Where Did Jevons' Energy Come From?

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1.

Philip Mirowski is no conservationist. At one point in this book he observes that it "is a difficult task to discern the wood from the many trees that have passed through the pulper in the cause of game theory" (p.77)[1]. However, so far as postclassical economic theory in general is concerned,[2] Mirowski argues that there is no difficulty with identifying the wood and he takes to it with a chainsaw of historical analysis (including some cliometrics), philosophy, puns, and word play. Despite an irritating number of misprints (although I liked the reference to "the Australian school of economics, and particularly Hayek" at p.82), *Against Mechanism* is a stimulating piece of work. Most of the chapters have appeared previously as journal articles, although some have been altered slightly for the book. Chapter 8, for example, which critically examines McCloskey's treatment of 'the rhetoric of economics', has an amusing introduction which did not appear in its (1987) *Economics And Philosophy* version. *Against Mechanism* provides a framework for the articles with an introduction where Mirowski explains his general project.

The project has two broad aims. The first is to show that many of the problems which critics have identified with the general framework of orthodox economic theory, in particular its mechanistic depiction of economic activity, can be explained by its historical basis. Specifically, the type of supply and demand theory which began formally with the work of Jevons and Walras was "a bowdlerized imitation of nineteenth-century physics". Hence, by examining the history of that physics, it is possible to explain "the origins and content of orthodox neoclassical theory, including the previously mysterious 'simultaneous discovery' of marginal utility theory" (pp.5,6). The general framework was buttressed by an empiricist epistemology of science which is identified as part of the Cartesian Tradition (see esp. pp.111-2). Mirowski's analysis of how "physics has been the dog wagging the economics tail" is contained in Chapters 1 - 3, 6, and 8.

The second broad aim of the project is to "revive the spirit" of the institutionalist economics of Veblen, Commons and Mitchell. Mirowski argues that, in criticising the mechanism of their orthodox opponents, the Institutionalists drew upon a sophisticated, albeit flawed, hermeneutic philosophy which was subsequently ba-

Review article of Philip Mirowski, **Against Mechanism. *Protecting Economics from Science,*** *(Rowman and Littlefield), Totowa, 1988. 264 pp. $US34.95. 0 8476 7436 3.*

stardised as pragmatism and characterised as a crude empiricism (Chapter 7). With some modifications, however, the analysis can be used today to inform an approach which depicts institutions as "socially constructed invariants that provide actors who participate in them with the means and resources to cope with change and diversity" (p.132).[3] Mirowski also examines the self-styled New Institutionalist game-theoretic approach to economic theory, so as to consider whether it avoids the pitfalls of postclassicism. In a careful discussion of the work of Schotter and Shubik (Chapters 4-5), he concludes that, while their approach avoids certain problems, it is ultimately flawed because it still relies on a mechanistic constrained optimisation theory to explain the behaviour of actors and institutions.

Some examples are provided of how a reworked institutionalism can examine economic problems, without having to retreat into nihilism as far as mathematics and econometrics are concerned. In a discussion of 'What Markets Do' (Chapter 12), for example, Mirowski uses 18th century stock market data to drive home the importance of hysteresis, as compared with 'Laplacean' notions of efficient markets (in 'weak' or 'strong' versions). In another discussion (Chapter 11) of Adam Smith's treatment of profits, careful use is made of the meagre statistics to evaluate Smith's arguments. However, this is not just a variant of 'let's test Adam Smith' since the analysis has a sting in the tail. Mirowski argues that Smith considered that the epistemological notion of empiricism which came to dominate 20th century economics would retard the process of economic inquiry. For Smith, 'science' was more an "artistic representation". There is also an interesting cliometric treatment of Jevons' 'sunspot' explanation of economic fluctuations, which Mirowski likens to the Lucas variant of rational expectations theory (Chapter 3).

