comes by way of Chapter 15 of *Das Kapital* where he demonstrates a keen understanding of the role of machinery in production, to the point of couching the discussion in the language of classical mechanics and thermodynamics.

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.

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: p. 261).

This led to what we refer to as the neoclassical backlash, as the disproportionate emphasis placed on labor from Smith to Marx had fueled a radical element which argued that profits were a form of theft, given the fact that labor and labor alone was physically productive. In short, what was an attempt at dealing with the marginalized role of labor and the problem of effective demand, had gone painfully wrong. So, instead of rejecting classical production theory outright, it responded by compounding the problem, arguing—or more accurately, decreeing—that capital was physically productive. Now, production theory would be doubly inaccurate by maintaining that what were two organizational factor inputs were physically productive.

Fast forward to the early 20th century where a series of energy-related innovations (e.g., electric unit drive) increased productivity by leaps and bounds, thus reintroducing the pay-productivity gap. One of the first to acknowledge the problem was industrialist Henry Ford, who was on the front-line of the new power transmission technology. Fully aware of the fact that increased productivity at his

Highland Park plant owed to electric power, he nonetheless made a convincing case for higher wages, going as far as doubling the wages of his employees in January 1914.

The 1910s and 1920s highlight the problem of excess capacity and deficient aggregate demand/low wages. Perhaps the most celebrated of authors was that of University of Chicago economics professor, Paul Douglas who like Smith, Owen, Marx and others, argued that productivity had increased but that wages and aggregate demand had not. However, unlike the others, his approach was nothing less than genial—and neoclassical. In short, he argued that there existed scientific laws of distribution—between labor and capital. In his classic 1928 paper with mathematician Charles Cobb, he argued that the law was a 3/4 - 1/4 split between labor and capital. This was the necessary first step, as it paved the way for the final solution, namely forcing a 3/4 - 1/4 distribution. In other words, if productivity increased (owing to technological change), then labor would be entitled to three-quarters and capital, the remaining one-quarter.

Another line of attack to the pay-productivity gap was that of a group of Columbia University engineers known as the Technocrats. The interesting thing about them is their irreverence, not being political economists and not being constrained by the past. Put differently, they offered a fresh approach to the problem and innovative, science-based solutions. First, they dismissed implicitly neoclassical production theory by insisting that energy and energy alone was physically productive and thus the source of all wealth. The notions of labor and capital productivity were evacuated from the debate—and rightly so. Like Owen, they advocated the replacement of gold-based currency with an energy-based one—energy certificates. These would be issued in an amount equal to the available energy/output, thus eliminating the problem of effective demand. In turn, they would be distributed in an egalitarian fashion—in short, distributing publicly-owned energy rents on an egalitarian basis.

Other period approaches to the pay-productivity gap include the first and second New Deals which called for higher wages against a background of higher productivity. The first New Deal attempted to accomplish this via sector-negotiated wage increases as defined in the 1933 National Industrial Recovery Act, while the second New Deal would do so via the institution of collective bargaining, as defined by the National Labor Relations Act of 1935 (Wagner Act). The point is that both were responses to the alleged pay-productivity gap.

6.5. Why Wages Shouldn't Follow Productivity: The Moralistic Reason

On the basis of our results, one would be inclined to argue that wages should follow productivity as while labor is not directly responsible for the increase, it would nonetheless be a means whereby labor could, via the bargaining process, obtain its share of the resulting energy rents. However, one could argue against such a view on what are moralistic grounds. Energy in Western industrialized nations is essentially a public good, provided by government owned or controlled utilities. It therefore stands to reason that energy rents are a form of public good, one that should be distributed equally, and not on a piecemeal basis, going disproportionately to those with the most bargaining power (e.g. unionized workers) in industries that generate the most energy rents (i.e. energy intensive).

Table 5 presents 2015 U.S. Annual Survey of Manufactures data on electric power consumption per hour per production worker (EPH) as well as the hourly wage (HW) for 20 NAICS 3-digit U.S. industries. We see that electric power per production worker varies greatly, from a high of 442 kwh in Petroleum and Coal Products Manufacturing to a low of 5 kwh in Apparel Manufacturing. Column 2 presents the corresponding production worker wage per hour, where we continue to see variation, but on a lesser scale.

Table 5. Electric power consumption and wage per hour (Production Workers) 2015.

