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An Instrument Can Make a Science: Jevons's Balancing Acts in Economics

Harro Maas

23 May 1864

But we noticed also the letters RJ1845. There can be no doubt I think that they were carved upon the tree . . . by my excellent but unhappy brother¹ . . . I admired him & the things he made. I have some few of them yet, for instance the little set of grain weights, which he constructed for his chemical balance. The latter was ingeniously made of wood with a common knife edge; the movement & pans & weights were all complete, & he was able to make quantitative experiments with considerable exactness.

—Jevons, *Papers and Correspondence I*

In other branches of science, the invention of an instrument has usually marked, if it has not made, an epoch.

—Jevons, *Principles of Science*

Throughout his life, William Stanley Jevons showed a keen interest in scientific instruments. As witness, we may point to the eight entries he

Correspondence may be addressed to Harro Maas, Department of Economics, Room E 9.09, Roetersstraat 11, 1018 WB, Amsterdam, The Netherlands; e-mail: harro@fee.uva.nl. I would like to thank Mary Morgan and Judy Klein for their encouragement and for comments on an earlier version of this essay. Comments by the participants of the Duke workshop were very helpful in rewriting the paper; thanks especially to Kevin Hoover and Ted Porter, who pushed me to explicate my thoughts. Discussions with Ivor Grattan-Guinness, Hasok Chang, Marcel Boumans, and Jo Wachelder and comments of two anonymous referees finally helped me to reframe my argument in the present form. The usual caveat remains, of course.

1. In the introduction to Jevons (1972–81, 1:7), Black gives us the following information on Roscoe Jevons. Roscoe (1829–1869) was Jevons's elder brother. He turned insane at the age of about eighteen, shortly after their mother died in 1845.

wrote for the *Dictionary of Chemistry and the Allied Branches of Other Sciences* (1863–68), most of them on measurement instruments: balance, barometer, hydrometer, hygrometer, thermometer, volumenometer. Jevons wrote these entries in the early 1860s, the period in which his major statistical and logical studies came to fruition and his outline for a mathematical approach to economic theory was read to Section F of the British Association for the Advancement of Science.² In his *Principles of Science* [1874] (1958), he even devoted a separate section to measurement instruments to point out “the general purpose of such instruments, and the methods adopted to carry out that purpose with great precision” (284).

In highlighting the importance of measurement instruments for scientific practice, Jevons differed from many of his contemporaries. Neither *measurement* nor *instrument* is, for example, an entry in John Stuart Mill’s highly influential *Logic* (1843). This was no accident, for the *Logic* was a book about proof, not about discovery, as Mill’s friend and biographer Alexander Bain (1882) noted. Mill had no experience with, nor knowledge of, concrete scientific practice.³ William Whewell’s *Philosophy of Discovery* (1856) also had extremely little to say on the importance of measurement instruments, even though he included short autobiographical sketches of some of the great practical reformers of science—like Galileo, for whom instruments (such as the balance) were indispensable tools to disclose the laws governing the universe (Machamer 1998).

To depict Jevons’s writings on philosophy of science as an “attempt to reconcile some of the disputes between Mill and Whewell on scientific methodology” (Schabas 1990, 54) therefore leads our attention away from the role Jevons attributed to measurement instruments in scientific discovery. Indeed, in the *Principles* ([1874] 1958), Jevons stressed the importance of scientific instruments for the formation of scientific disciplines, most notably for chemistry. Chemistry, he suggested, “has been created chiefly by the careful use of the balance” (272), a claim widely supported by historians of science (see, for example, Levere 1990; Wise

2. Another instance is Jevons’s interest in the so-called arithmometer, a calculating device that the French engineer Colmar invented about 1820. In November 1878 Jevons gave a short presentation for the London Statistical Society on the gains in terms of depth and scope of research a statistician might make by the use of this instrument. On the influence of the Colmar arithmometer on Victorian scientific practice, see Warwick 1995 and Johnston 1997.

3. This was notably regretted by Mill himself in the *Autobiography*. See Mill 1981, 21.

1993; Wise and Smith 1989a, 1989b; also Theodore Porter's article in this volume).