For readers of this *Review*, the most interesting aspect of *Against Mechanism* will probably be Mirowski's explanation for the appearance of marginalism. The crux of the argument is that the "identifiable discontinuity in economic thought in the 1870s and 1880s" was not due principally to the supply and demand theory of price determination. Nor were the notions of declining marginal utility and utility-determined prices "particularly novel in the 1870s". Instead, the "most discontinuous aspect" of the new framework was "the successful penetration of mathematical discourse into economic theory". This penetration was part of a more general appropriation of a framework or 'paradigm' which had been developed in physics by the mid-nineteenth century (pp.11, 12, 13).

The physics framework had three basic components. The first was the concept of 'energy' which was depicted as an elementary entity in nature. It was "ontologically undefined" and could "only be discussed cogently through the intermediary of its mathematical eidolon" (p.17).[4] An important distinction was drawn here between the potential and kinetic energy of a system. The second component was the use of mathematical techniques such as Lagrangean (and, later, Hamiltonian) constrained maximisation / minimisation which superseded the Newtonian-based fluxions form of the calculus. The third component was a changed attitude to theory construction, including "an increasing refusal to specify the underlying nature of the phenomena described mathematically ... and a predisposition to accept the 'usefulness' of a model as a form of proof" (p.17).

The new supply and demand theory was a "simple appropriation and bowdlerization" of the energy theory, with marginal utility treated as a vector by analogy with force. Utility became the metaphorical equivalent of potential energy (the utility 'field') and expenditure the analogue for kinetic energy (pp.18,19).[5] As far as the mathematics were concerned, "the progenitors of neoclassicism [simply] copied down the physical equations and ... changed the names attached to the variables"; "they appropriated a mathematical model lock, stock and barrel ... in the guise of a metaphor" (pp.31,149).

The physics paradigm preceded the formalisation of the second law of thermodynamics (the entropy law) in the mid-1860s. Consequently, the economic theory was based on a system where all energy was conserved (the first law of thermodynamics) and all phenomena were fully reversible, so that the system could not exhibit hysteresis. All outcomes were thus path-independent (p.152). The borrowing, however, was no state-of-art affair. The progenitors' "grasp of the physics was shallow and superficial", so that they appropriated "the *appearances*" rather than "the *methods* of science" (pp.6,31,37 OE).[6] This created substantive problems for Walras, Pareto and Fisher when they had to deal with the economic implications of the Conservation Principle, in so far as it required the integrability of utility (Chapter 2).

2.

There are at least two principal difficulties which face historians of economics when attempting to assess Mirowski's argument. The first is that some commentators do not appear to be familiar with the more recent secondary literature [Harman 1982, for example] on the energy framework. This has led to confusion as to whether that framework was different from previous explanations such as the indestructibility of matter.[7]

The second problem arises because the explanation Mirowski gives for some of his key arguments can be misleading. In part, this is because the analysis in the book under review is a summary of the more detailed analysis given in Mirowski's *More Heat than Light* (1990). My own experience has been that some of the statements in *Against Mechanism* can appear erroneous unless seen in the wider context set out in MHTL. In part, however, the problem lies also with the sometimes careless way in which Mirowski expresses himself. For example, the language used seems to entail that the explanation for the appearance of marginalism can be reduced to the appearance of the physics framework. It is argued, for example, that the marginalist theory had its "genesis" in the physics research program and that the energetics theory "induced the invention" of marginalism (pp. 13,17,30). The argument, however, is more complex than these phrases suggest. While the 'energetics revolution' explains what was analytically distinctive about late nineteenth-century supply and demand theories, a more precise explanation for their appearance must take account of factors such as "class interests", the "sociology of the professions", the state of 'Millian' political economy (in England), and "personal motivations" (p.30).

Given Mirowski's wide reading in the history and philosophy of 'science' and his critical comments on the 'internalist-externalist dichotomy' when writing histories (pp.12-13),[8] it would seem that he is arguing that the appearance of a particular discourse should be analysed in terms of its 'conditions of existence'. These conditions could include an explanation of the use of metaphors, to what extent they were transformed, why they were seen as relevant for the questions being analysed, what (economic, social and political) conditions made the resolution of those questions relevant, and so on. This enables, at least in principle, the presentation of a multi-layered explanation, which can accord varying degrees of importance to different explanatory conditions (cf. Foucault 1975; Ashcraft 1986). Difficulties remain, however, with some of the statements in this book, which can be illustrated by the case of Jevons to whom Mirowski devotes some attention (Chapters 1 and 3).

