Capitalism and the Curse of Energy Efficiency

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The curse of energy efficiency, better known as the Jevons Paradox—the idea that increased energy (and material-resource) efficiency leads not to conservation but increased use—was first raised by William Stanley Jevons in the nineteenth century. Although forgotten for most of the twentieth century, the Jevons Paradox has been rediscovered in recent decades and stands squarely at the center of today's environmental dispute.

The nineteenth century was the century of coal. It was coal above all else that powered British industry, and thus the British Empire. But in 1863 the question was raised by industrialist Sir William George Armstrong, in his presidential address to the British Association for the Advancement of Science, as to whether Britain's world supremacy in industrial production could be threatened in the long run by the exhaustion of readily available coal reserves.1 At that time, no extensive economic study had been conducted on coal consumption and its impact on industrial growth.

In response, William Stanley Jevons, who would become one of the founders of neoclassical economics, wrote, in only three months, a book entitled *The Coal Question: An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal-Mines* (1865). Jevons argued that British industrial growth relied on cheap coal, and that the increasing cost of coal, as deeper seams were mined, would lead to the loss of "commercial and manufacturing supremacy," possibly "within a lifetime," and a check to economic growth, generating a "stationary condition" of industry "within a century."2 Neither technology nor substitution of other energy sources for coal, he argued, could alter this.

Jevons's book had an enormous impact. John Herschel, one of the great figures in British science, wrote in support of Jevons's thesis that "we are using up our resources and expending our national life at an enormous and increasing rate and thus a very ugly day of reckoning is impending sooner or later."3 In April 1866, John Stuart Mill praised *The Coal Question* in the House of Commons, arguing in support of Jevons's proposal of compensating for the depletion of this critical natural resource by cutting the national debt. This cause was taken up by William Gladstone, Chancellor of the Exchequer, who urged Parliament to act on debt reduction, based on the uncertain prospects for national development in the future, due to the anticipated rapid exhaustion of coal reserves. As a result, Jevons's book quickly became a

bestseller.4

Yet Jevons was stunningly wrong in his calculations. It is true that British coal production, in response to increasing demand, more than doubled in the thirty years following the publication of his book. During the same period in the United States, coal production, starting from a much lower level, increased ten times, though still remaining below the British level.5 Yet no enduring "coal panic," due to exhaustion of available coal supplies, ensued in the late nineteenth and early twentieth centuries. Jevons's chief mistake had been to equate the energy for industry with coal itself, failing to foresee the later development of energy substitutes for coal, such as petroleum and hydroelectric power.6 In 1936, seventy years after the parliamentary furor generated by Jevons's book, John Maynard Keynes commented on Jevons's projection of a decline in the availability of coal, observing that it was "overstrained and exaggerated." One might add that it was quite narrow in scope.7

The Jevons Paradox

But there is one aspect of Jevons's argument—the Jevons Paradox itself—that continues to be considered one of the pioneering insights in ecological economics.8 In chapter 7 of *The Coal Question*, entitled "Of the Economy of Fuel," Jevons responded to the common notion that, since "the falling supply of coal will be met by new modes of using it efficiently and economically," there was no problem of supply, and that, indeed, "the amount of useful work got out of coal may be made to increase manifold, while the amount of coal consumed is stationary or diminishing." In sharp opposition to this, Jevons contended that increased efficiency in the use of coal as an energy source only generated increased demand for that resource, not decreased demand, as one might expect. This was because improvement in efficiency led to further economic expansion. "*It is wholly a confusion of ideas*," he wrote, "*to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth*. As a rule, new modes of economy will lead to an increase of consumption according to a principle recognised in many parallel instances….The same principles apply, with even greater force and distinctness, to the use of such a general agent as coal. It is the very economy of its use which leads to its extensive consumption."9