NAICS	Industry	EPH	HW
311	Food manufacturing	33.417	18.247
312	Beverage and tobacco product manufacturing	54.748	27.888
313	Textile mills	63.958	16.421
314	Textile product mills	19.991	15.491
315	Apparel manufacturing	5.727	13.281
316	Leather and allied product manufacturing	10.326	15.218
321	Wood product manufacturing	38.159	17.525
322	Paper manufacturing	112.033	25.860
323	Printing and related support activities	21.072	21.303
324	Petroleum and coal products manufacturing	442.816	39.267
325	Chemical manufacturing	203.201	30.219
326	Plastics and rubber products manufacturing	45.908	19.216
327	Non-metallic mineral product manufacturing	63.422	21.826
331	Primary metal manufacturing	179.771	25.965
332	Fabricated metal product manufacturing	20.750	21.519
333	Machinery manufacturing	18.995	23.784
334	Computer and electronic product manufacturing	65.061	27.207
335	Electrical equipment. appliance. and component	23.801	21.279
336	Transportation equipment manufacturing	28.502	27.188
337	Furniture and related product manufacturing	10.545	17.7382
339	Miscellaneous manufacturing	16.030	19.878

Source: ASM, 2015. Sum of Electric power purchased, electric power generated and electric power transferred.

These data provide the wherewithal to test, albeit incompletely, the main prediction of the bargaining approach to factor shares, namely that wages at the industry level are increasing in energy rents. Ideally, a complete test would require data on such things as labor and capital's bargaining power. However such data are not available. Nonetheless, they do allow us to test whether wages are, in general, higher in industries that are more energy intensive—and thus generate more energy rents—than in less energy-intensive industries.

To this end, the log of the hourly wage in the industries listed in Table 5 was regressed against the log of hourly electric power consumption. Despite the shortcomings of this exercise (e.g. omitted variables, limited sample), the results are nonetheless suggestive. Referring to Table 6 where we see that a one percent increase in hourly electric power consumption across industries results in a 0.1972 percent increase in the industry hourly wage. This result suggests that, in fact, industries whose material processes are more energy intensive, are more likely to pay out higher wages, the latter being determined by a bargaining process between the owners of energy, labor and capital.

It also is consistent with the historical record which shows wages rising with energy use, again the result of a bargaining process. Wages over the course of the past two hundred years have increased not because workers have become more physically productive, but rather because they have shared in the spoils of ongoing energy-based rising productivity, As for the widening gap illustrated in Figure 1 and Figure 2, it can be attributed to automation and ICT technology that have reduced the demand for human supervision (i.e. S), thus reducing labor's share of overall energy rents, and increasing that of capital. Not helping matters, over the course of the period in question, has been the decrease in labor's bargaining power due to decreasing unionization and off-shoring.

Table 6. OLS regression results.

Dep. Var.: lnWage	Coefficient	Std. Err.	Student-t	Critical *p* value
const	2.33792	0.146881	15.92	4.76e−012
lnKWH	0.197271	0.0382746	5.154 0.66e−05	
R^2	0.596092	R^2 ajusted	0.573653	
F(1, 18)	26.56462	*p*. critical (F)	0.000067	

Implications for Energy Rent Sharing

This result also allows us to infer that on the basis of what is admittedly a limited sample, workers in more energy-intensive industries are more likely to receive more energy rents than those in less energy-intensive industries. This brings us to the moralistic reason, namely that the fact that workers in energy-intensive industries earn higher wages is unfair as it favors one group of workers over another. Put differently, the energy rents which are a public good are not distributed equally. Workers who find themselves in energy-poor industries receive less energy rents (public good) than those in energy-rich ones.

This then raises the bigger question, namely how should energy rents be apportioned both across workers (or citizens) in general, and between organizational factor inputs, namely between the owners of the supervisory input and the owners of tools? Clearly, this question—or rather, its answer—is beyond the scope of the present paper. What we can say, however, is that the question of energy rents and their distribution is one that has and will continue to challenge the profession. It is our hope that this paper will provide a number of promising research avenues.

7. Alternative Energy Rent Distribution Mechanisms

As shown, the current mechanism of energy rent distribution evolved in a haphazard way, without much fore- or after-thought. Energy deepening throughout the decades and centuries led to higher profits and, in some cases, higher wages. Put differently, the resulting productivity gains were shared between the owners of tools and supervision almost randomly. In this section, we examine possible alternative distribution mechanisms.

Table 7. Alternative energy rent distribution mechanisms (ERDM).