Mirowski argues that Jevons dedicated "his life's work to drawing out the meaning of the metaphor of energetics for the sphere of the economy" (p.21). Specifically, the *Theory of Political Economy* (1871) was concerned with the maximisation of utility; the *Coal Question* (1865) focussed on "the prediction that England was rapidly exhausting energy stocks in the form of coal"; and, the analysis of sunspots and business cycles was part of "the lifelong theme that economic crises must be caused by energy fluctuations exogenous to the social operation of the economy." Given an epistemological and methodological credo by Jevons' *Principles of Science* (1874, 1877), these were "all direct extrapolations from the energetic movement of the mid-nineteenth century" (p.22). At the same time, this "unified rational response" was driven by a political objective. Jevons presented a "unified ... theoretical project" designed to "portray the market as a 'natural' process, so that doubts about its efficacy would be assuaged, or at the very least, countered, by scientific discourse. The ultimate object was to reconstruct the foundations of the case for free trade" (p.46).

Mirowski remarks that his explanation produces "a neat pattern; perhaps too neat" (p.29). With this I agree. To reduce Jevons' political objectives to that of rationalising free trade is far too simplistic. Again, while there is no space here to deal with Jevons on economic fluctuations, Mirowski's conclusion requires qualification. Although the work on fluctuations owed a good deal to his work in chemistry and meteorology,[9] it was only in the 1870s that Jevons introduced sunspots into his argument. Before that time he had relied, to a significant extent, on the work of either James Wilson or a number of papers which were presented to the Manchester Statistical Society. Without a more detailed analysis, it is difficult to see how these borrowings can be explained simply as indicating a 'lifelong theme that economic crises must be caused by energy fluctuations'.

I want to focus here, however, on Jevons' use of the energy metaphor, showing how two aspects of it can be clarified through consideration of *The Coal Question* (CQ). The first point concerns the different roles of the metaphor in Jevons' publications. In TPE utility was made isomorphic to energy. In CQ, however, the metaphor was used in an indirect manner. Section III explains why Mirowski's characterisation of CQ appears misleading unless the role of the metaphor is identified. The second point follows from Mirowski seeming to present Jevons as using the metaphor from the early 1860s. This was not the case. Before the mid-1860s, Jevons was using a 'correlation of forces' argument (see below) which was different from that of energy, although the two were (and sometimes still are) conflated. Section IV explains how Jevons switched from the metaphor of force to that of energy in the three editions of CQ (1865,1866,1906). This will hopefully provide a specific example of Mirowski's 'canonical neoclassical model' which he uses to explain the analogy between energy and utility (pp.16-19, 149-50).

3.

Mirowski argues that CQ was concerned with the exhaustion of "energy stocks in the form of coal" (p.21). This is similar to the description given by Jevons' colleague, Balfour Stewart, professor of natural philosophy at Owens College, Manchester. In his widely-read 'elementary treatise on energy and its laws', first published in 1873, Stewart argued that, after CQ, "we must contemplate a time ... when our supplies of coal will be exhausted, and we shall have to resort to other forms of energy". The use of coal constituted a 'dissipation of energy' which was made analogous to "spending our capital" [Stewart 1874, pp.144-5]. The meaning of the 'dissipation of energy', a term which was due to William Thomson [Wise 1990, pp.237-51], had been explained by Stewart in 1868: "there is a tendency in the universe to change the superior kinds of energy into inferior or degraded kinds, which ... can only to a very small extent be changed back again into superior forms" [Stewart and Lockyer 1868, p.322].

Stewart's reading can certainly find support in CQ. Jevons argued, for instance, that, *"while other countries mostly subsist upon the annual and ceaseless income of the harvest, we are drawing more and more upon a capital which yields no annual interest, but once turned into light, heat and force, is gone forever into space"* [Jevons 1866, p.332 OE].[10] The problem is, however, that Jevons also specifically denied that his account was principally concerned with exhaustion, and complained that he had been misunderstood on that matter. Instead, the analysis was concerned with the effects of rising coal costs on Britain's dominance of international trade in manufactured commodities. As Jevons put it, "the high price of coal constitutes the evil of exhaustion" [Jevons 1866, pp.v-vi, 70]. At first sight, this seems to deny the role of the energy metaphor. That conclusion, however, need not be drawn.