"Nor is it difficult," Jevons wrote, "to see how this paradox arises." Every new technological innovation in the production of steam engines, he pointed out in a detailed description of the steam engine's evolution, had resulted in a more thermodynamically efficient engine. And each new, improved engine had resulted in an increased use of coal. The Savery engine, one of the earlier steam engines, he pointed out, was so inefficient that "practically, the cost of working kept it from coming into use; *it consumed no coal, because its rate of consumption was too high*."10 Succeeding models that were more efficient, such as Watt's famous engine, led to higher and higher demand for coal with each successive improvement. "Every such improvement of the engine, when effected, does but accelerate anew the consumption of coal. Every branch of manufacture receives a fresh impulse—hand labour is still further replaced by mechanical labour, and greatly extended works can be undertaken which were not commercially possible by the use of the more costly steam-power."11

Although Jevons thought that this paradox was one that applied to numerous cases, his focus in *The Coal Question* was entirely on coal as a "general agent" of industrialization and a spur to investment goods industries. The power of coal to stimulate economic advance, its accelerated use, despite advances in efficiency, and the severity of the effects to be expected from the decline in its availability, were all due to its dual role as the necessary fuel for the modern steam engine and as the basis for blast furnace technology.

In the mid-nineteenth century, coal was the key material input for blast furnaces in the smelting of iron—the crucial industrial product and the foundation of industrial dominance.12 It was by virtue of its greater development in this area, as "the workshop of the world," that Britain accounted for about half of world output of iron in 1870.13 Greater efficiency in the use of coal thus translated into a greater capacity to produce iron and expand industry in general, leading to spiraling demand for coal. As Jevons put it:

> If the quantity of coal used in a blast-furnace, for instance, be diminished in comparison with the yield, the profits of the trade will increase, new capital will be attracted, the price of pig-iron will fall, but the demand for it [will] increase; and eventually the greater number of furnaces will more than make up for the diminished consumption of each. And if such is not always the result within a single branch, it must be remembered that the progress of any branch of manufacture excites a new activity in most other branches, and leads indirectly, if not directly, to increased inroads upon our seams of coal.14

What made this argument so powerful at the time was that it seemed immediately obvious to everyone in Jevons's day that industrial development depended on the capacity to expand iron production cheaply. This meant that a reduction in the quantity of coal needed in a blast furnace would immediately translate into an expansion of industrial production, industrial capacity, and the ability to capture more of the world market—hence more demand for coal. The tonnage of coal consumption by the iron and steel industries of Britain in 1869, 32 million tons, exceeded the combined amount used in both general manufactures, 28 million tons, and railroads, 2 million tons.15

This was the age of capital and the age of industry, in which industrial power was measured in terms of coal and pig iron production. Output of coal and iron in Britain increased basically in tandem in this period, both tripling between 1830 and 1860.16 As Jevons himself put it: "Next after coal…iron is the material basis of our power. It is the bone and sinews of our laboring system. Political writers have correctly treated the invention of the coal-blast furnace as that which has most contributed to our material wealth….The production of iron, the material of all our machinery, is the best measure of our wealth and power."17

Hence none of Jevons's readers could fail to perceive the multiplier effects on industry of an improvement in efficiency in the use of coal, or the "increased inroads" upon "seams of coal" that this would tend to generate. "Economy," he concluded, "multiplies the value and efficiency

of our chief material; it indefinitely increases our wealth and means of subsistence, and leads to an extension of our population, works, and commerce, which is gratifying to the present, but must lead to an earlier end."18

A Natural Law

In treating coal as the "chief material" of British industry, Jevons emphasized what he saw as a shift in industrial development over time from what he referred to as one "staple produce of the country" to another. The great battle over the Corn Laws had already pointed to the fact—noted by his father, Thomas Jevons, among others—that a lower price for a staple product would greatly expand demand and ultimately scarcity (which, in the case of corn, was to be satisfied by imports).19 But by the late nineteenth century, it was coal, not corn, that was the focus of a kind of Malthusian scarcity.20

"It was Jevons's thesis in this book," Keynes noted, "that the maintenance of Great Britain's prosperity and industrial leadership required a continuous growth of her heavy industries on a scale which would mean a demand for coal increasing in a geometrical progression. Jevons advanced this principle as an extension of Malthus's law of population, and he designated it the *Natural Law of Social Growth*.…From this it is a short step to put *coal* into the position occupied in Malthus's theory by *corn*."21