For Jevons, measurement instruments were an indispensable part of scientific practice: they were analytical tools of investigation as well as practical tools to give numerical precision to conclusions. Jevons's daily use of these instruments shows, even more than the entries in the *Dictionary of Chemistry* or the attention paid to them in the *Principles*, the importance of using measurement instruments. For Jevons, this was the way to access the world. There is virtually no page in his diary in which he did not record his measurements together with other descriptions.⁴ There was no walk in the country in which Jevons did not take his barometer with him to measure the height of the hills.

One instrument stood out in these accounts: the balance. Antoine-Laurent Lavoisier, Jevons's great predecessor in chemistry, had used the balance as the "most glorious weapon" in his battle against error,⁵ and Jevons, I will argue, used it similarly. It was his weapon against those political economists, such as Mill and John Cairnes, who considered political economy to be an inexact science in contrast to the exact natural sciences and hence not accessible to the use of numerical tools of research. "In matters of this kind," Jevons (1871b, 9) wrote in the *Theory*, "those who despair are almost invariably those who have never tried to succeed." Jevons's own empirical and theoretical investigations form, by contrast, benchmarks for standards of accuracy and precision in economics. My aim in this essay is to show what role measurement instruments, such as the balance, played in this transformation of political economy. Focusing on measurement instruments brings out Jevons's essentially uniform approach to what we currently call distinct scientific disciplines.

The essay is organized into five sections. Jevons's entry on the balance in the *Dictionary* shows how it was both an analytical tool of investigation and a measurement instrument. These different functions will be addressed in the first two sections. The remaining three sections of the essay investigate how his analysis of exchange in analogy with the balance changed political economy. The third section considers Jevons's use of the balance to make a numerical causal inference about the fall in the value of gold. The fourth section explores how the balance was used as

4. Jevons's diary of his journey to the gold diggings at Sofala, for example, is preceded by fourteen pages of meteorological observations.

5. See especially Bensaude-Vincent 1992 on Lavoisier's revolutionary use of the balance.

an analytical tool in the *Theory* in a way that restructured economists' thinking about the "laws of supply and demand."

The Balance as a Tool of Analysis

The balance played a pivotal role in Jevons's attempts to improve standards of precision in economics. Jevons's educational background in the natural sciences has of course been noticed in earlier accounts (see especially Black's introduction to Jevons 1972–81 and Schabas 1990, chap. 2), but it cannot be emphasized enough. He attended first the Liverpool Mechanics Institute High School, and then—after an interlude of two years at a private grammar school which was not to his liking—he studied at the preparatory school for University College London and then at the college itself.⁶ Jevons's family background was also important for his early inclination toward the natural sciences. He came from a Unitarian and solidly middle class background (Schabas 1990, 12) and shared in the "superb confidence of the Victorian middle class" (Thompson 1978, 264) in the promises of rational argument and the advancement of science for the public good. Middle class Unitarians in Lancashire had been influential both in the establishment of Mechanics' Institutes designed for the education of the higher working class in the principles of the natural sciences and in the formation of the various literary, philosophical, and statistical societies (Kidd and Roberts 1985, 10–11). Advancement of society was the goal, progress of science the means.

After their initial creation in the early nineteenth century, the Mechanics' Institutes spread rapidly throughout Britain.⁷ The range of topics taught, in many cases by outstanding specialists in their fields, was

6. The importance of the educational structure for the development of political economy has been extensively discussed for the French case. See, for example, Porter 1991 and 1995. The obvious reference for the relation of French engineering to the development of neo-classical theory is Ekelund and Hébert 1999. In the English context, the influence of educational structure on the methodological and doctrinal developments in economics has to my knowledge not been systematically addressed.