In deciding to write CQ, Jevons was deeply impressed by Sir William Armstrong's Presidential Address to the British Association for the Advancement of Science in 1863. A prominent weapons manufacturer, Armstrong argued that the key point of 'the coal question' was not the absolute size of coal reserves, but rather the threat posed to England's manufacturing "supremacy" by increasing coal costs as deeper seams were mined [Armstrong 1864, pp.lii-liv].[11] Jevons followed Armstrong on this point, so that his argument was not that the key problem was the 'dissipation of energy' (Stewart) or the 'exhaustion' of the coal stock. Certainly, the power (or energy) metaphor had an important role to play, but it was used in a more indirect manner. The effects of depleting the energy source were made evident through the political economy variables of relative costs and prices. In that sense, the metaphor was displaced. The relative loss of the power source would occur because other countries could produce coal at a lower cost. This would then result in a relative loss of British economic power. It was for this reason that Jevons continued to insist that exhaustion was not the focus of his analysis, while also linking a number of his arguments with the new energy physics (see below).

4.

Armstrong's Address was important for the argument in CQ in another respect. Describing coal deposits as "vast magazines" of "embodied ... power" which derived from the sun [Armstrong 1864, p.lii], Armstrong linked the discussion of coal with a series of topics which Jevons was familiar with from his previous work in chemistry and meteorology [White 1990]. The key to this was the role of the theory of heat in, as Jevons put it, the explanation for a general 'mechanical theory of nature' (see below). The manner in which Jevons used and altered his references to that analysis in different editions of CQ helps to explain the precise manner in which he switched to the energy metaphor which was used in TPE.

For Armstrong, the dynamical theory of heat (which he attributed to the work of J.R. Mayer, J.P. Joule, W. Thomson and W.J. Rankine) was "probably the most important discovery of the present century". With the interconvertibility of work (or mechanical effect) and heat demonstrated by the theory, the formation of coal could be explained by the "principle of conservation of force and the relationship now established between heat and motion". The "mechanical energy resident ... in coal", for example, could be expressed as the numerical equivalent of lifting a weight through a particular height. Or, in an example closer to Armstrong's heart, it was possible to calculate the "number of dynamical units of heat representing the whole mechanical power of the projectile" in the "science of gunnery". The heat theory could then be used to explain that, although the conditions for coal formation had "passed away for ever", coal was the only feasible source of power in the future. The use of heat or electricity required "chemical affinity as the source of supply". This necessitated the use of oxygen and the only feasible "oxidizable substance" available was coal. At the same time, it was alarming that the heat theory showed that steam engines used in industry "realise ... only a small part of the thermic effect of the fuel", where the point of comparision was a "perfect heat-engine". It was thus crucial to improve the existing rate of the conversion of "heat of combustion into available power" [Armstrong 1864, pp.lii-lv,lx].

As Mirowski notes, "the development of the principle of the conservation of energy grew quite directly out of industrial concerns" (p.97), such as those outlined by Armstrong. Indeed, physicists such as John Tyndall, William Thomson and P.G. Tait had referred to recent experiments with the "12-ton Armstrong gun" in their 'popular' explanations of the theory of heat and of the conservation of energy [Tyndall 1892, p.371; Thomson and Tait 1862, p.602]. It should be noted, however, that the terms of Armstrong's discussion effectively referred to a recent bitter public argument between those physicists.