Extending Malthus's theory to coal, Jevons wrote: "Our subsistence no longer depends upon our produce of corn. The momentous repeal of the Corn Laws throws us from corn upon coal. It marks, at any rate, the epoch when coal was finally recognised as the staple produce of the country;—it marks the ascendancy of the manufacturing interest, which is only another name for the development of the use of coal." Jevons contended that although population had "quadrupled since the beginning of the nineteenth century," the consumption of coal had increased by "sixteenfold," and that this growth of coal production "per head" was a necessity of rapid industrial development, which must come to an end.22

Yet the chief contradiction behind the paradox that Jevons raised—the whole dynamic of accumulation or expanded reproduction intrinsic to capitalism—was not analyzed in *The Coal Question*. As one of the early neoclassical economists, Jevons abandoned the central emphasis on class and accumulation that distinguished the work of the classical economists. His economic analysis took the form of static equilibrium theory. There is nothing in his argument resembling Karl Marx's notion of capital as self-expanding value, and the consequent need for continual expansion.

Jevons's economic framework was thus ill equipped to deal concretely with issues of accumulation and economic growth. The expansion of population, industry, and the demand for coal (as the "central material" of industrial life) was, in his view, simply the product of an abstract Natural Law of Social Growth, building on Malthus. Viewing capitalism more as a natural phenomenon than a socially constructed reality, he could find no explanation for continuously increasing economic demand, other than to point to individual behavior, Malthusian demographics, and the price mechanism. Rather than emphasizing the profit

motive itself, he drew on Justus von Liebig's abstract law of power: "Civilisation, says Baron Liebig, is *the economy of power*, and our power is coal."23 The forces driving economic expansion, feeding industrialization, and resulting in the growing demand for coal, were thus strangely weak and undeveloped in *The Coal Question*, reflecting the fact that Jevons lacked a realistic conception of a capitalist economy and society.

Industrial Hegemony, Not Ecological Sustainability

British hegemony, rather than ecology, lay at the bottom of Jevons's concerns. Despite the emphasis he placed on resource scarcity and its importance for ecological economics, it would be a mistake to see *The Coal Question* as predominantly ecological in character. Jevons was unconcerned with the environmental problems associated with the exhaustion of energy reserves in Great Britain or the rest of the world. He even failed to address the air, land, and water pollution that accompanied coal production. Charles Dickens, decades before, had described the industrial towns, with their concentrated coal burning, as characterized by a "plague of smoke, [which] obscured the light, and made foul the melancholy air" in a ceaseless progression of "black vomit, blasting all things living or inanimate, shutting out the face of day, and closing in on all these horrors with a dense dark cloud."24 Of this, there is not a trace in Jevons. Similarly, the occupational illnesses and hazards confronting workers in the coal mines and coal-fed factories did not enter his analysis, though such concerns were evident in the work of other nineteenth-century analysts, as witnessed by Frederick Engels's *The Condition of the Working Class in England*.25

Indeed, there was in Jevons no concern for nature as such. He simply assumed that the mass disruption and degradation of the earth was a natural process. Although the shortage of coal, as an energy source, generated questions in his analysis about whether growth could be sustained, the issue of ecological sustainability itself was never raised. Because the economy must remain in continual motion, Jevons disregarded sustainable sources of energy, such as water and wind, as unreliable, limited to a particular time and location.26 Coal offered capital a universal energy source to operate production, without disruption of business patterns.

Jevons therefore had no real answer to the paradox he raised. Britain could either rapidly use up its cheap source of fuel—the coal on which its industrialization rested—or it could use it up more slowly. In the end, he chose to use it up rapidly: "If we lavishly and boldly push forward in the creation of our riches, both material and intellectual, it is hard to over-estimate the pitch of beneficial influence to which we may attain in the present. *But the maintenance of such a position is physically impossible. We have to make the momentous choice between brief but true greatness and longer continued mediocrity*."27