7. The Mechanics' Institutes find their basis in John Anderson's "Anti-Toga class" at Glasgow University, an experimental course in natural philosophy. Anderson explicitly allowed the general public to attend the lectures that were taught with experiments, models, and little formal mathematics so that even a laborer could understand their content. See Katoh 1989 for a short and helpful overview on the emergence of Mechanics' Institutes as a means for adult education. Inkster (1975) and Shapin and Barnes (1977) emphasize the political role of these institutes. Their thesis is critically examined in Watson 1987. On the educational effectiveness of these institutes, see Stephens and Roderick 1972 and more positively Inkster 1975.

extremely broad, ranging from the first principles of mechanical philosophy to lectures on Milton, German customs, or phrenology (see Stephens and Roderick 1972, 355; also Parssinen 1974). George Birkbeck, the founder of the London Mechanics' Institute, focused on the education of the craftsman, to "keep him abreast" of the technological changes that affected the machines, tools, processes, and materials he worked with rather than the education of the mere operative "doing a routine and mechanical job" (Stephens and Roderick 1972, 352). In some instances schools for the education of youth were affiliated with these adult education institutes, as was the case for the Liverpool Mechanics' Institute.

Mechanical philosophy formed an important part of the curriculum. By close study of diagrams, students learned to comprehend the mechanical principles of a number of contrivances, ranging from the balance to the steam engine. According to Henry Brougham, an early advocate of scientific education of the people, "enough will be accomplished, if they are made to perceive the nature of geometrical investigation, and learn the leading properties of figure" (Shapin and Barnes 1977, 49, quoting Brougham). The practical use of an instrument, such as the balance, for measurements may have been part of the education of the youngsters, though I have been unable to find evidence for this.⁸

Whether or not in general the youthful pupils gained practical experience, there is no doubt about it in Jevons's case. When he was still very young, he conducted experiments with his brother Roscoe and his cousin Harry Roscoe (later professor of chemistry at Owen's college, Manchester) in which they used a wooden balance with a fair amount of precision. His cousin Harry recollects in his autobiography the "delights" of making "fireworks for the 5th November" (Jevons 1972–81, 1:7, Black quoting Harry Roscoe). Jevons got even better acquainted with the secrets of the balance when trained as a gold assayer by his professor of chemistry at University College London. His daily use of the balance as gold assayer in Sydney ensured its principles became part of Jevons's second nature. It is no surprise that Jevons framed his empirical and theoretical work in accordance with these principles: the balance, for Jevons, was not just a metaphor, it was a genuine means to disclose the mechanics of the world—the physical and, as we will see, the mental.

8. The literature on the Mechanics' Institutes tends to focus on their role in adult training to the neglect of their importance in establishing opportunities for secondary education for the higher working class and middle class youth.

It was therefore natural that Jevons be asked to contribute several entries to the *Dictionary of Chemistry and the Other Allied Branches of the Sciences* (1863–68) on, among others, the topics of the balance and gold assaying in a period when dictionaries were an important aid in the diffusion of scientific knowledge (Layton 1965). From Jevons's entry on the balance, we get an extremely rich and detailed description not only of the balance itself, but also of the intricacies of its use and the precautions that should be taken to get significant results. The reader is struck by the effort Jevons makes to spell out all possible difficulties in making an accurate measurement with a balance and how to circumvent these difficulties. His entry was, in this respect, an effort to express tacit knowledge and give practical guidance in using the balance.

Jevons's entry contains a description of the geometry of the balance, a description of the actual instrument and how it should be used with care in practice. His geometrical account nicely captures the aim of such dictionaries to convey useful knowledge without troubling readers with notations they may not know.⁹ One of his drawings (reproduced as figure 1) gives a detailed geometry of the balance, showing how the different forces acting on the balance were interrelated. It can be easily seen that the geometry of the balance is identical to that of a lever. Figure 2 shows how the effect of an additional weight, p , added to a balance at rest, may be understood by conceiving of the balance as a compound pendulum, where the greatest velocity of the beam (proportional to θ) gives an indication of p .

The Balance as a Measurement Instrument

Given its role in Lavoisier's "chemical revolution," it is no surprise that Jevons (1863, 481) described the balance as "the chemist's most important instrument." As Sibum (1995, 74n. 4) notes, in Jevons's days *precision* and *accuracy* related to different aspects of scientific instruments. Precision referred to the tools and their quality, whereas accuracy referred to the skill of the user. Jevons discussed both these issues in his entries on the balance and on gold assaying. An image of a balance used in gold assaying, for which great precision and accuracy were required,

9. Even though the secondary literature Jevons refers to makes use of the principle of virtual velocities (Charles Knight's *English Cyclopaedia* of 1861 calls it "perhaps the most important generalisation in mechanics"), Jevons does not use this principle in his dictionary entry. I would like to thank Michael White for having drawn my attention to this.