Two matters were in dispute. The first was the role of J.R. Mayer, a German physician, in formulating the theory of the interconvertibility of work and heat. In a lecture delivered at the Royal Institution in June 1862, Tyndall argued that Mayer first formulated the theory [Tyndall 1892, Ch.16]. This claim was then attacked by Thomson and Tait [1862], who claimed analytical priority for J.P. Joule of Manchester. The second contentious matter concerned the more general representation of the heat theory. While Tyndall discussed it in his lecture with the title of "On Force", Thomson and Tait drove a wedge between the force and energy frameworks in their highly polemical article. They referred, for example, to the "host of errors which are due to confounding Force with Energy" and described the notion of "the Conservation of Force" as an "error" [Thomson and Tait 1862, p.601].[12] This debate, focussing on the role of Mayer, continued into 1863. Its increasingly bitter tone seems to have been due, in large part, to the acerbic Tait [Eve and Creasey 1945, Chapter 9; Smith and Wise 1989, p.353n].

In his 1863 Address, apart from referring to the importance of Tyndall's analysis of heat [Armstrong 1864, p.lxi], Armstrong linked Mayer with the British physicists and referred explicitly to the heat theory within a conservation of force framework (see above). This effectively indicated his support for Tyndall. Jevons followed Armstrong's lead when amplifying his arguments in chapters VII ("The Economy of Fuel") and VIII ("Of Supposed Substitutes for Coal") of CQ.[13] For Jevons placed the discussion of the theory of heat firmly within a 'forces' framework. Perhaps the clearest example of this was the following:

> "The great advances which have been achieved in the mechanical theory of nature, during the last twenty or thirty years, have greatly cleared up our notions of force ... [T]he universe ... is one great manifestation of a *constant whole of force*. The motion of falling bodies, the motions of magnetic or electric attractions, the unseen agitation of heat, the vibration of light, the molecular changes of chemical action, and even the mysterious life-motions of plants and animals, are all but the several modes of greater or lesser motion, and their cause one general *living force*" [Jevons 1866, p.141 OE].

A number of important changes were, however, made to this summary in the third edition of CQ, which was first published in 1906. (The alterations were made by the editor, A.W. Flux, working from Jevons' comments and notes on the second edition [Jevons 1906, pp.xxvii-xxviii]). In the quotation above, "*constant whole of force*" was changed to "*constant aggregate of energy*"; the words "and energy" were added after "force" at the end of the first sentence; and the section of the last sentence after 'motion' was omitted [ibid. p.161]. Throughout the text, references to 'force' were changed to 'energy' or 'motive power'.[14] Clearly, these changes indicate a shift from the use of a conservation of force framework to one of energy.[15] Although the terminology of 'forces' remained in the text of the second edition, there is clear evidence that Jevons had switched his position by early 1866.

In the Preface to the second edition, Jevons cited some correspondence from Tyndall. He then used a long quotation from Tyndall's 1865 paper, "The Constitution of the Universe", noting that, regarding the "impossibility" of finding a substitute for coal "as a source of heat and power ... I have ... only interpreted the opinions of Professor Tyndall" [Jevons 1866, p.xvi]. The relevance of the long quotation which followed from Tyndall's article in the *Fortnightly Review* [ibid. pp.xvii-xviii; Tyndall 1865, p.143] was that the argument for the formation of coal and the lack of a substitute was no longer explained by reference to the conservation of force (as it was in the text), but rather in terms of 'potential' and 'actual' (i.e kinetic) energy. While he was in Australia, Jevons had been effusive about some of Tyndall's earlier work [Black 1973-81, II, p.250].[16] But the attraction of the physicist's clearly-written 1865 article was that it provided an argument for the reconciliation of the forces and energy frameworks, incorporating the troublesome case of gravity.

In TPE Jevons made marginal utility analogous to a gravitational force.[17] As he put it in 1874 when describing the marginalist theory: "just as the gravitating force of a material body depends not alone upon the mass of that body, but upon the masses and relative positions and distances of the surrounding material bodies, so utility is an attraction between a wanting body and what is wanted" [Black 1973-81, VII, p.80]. The problem with gravity, however, was that, within the conservation of forces framework, it appeared to be anomalous. As Jevons explained in the *Principles of Science*, when characterising the law of gravitation as one which held "without exception" :

> "In its exact equality and its perfect independence of all circumstances, except mass and distance, the force of gravity stands apart from all the other forces and phenomena of nature, and has not yet been brought into any relation with them except through the general principle of the conservation of energy" [Jevons 1887, p.605].