Expressed in these terms, the path to be taken was clear: to pursue glory in the present and accept the prospect of a drastically degraded position for future generations. Since Jevons had no answer to what he saw as the inevitable and rapid depletion of Britain's coal stocks—and British capital and the British government saw no other conceivable course than "business as usual"—the response to Jevons's book largely took the form, oddly enough, of an added

justification for reduction of the national debt. This was presented as a precautionary measure in the face of the eventual slowdown of industry. As Keynes wrote, “The proposition that we were living on our natural capital” gave rise to the irrational response that it was necessary to effect “a rapid reduction of the dead-weight debt.”28

Indeed, nearly the entire political impact of Jevons’s book was confined, ironically, to its penultimate chapter, “Taxes and the National Debt.” Jevons and other figures, such as Mill and Gladstone, who took up his argument, never seriously raised the idea of the conservation of coal. There was no mention anywhere in Jevons’s analysis of the point raised by Engels in a letter to Marx, in which industrial capitalism was characterized as a “squanderer of *past* solar heat” as evidenced by its “squandering [of] our reserves of energy, our coal, ore, forests, etc.”29 For Jevons, the idea of an alternative to business as usual was never discussed, and doubtless never entered his mind. Nothing was further from his general economic outlook than the transformation of the social relations of production in the direction of a society governed, not by the search for profit, but by people’s genuine needs and the requirements of socio-ecological sustainability. In the end, the problems he foresaw were delayed in the actual historical course of events by the expansion in the use of other fossil fuels—oil and natural gas—as well as hydroelectric power, and by the ongoing exploitation of the resources of the entire globe. All of this, however, has prepared the way for our current planetary dilemma and the return of the Jevons Paradox.

The Rediscovery of the Jevons Paradox

The Jevons Paradox was forgotten in the heyday of the age of petroleum during the first three-quarters of the twentieth century, but reappeared in the 1970s due to increasing concerns over resource scarcity associated with the Club of Rome’s *Limits to Growth* analysis, heightened by the oil-energy crisis of 1973-74. As energy efficiency measures were introduced, economists became concerned with their effectiveness. This led to the resurrection, at the end of the 1970s and the beginning of the 1980s, of the general question posed by the Jevons Paradox, in the form of what was called the “rebound effect.” This was the fairly straightforward notion that engineering efficiency gains normally led to a decrease in the effective price of a commodity, thereby generating increased demand, so that the gains in efficiency did not produce a decrease in consumption to an equal extent. The Jevons Paradox has often been relegated to a more extreme version of the rebound effect, in which there is a *backfire*, or a rebound of more than 100 percent of “engineering savings,” resulting in an *increase* rather than decrease in the consumption of a given resource.30

Technological optimists have tried to argue that the rebound effect is small, and therefore environmental problems can be solved largely by technological innovation alone, with the efficiency gains translating into lower throughput of energy and materials (dematerialization). Empirical evidence of a substantial rebound effect is, however, strong. For example, technological advancements in motor vehicles, which have increased the average miles per gallon of vehicles by 30 percent in the United States since 1980, have not reduced the overall energy used by motor vehicles. Fuel consumption per vehicle stayed constant while the

efficiency gains led to the augmentation, not only of the numbers of cars and trucks on the roads (and the miles driven), but also their size and “performance” (acceleration rate, cruising speed, etc.)—so that SUVs and minivans now dot U.S. highways. At the macro level, the Jevons Paradox can be seen in the fact that, even though the United States has managed to double its energy efficiency since 1975, its energy consumption has risen dramatically. Juliet Schor notes that over the last thirty-five years:

> energy expended per dollar of GDP has been cut in half. But rather than falling, energy demand has increased, by roughly 40 percent. Moreover, demand is rising fastest in those sectors that have had the biggest efficiency gains—transport and residential energy use. Refrigerator efficiency improved by 10 percent, but the number of refrigerators in use rose by 20 percent. In aviation, fuel consumption per mile fell by more than 40 percent, but total fuel use grew by 150 percent because passenger miles rose. Vehicles are a similar story. And with soaring demand, we’ve had soaring emissions. Carbon dioxide from these two sectors has risen 40 percent, twice the rate of the larger economy.