ERDM	Description
Technocratic ERDM	Energy Rents Distributed Equally
Douglasian ERDM	3/4 - 1/4 Labor-Capital Split
Marxian ERDM	All Energy Rents to Labor
MVP ERDM	Energy Rents Paid to Owners of Energy

Table 7 presents four alternative energy rent distribution mechanisms, beginning with the Technocratic ERDM, which is based on the writings of the Technate in the 1930s. According to this view, the energy value of goods and services, measured by the energy content of goods and services, is measured in the equivalent energy certificates (i.e. on the basis of joules or kwhs), aggregated, and then distributed on an egalitarian basis. Conventional money (based on gold or fiat) is abandoned in favor of an energy theory of value. Goods and services are exchanged at their relative energy costs—that is, the amount of energy needed to produce individual units of the goods and services.

The second energy rent distribution mechanism is the Douglasian ERDM, named after Paul Douglas who throughout his career argued in favor of the 3/4 - 1/4 rule, namely that increases in productivity should be divvied up 3/4 to labor and 1/4 to capital. Interestingly, he went as far as to argue that this was an immutable law of nature, akin to the laws of classical mechanics and thermodynamics. In this particular case, energy rents would be shared/distributed uniquely to the actors in the sector, making for a situation in which sectors or industries that are not energy intensive would be left out.

The third ERDM is the Marxian ERDM which attributes all energy rents to the owners of supervision (labor). In this case, the owners of capital would receive payment (i.e. dividends) in an amount equal to their contribution. However, the bulk of energy rents would be paid to labor, either at the firm, industry, or sector level. The last ERDM is the marginal value product (MVP) ERDM which prices energy at the value of its marginal product. In this case, energy rents are defined as the MVP net of the costs of energy. These rents would then be remitted to the owners of energy (society), who would then distribute them according to pre-determined sharing rules.

8. Summary and Conclusion

Thus, in answer to the question, why wages and pay in general shouldn't follow productivity? The reason is straightforward, namely that (*i*) labor has, in general, nothing to do with productivity, something we referred to as the decoupling of labor from overall productivity, and (*ii*) given the uneven use of energy across sectors and industries, tying wages to what is energy use-based productivity would be unfair to those in low energy-use sectors. Labor and physical productivity were decoupled at the beginning of the industrial revolution, as workers went from being a source of force/work/energy to essentially a supervisory input, or what Alfred Marshall referred to as "machine operatives".

As such, far from being an anomaly, the much analyzed post-1980 pay-productivity gap was in fact the norm, with a history going back as far as the early 19th century. Periods of pay-productivity collinearity were, it therefore follows, outliers, with pay-productivity gaps being the norm. Hence, from a purely legalistic and scientific point of view, there is no reason why wages should follow productivity. In fact, there is every reason that they shouldn't.

However, this raised another question, namely if wages shouldn't follow productivity, then who or which factor input(s) should? As argued, from a purely legal/scientific point of view, it would follow that the owners of the energy input should receive the value of their marginal physical product. But this only served to raise the question, how should the owners of the organizational inputs be compensated? How should Marshall's machine operatives be paid?

How should investors be paid? Again, from legal, scientific point of view, the resulting energy rents would need to be shared with both organizational factor inputs. To help understand the underlying issues, we formalized the problem in terms of bargaining theory, were the owners of the factor inputs bargain over energy rents, with the outcome being determined by outside options and each factor's relative bargaining power.

In addition to putting the current pay-productivity gap in its proper historical context, this paper has also served to raise the all-important question of income distribution in a world in which labor and capital are not physically productive factor inputs and, as such, the current physical productivity standard cannot be invoked (i.e. neoclassical distribution theory). As shown, few have been those who attempted to address this issue. Among them were the Technocrats who, in addition to having a consilient view of material processes based on energy, advocated what could best be described as an egalitarian approach to energy rent distribution. Other similar approaches included Upton Sinclair's EPIC (End Poverty in California) movement and Clifford Douglas' Social Credit movement. What is important to understand is that these movements were based on sound scientific fundamentals.

The upshot of this paper is straightforward, namely that the current pay-productivity gap is a timely reminder of an issue that has dogged the economics profession from the very beginning, namely the question of income distribution in a world in which two of the three factor inputs are not physically productive.

As information and communication technology as well as artificial intelligence come to replace human supervision, conventionally-measured labor productivity (Product per Labor Input) will increase as fewer supervisors/machine operatives are need. Consequently, there is no reason to believe that those remaining (if any) will appropriate the energy rents their former colleagues left behind. In other words, there is no reason for pay to increase. The bottom line is that pay and productivity are unrelated as conventionally-defined labor is not productive in the physical sense.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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