Tyndall's paper provided an account of that 'relation'. After explaining how "gravity and chemical affinity stand on precisely the same footing" in terms of convertibility into heat [Tyndall 1865, pp.134-5], he turned to the question of gravity, dealing first with its 'static' representation. The analysis can be illustrated with Figure 1, which has been drawn following Tyndall's account [ibid. pp.138-9]. The diagram represents two particles - F, which is fixed, and D, which is movable.

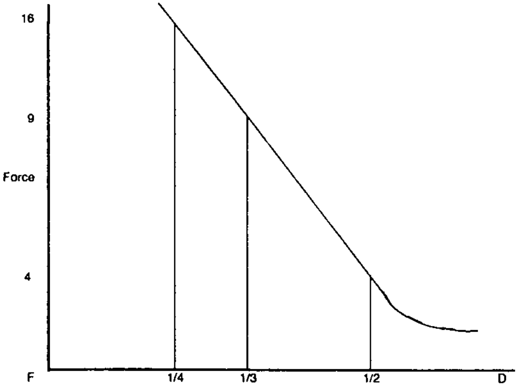

Figure 1

The 'gravitation law' was that "gravity is proportional directly to the product of the gravitating masses, and indirectly to the square of their distance" ($F = Mm/D^2$) [Jevons 1887, p.462]. Tyndall noted that the force of attraction is measured by a spring balance, so that the force is "the amount of tension which is just sufficient to prevent D from moving towards F" [Tyndall 1865, p.139]. It was "customary" in mechanics to measure the magnitude of the force on the ordinate, with the distance between the particles represented on the abscissa. (In the diagram, half the distance between F and D corresponds to a proportional force of 4, a third of the distance to 9 and so on). Vertical lines proportional in length to the attraction are drawn from every point on the abscissa. When joined by a curve, the infinite number of these lines form "a perfectly definite image of the sum total of gravitating force existing within the assumed limits". If the pull or tension of gravity at D was zero, the sum of tensions exerted on particle D is a maximum at that point [ibid]. When it is remembered that, in his 'static' explanation of exchange, Jevons made utility analogous to a gravitating force, the diagram above, coupled with Tyndall's account of the static gravitational field indicates how Jevons could have formulated the utility analysis with diagrams in the early 1860s [cf. Jevons 1871, pp.55-8]. Of course, the "logic" of the physics argument was reversed in that utility was not derived, but was rather "postulated ... as the fundamental exogenous data to which the market transactions adjusted" (Mirowski, p.19).

Tyndall emphasised that this account was only a static picture because there was no discussion of "any motion produced" in the system. A dynamic account would explain that, in the passage from D to F, the tensions would be "consumed" and replaced with *vis viva* ('living force'), which expresses the mechanical measure of the work performed. (Work = mass x the square of velocity). The principle of conservation then followed. The sum of the *vis viva* and the tensions is a constant, or the 'invariable' of the system. At any point between D (assumed to be zero so that the tension is at a maximum) and near F (where *vis viva* is a maximum), the invariable for particle D is : work performed + remaining space of tensions = a constant. The same principle could be applied to explain all natural phenomena which were fully and completely reversible: "This, then, is the rhythmic play of nature as regards her forces. Throughout all her regions she oscillates from tension to *vis viva* from *vis viva* to tension" [Tyndall 1865, pp.139-141].

Tyndall acknowledged that he was "following Helmholtz" in his exposition [ibid. p.138]. This was presumably a reference to Helmholtz's 1847 paper which "created" energetics "as a unifying principle ... drawing upon earlier study of the conceptualisation of *vis viva* ... and the interconvertability of heat and mechanical work" (Mirowski, p.17). But since the language of 'forces' had now become confused, if not partially redundant, Tyndall suggested that it was better to couch the analysis in the terminology of energy as suggested by Rankine [cf. White 1990, pp.21-2]. The old 'tensions' could then be referred to as the system's potential energy (the energy possessed by the system if "all hindrances [are] removed"), while *vis viva* became "*actual* or *dynamic*" (i.e. kinetic) energy, possessed by bodies in motion. The new framework could be used as a general mechanical explanation for gravity, light, heat, magnetism, electricity, chemical affinity and "muscular force". Given the generality of the explanation, it followed that "the energy of the universe is as constant as its matter" [Tyndall 1865, pp.141-3].