Economists and environmentalists who try to measure the direct effects of efficiency on the lowering of price and the immediate rebound effect generally tend to see the rebound effect as relatively small, in the range of 10 to 30 percent in high-energy consumption areas such as home heating and cooling and cars. But once the indirect effects, apparent at the macro level, are incorporated, the Jevons Paradox remains extremely significant. It is here at the macro level that scale effects come to bear: improvements in energy efficiency can lower the effective cost of various products, propelling the overall economy and expanding overall energy use.[31] Ecological economists Mario Giampietro and Kozo Mayumi argue that the Jevons Paradox can only be understood in a macro-evolutionary model, where improvements in efficiency result in changes in the matrices of the economy, such that the overall effect is to increase scale and tempo of the system as a whole.[32]

Most analyses of the Jevons Paradox remain abstract, based on isolated technological effects, and removed from the historical process. They fail to examine, as Jevons himself did, the character of industrialization. Moreover, they are still further removed from a realistic understanding of the accumulation-driven character of capitalist development. An economic system devoted to profits, accumulation, and economic expansion without end will tend to use any efficiency gains or cost reductions to expand the overall scale of production. Technological innovation will therefore be heavily geared to these same expansive ends. It is no mere coincidence that each of the epoch-making innovations (namely, the steam engine, the railroad, and the automobile) that dominated the eighteenth, nineteenth, and twentieth centuries were characterized by their importance in driving capital accumulation and the positive feedback they generated with respect to economic growth as a whole—so that the scale effects on the economy arising from their development necessarily overshot

improvements in technological efficiency.33 Conservation in the aggregate is impossible for capitalism, however much the output/input ratio may be increased in the engineering of a given product. This is because all savings tend to spur further capital formation (provided that investment outlets are available). This is especially the case where core industrial resources—what Jevons called “central materials” or “staple products”—are concerned.

The Fallacy of Dematerialization

The Jevons Paradox is the product of a capitalist economic system that is unable to conserve on a macro scale, geared, as it is, to maximizing the throughput of energy and materials from resource tap to final waste sink. Energy savings in such a system tend to be used as a means for further development of the economic order, generating what Alfred Lotka called the “maximum energy flux,” rather than minimum energy production.34 The deemphasis on absolute (as opposed to relative) energy conservation is built into the nature and logic of capitalism as a system unreservedly devoted to the gods of production and profit. As Marx put it: “Accumulate, accumulate! That is Moses and the prophets!”35

Seen in the context of a capitalist society, the Jevons Paradox therefore demonstrates the fallacy of current notions that the environmental problems facing society can be solved by purely technological means. Mainstream environmental economists often refer to “dematerialization,” or the “decoupling” of economic growth, from consumption of greater energy and resources. Growth in energy efficiency is often taken as a concrete indication that the environmental problem is being solved. Yet savings in materials and energy, in the context of a given process of production, as we have seen, are nothing new; they are part of the everyday history of capitalist development.36 Each new steam engine, as Jevons emphasized, was more efficient than the one before. “Raw materials-savings processes,” environmental sociologist Stephen Bunker noted, “are older than the Industrial Revolution, and they have been dynamic throughout the history of capitalism.” Any notion that reduction in material throughput, per unit of national income, is a new phenomenon is therefore “profoundly ahistorical.”37

What is neglected, then, in simplistic notions that increased energy efficiency normally leads to increased energy savings overall, is the reality of the Jevons Paradox relationship—through which energy savings are used to promote new capital formation and the proliferation of commodities, demanding ever greater resources. Rather than an anomaly, the rule that efficiency increases energy and material use is integral to the “regime of capital” itself.38 As stated in *The Weight of Nations*, an important empirical study of material outflows in recent decades in five industrial nations (Austria, Germany, the Netherlands, the United States, and Japan): “Efficiency gains brought by technology and new management practices have been offset by [increases in] the scale of economic growth.”39

The result is the production of mountains upon mountains of commodities, cheapening unit costs and leading to *greater squandering of material resources*. Under monopoly capitalism, moreover, such commodities increasingly take the form of artificial use values, promoted by a

vast marketing system and designed to instill ever more demand for commodities and the exchange values they represent—as a substitute for the fulfillment of genuine human needs. Unnecessary, wasteful goods are produced by useless toil to enhance purely economic values at the expense of the environment. Any slowdown in this process of ecological destruction, under the present system, spells economic disaster.

In Jevons's eyes, the "momentous choice" raised by a continuation of business as usual was simply "*between brief but true* [national] *greatness and longer continued mediocrity*." He opted for the former—the maximum energy flux. A century and a half later, in our much bigger, more global—but no less expansive—economy, it is no longer simply national supremacy that is at stake, but the fate of the planet itself. To be sure, there are those who maintain that we should "live high now and let the future take care of itself." To choose this course, though, is to court planetary disaster. The only real answer for humanity (including future generations) and the earth as a whole is to alter the social relations of production, to create a system in which efficiency is no longer a curse—a higher system in which equality, human development, community, and sustainability are the explicit goals.

Notes

↩ Sir William George Armstrong, Presidential Address, *Report of the 33rd Meeting of the British Association for the Advancement of Science, Held at Newcastle-upon-Tyne* (London: John Murray, 1864), li-lxiv. See also William Stanley Jevons, *The Coal Question: An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal-Mines*, ed. A. W. Flux (London: Macmillan, 1906 [1865]), 32-36.
↩ Jevons, *The Coal Question*, xxxi, 274.
↩ John Herschel, quoted in Juan Martinez-Alier, *Ecological Economics* (Oxford: Basil Blackwell, 1987), 161-62.
↩ Michael V. White, "Frightening the 'Landed Fogies' Parliamentary Politics and the *Coal Question*," *Utilitas* 3/2 (November 1991): 289-302; Leonard H. Courtney, "Jevons's Coal Question: Thirty Years After," *Journal of the Royal Statistical Society* 60/4 (December 1897): 789; John Maynard Keynes, *Essays and Sketches in Biography* (New York: Meridan Books, 1956), 132. Gladstone's approach to Jevons's work was primarily a tactical ploy, used politically to justify a debt reduction argument that was never actually implemented in the budget.
↩ Courtney, "Jevons's Coal Question," 797.
↩ Jevons was not alone in making such an error. John Tyndall, one of the premier physicists of the day, observed in 1865: "I see no prospect of any substitute being found for coal, as a source of motive power." Quoted in Jevons, *The Coal Question*, xi. It is worth noting that the drilling of Edwin Drake's historic oil well in northwestern Pennsylvania had only occurred six years before, in 1859, and its full significance was not yet understood.
↩ Keynes, *Essays and Sketches in Biography*, 128.
↩ Mario Giampietro and Kozo Mayumi, "Another View of Development, Ecological Degradation, and North–South Trade," *Review of Social Economy* 56/1 (1998): 24-26;