Because of the way in which Jevons effectively linked Tyndall's article to his switch to the energy metaphor in 1866, it may be argued that the article played an important role in Jevons' adoption of the metaphor in TPE. Tyndall's analysis can then help to clarify Jevons' (marginalist) use of the metaphor in a number of ways. For example, it helps explain why Jevons thought that a static representation of utility and exchange, initially specified within a correlation of forces framework, could be reconciled with energy physics. It thus illustrates how one marginalist theorist could have arrived at the analogies identified in Mirowski's 'canonical neoclassical model'. Potential energy was made equivalent to the utility field (the area under the marginal utility curve).[18] Kinetic energy, which was the integral of forces times displacements, was made analogous to expenditure. The forces were identified with prices, which reflected the marginal utility for a commodity in equilibrium. Expenditure became the equivalent of kinetic energy in the system with the assumption of the law of one price.

A further reason why Tyndall's article is useful for understanding TPE is that it helps to explain the absence of anything like hysteresis in TPE, since the gravitational system was fully and completely reversible. Finally, once heat and chemical affinity were presented in the same general framework as gravity, there was a metaphorical role for pressure-volume diagrams from chemistry, with which Jevons was also familiar. The different slopes of the diagrams, corresponding to changes in temperature (cf. Mirowski, pp.98-9), could be made analogous to different slopes of utility schedules, corresponding to different types of commodities. That is, the utility diagrams for necessary commodities would have a steeper slope than those for luxuries.[19]

Mirowski emphasises that the analogy of utility and energy breaks down or, rather, becomes incoherent, once it is considered carefully. The sum of utility and expenditure makes no sense in the economic model. An implication of the assumption of a given set of utility curves needs also to be noted. On the one hand, this requires that there be no surprise or regret in consumption, so that desire is equated with satisfaction. But Jevons understood also that, if the curves were not to shift, this required the assumption that endowments or real incomes were given and conserved. But this is tantamount to assuming that potential energy is conserved, which makes the metaphor anachronistic. One advantage of using Tyndall's discussion to read TPE is that it shows how this aspect of the analogy really only becomes clear in the 'dynamic' analysis of gravitation. This was, however, obscured in TPE, because the account was explicitly restricted to a 'static' presentation and, because of their form, Jevons' basic exchange equations could not identify clearly the analogues of kinetic and potential energy in the system [White 1990].

In attributing this significance to Tyndall's article, it should be emphasised that Jevons had been familiar with the correlation of forces framework from the early 1850s, due to his work in chemistry and meteorology. That familiarity derived, in part, from his study of, and admiration for, the writings of Michael Faraday [Mirowski, p.21; White 1990]. Jevons' early respect for Tyndall would only have been reinforced by the close association between Tyndall and Faraday.[20] But the attraction of Tyndall's 1865 *Fortnightly Review* article was, as noted above, that it provided an apparently easy reconciliation of the forces and energy frameworks. This catholic approach was not evident in the work of physicists such as Thomson and Tait. Perhaps Jevons had begun to query the forces metaphor while writing CQ. Even if that was the case, it would appear that it was Tyndall's article which crystallized his metaphorical switch.

5.

Jevons described his marginalist theory as *"the mechanics of utility and self-interest"* [Jevons 1970, p.90 OE]. The analogy between mechanics and political economy was by no means a new one. In 1858, for example, W.J. Rankine co-authored a "Report on the progress and state of applied mechanics", which was presented to the Philosophical Society of Glasgow. The report noted that:

> "In the perfecting of Applied Mechanics, whether as a science or as an art, the end aimed at ... may be expressed by the word ECONOMY; that is, the production of every desired effect by those means which are exactly adequate to produce it, and no more ..." [Wise 1990, p.251].

This can be compared with Jevons' description of "the problem of Economy" in TPE:

> *"Given, a certain population, in possession of certain lands and other sources of material: required, the mode of employing their labour so as to maximise the value of the produce"* [Jevons 1871, p.255 OE].