John M. Polimeni, Kozo Mayumi, Mario Giampietro, and Blake Alcott, eds., *The Jevons Paradox and the Myth of Resource Efficiency Improvements* (London: Earthscan, 2008).
↩ Jevons, *The Coal Question*, 137-41.
↩ Ibid., 141-43.
↩ Ibid., 152-53.
↩ As late as 1842, British fireplaces still consumed two-thirds of the country's coal, but by the time Jevons wrote his book, more than two decades later, this had diminished to about a fifth of national consumption and barely entered his argument, which focused on the industrial demand for coal as the major and indispensable source of demand. As Jevons said, "I speak not here of the *domestic consumption of coal*. This is undoubtedly capable of being cut down without other harm than curtailing our home comforts, and somewhat altering our confirmed national habits." See Jevons, *The Coal Question*, 138-39; Eric J. Hobsbawm, *Industry and Empire* (London: Penguin, 1969), 69.
↩ Eric J. Hobsbawm, *The Age of Capital, 1848-1873* (New York: Vintage, 1996), 39-40.
↩ Jevons, *The Coal Question*, 140-42.
↩ The data for 1869 was provided in A.W. Flux's annotated edition of Jevons's work. By 1903 the relationships had changed, with the iron and steel industries accounting for 28 million tons of coal consumption (less than in Jevons's day), while the consumption of general manufactures had grown to 53 million tons and the railways to 13 million tons. See Jevons, *The Coal Question*, 138-39.
↩ Hobsbawm, *Industry and Empire*, 70-71.
↩ Jevons, *The Coal Question*, 245.
↩ Ibid., 156.
↩ Ibid., 195, 234-41; Thomas Jevons, *The Prosperity of the Landholders Not Dependent on the Corn Laws* (London: Longmans, 1840).
↩ Malthus himself denied the possibility of scarcity in minerals, arguing that raw materials, in contrast to food, "are in great plenty" and "a demand…will not fail to create them in as great a quantity as they are wanted." See Thomas Robert Malthus, *An Essay on the Principle of Population and a Summary View of the Principle of Population* (London: Penguin, 1970), 100.
↩ Keynes, *Essays and Sketches in Biography*, 128-29.
↩ Jevons, *The Coal Question*, 195-96. Jevons's discussion of industrial development in terms of various staple products anticipated the work of Harold Innis and the staple theory of economic growth. See Mel Watkins, *Staples and Beyond* (Montreal: McGill-Queens University Press, 2006).
↩ Jevons, *The Coal Question*, 142.
↩ Charles Dickens, *The Old Curiosity Shop* (New York: E.P. Dutton and Co., 1908), 327.
↩ Frederick Engels, *The Condition of the Working Class in England* (Chicago: Academy Publishers, 1984). See also John Bellamy Foster, *The Vulnerable Planet* (New York: Monthly Review Press, 1994), 50-59; Brett Clark and John Bellamy Foster, "The Environmental Conditions of the Working Class: An Introduction to Selections from Friedrich Engels's *The Condition of the Working Class in England in 1844*," *Organization & Environment* 19/3 (2006): 375-88.

↩ Jevons, *The Coal Question*, 164-71.
↩ Ibid., 459-60.
↩ Keynes, *Essays and Sketches in Biography*, 132.
↩ Karl Marx and Frederick Engels, C*ollected Works* (New York: International Publishers, 1975), vol. 46, 411.
↩ Blake Alcott, “Historical Overview of the Jevons Paradox in the Literature,” in Polimeni, et al., *The Jevons Paradox*, 8, 63. For the Club of Rome study, see Donella H. Meadows, Dennis L. Meadows, Jørgen Randers, William W. Behrens III, *The Limits to Growth* (New York: Universe Books, 1972).
↩ Juliet B. Schor, *Plenitude* (New York: Penguin Press, 2010), 88-90. For a detailed discussion of the empirical data on the Jevons Paradox, see John M. Polimeni, “Empirical Evidence for the Jevons Paradox,” in Polimeni, et al., *The Jevons Paradox*, 141-71.
↩ Mario Giampietro and Kozo Mayumi, “The Jevons Paradox,” in Polimeni, et al., *The Jevons Paradox*, 80-81.
↩ For a discussion of epoch-making innovations, see Paul A. Baran and Paul M. Sweezy, *Monopoly Capital* (New York: Monthly Review Press, 1966), 219-22.
↩ Alfred J. Lotka, “Contributions to the Energetics of Evolution,” *Proceedings of National Academy of Sciences* 8 (1922): 147-51; Giampietro and Mayumi, “The Jevons Paradox,” 111-15.
↩ Karl Marx, *Capital*, vol. 1 (New York: Vintage, 1976), 742.
↩ John Bellamy Foster, *Ecology Against Capitalism* (New York: Monthly Review Press, 2002), 22-24.
↩ Stephen G. Bunker, “Raw Materials and the Global Economy,” *Society and Natural Resources* 9/4 (July-August 1996): 421.
↩ Robert L. Heilbroner, *The Nature and Logic of Capitalism* (New York: W.W. Norton, 1985).
↩ Emily Matthews, Christof Amann, Stefan Bringezu, Marina Fischer-Kowalski, Walter Hüttler, René Kleijn, Yuichi Moriguchi, Christian Ottke, Eric Rodenburg, Don Rogich, Heinz Schandl, Helmut Schütz, Ester van der Voet, and Helga Weisz, *The Weight of Nations* (Washington, D.C.: World Resources Institute, 2000), 35.