Although the analogy is clear, it should be noted that, while the Glasgow report focussed on the necessary means to produce an effect, Jevons' summary reversed this to find the maximum effect for a given set of means. This followed from treating the utility field as the 'exogenous data' for the theory and was consistent with his claim in TPE that unregulated economic actions produced a maximum of material welfare. It is one of the strengths of Mirowski's work that he has focussed attention on how such mechanical analogues were used to produce the marginalist economic theory. More work needs to be done in researching the implications of the analysis for particular theorists. In that process, no doubt, qualifications or amendments will be made to Mirowski's basic account. In the meantime, this book sketches the basic contours of the story, posing new problems and providing some answers. It is highly recommended.

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Notes

1. All page citations in rounded brackets refer to the book being reviewed.
2. I use 'postclassical' in preference to 'neoclassical' because the latter term suggests a fundamental continuity, of some kind, between the analytical frameworks used by political economists writing in the early and late nineteenth century. CF Aspromorgous 1986.
3. See also Hodgson 1988 for a more detailed introduction to this type of approach.
4. An eidolon is an image or apparation. This 'ontological' difficulty was shown by Stewart and Lockyer: "this thing, energy, this capacity which exists in matter for performing work of one kind or another ... " [Stewart and Lockyer 1868, p. 321]
5. Mirowski discusses the concept of a field at pp. 19, 41. See also Section 4 below.
6. OE = original emphasis

7. See Kern 1990. This problem was reflected in a paper which I presented to the 1989 HETSA conference (see HETSA *Bulletin*, No. 12, p.4). For a correction and different evaluation, see White 1990.
8. For more general comments on writing histories of economics, see pp. 171-3 of the book under review and Mirowski 1987.
9. This was made clear in Jevons' first paper on commercial fluctuations: "all commercial fluctuations should be investigated according to the same scientific methods with which we are familiar in other complicated sciences, such especially as meteorology and terrestial magenetism" [Jevons 1884, p.4].
10. For a similar statement, see Jevons 1866, p. 371. In the third edition, the word 'force' in the quotation above was changed to 'motive power' [Jevons 1906, p.412]. The significance of this and other terminological changes is considered below.
11. For discussion of the importance of Armstrong's Address in the 1860s debate over coal, see White, 1991b.
12. As defined by Tyndall: "The principle of the conservation of force, broadly enunciated, asserts that the quantity of force in the universe is as unalterable as the quantity of matter; that it is alike impossible to create force and to annihilate it" [Tyndall 1865, p. 138].
13. The first attack on Tyndall by Thomson and Tait was published in *Good Words*. Jevons cited another article from the same journal [Rogers 1864] in CQ.
14. That Jevons was responsible for the changes was indicated in his unfinished Principles of Economics. He noted that, "within the last forty years ... Joule and other physicists have demonstrated that even in all the transmutations of heat and electric force there is neither creation nor destruction of energy." Jevons then referred to Ch. VIII of CQ for an illustration of the argument [Jevons 1905, pp. 93-4].
15. For a brief explanation of the differences between the two frameworks, see White 1990, pp. 17-20, and the references cited therein. In 1850, William Thomson neatly summarised the subordinate role that force played in the energy framework: "The action of a force ... is ... a transformation ... of Energy" [Wise 1990, p. 254].
16. Tyndall was elected to the chair of Natural Philosophy (i.e. physics) at the Royal Institution in 1853. Shortly before, both he and T.E. Huxly had "failed in candidatures for chairs in the newly founded University of Sydney, New South Wales" (Dictionary of National Biography).
17. The analogy was noted subsequently by T. Koopmans (Mirowski, p. 149).
18. As first discussed by Faraday and subsequently adopted by Thomson, a field was understood as the spatial distribution of a mechanical effect [Wise 1990, p. 252].
19. See Black 1973-81, VI, p. 16; White 1991a.
20. Faraday first attracted Tyndall to the Royal Institution. For an example for Tyndall's appreciation of Faraday's work, see Tyndall 1892, Chapter 18.

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