Figure 3 Jevons's drawing of a balance used in gold assaying. From Jevons 1864, 933.

accompanied his entry on gold assaying and is reproduced here as figure 3. If we take a look at this image of the balance, we see that it is depicted as in use in what looks like an experimental setting. At some points in his entries, Jevons indeed suggested that using the balance was the same as making an experiment (e.g., 482: “When a weighing is actually being made . . . retain [the planes on the edges] in the exact positions proper for a new experiment”). Such an experiment puts high demands both on the quality of the instrument and on the accuracy of the weigher.

Jevons provided criteria for the best materials for the balance, the weights used, and other technicalities concerning the construction of the

instrument. The material the balance was made of, for example, should be such that as many disturbing causes as possible were excluded. These constructive requirements were intimately linked with the geometry of the balance. That is, the geometry of the balance enforced requirements for the construction of the actual contrivance: "In its most perfect form . . . it consists of a perforated brass beam, cast in a single piece, combining great strength and perfect inflexibility with comparatively small weight" (482). These requirements were not easily reconcilable in practice. Small weight, for example, could be obtained by the use of aluminium. However, aluminium was highly corrosive and flexible and thus a bad choice for this purpose. In practice the instrument necessarily fell short of the ideal requirements.¹⁰ Other technicalities related to the adjustment possibilities of the beam or the edges. Screws—still known as precision instruments today—played an important role in adjusting the edges or the beam itself. The balance, Jevons wrote, should be enclosed in a "glass case, with convenient windows" to ensure that there were no "casual sources of mistake" (486).

Such casual sources of mistakes related to the inaccuracies on the part of the scientist, or weigher, and could not be known or corrected for in advance. Jevons gave the example of a "scrupulously exact gold-assayer led into serious mistakes by a small fly, which settled on his balance, unobserved at the time" (486). Even such an accurate assayer could be led astray by not taking proper care or not paying attention to all relevant details. In effect, Jevons wrote, "the casual sources of mistake are too many to mention" (486). To minimize these sources of inaccuracy, Jevons provided a list of "suggestions for the care of a balance" (486) which in fact urged the weigher to follow minutely fixed routines in handling the instrument so that when in doubt errors could be traced.

Even if the technical layout of the balance matched the highest standards of precision attainable and the instrument was handled by a skilled weigher, sources of error remained. In some of such sources of error, the geometry of the instrument came to the aid. The inequality of the arms

10. "All the instruments with which we perform our measurements are faulty" (Jevons [1874] 1958, 461). On the conflicting requirements of measurement instruments in relation to their mathematical ideal, see especially Boumans, this volume. Attempts to combine conflicting attributes created a separate discipline and literature on instrument making. Jevons was well read in this literature and refers to it throughout the *Principles*.

of the beam was a case in point, “for the extreme edges can never be adjusted at perfectly equal distances from the centre edge” (490). The geometry of the balance gave, however, a straightforward precept how to correct for this error. Jevons referred to Gauss, who, “by simply weighing the object alternately in one pan or the other” (490), had made use of the geometrical average of both measurements to obtain faultless results. It is easy to show that one obtains the true value of the required weight by this procedure. Another problem was the insensibility of the arms to very small differences between weights, but to turn the arm at all “some *definite* weight” was required. Once again, this type of error, Jevons argued, could be evaded by taking recourse to mean values instead of the read values (490).

We see then that the use of the balance involved a complex interplay of the actual instrument, its geometry, and its users. The balance imposed routines on its users; otherwise, accuracy could not be guaranteed. Its geometry imposed demands on the materials to be used and on the construction of the apparatus; otherwise, precision in the results was out of reach. These practical and analytical demands could not all be combined in practice (Marcel Boumans and Flavio Comim [both this volume] make a similar argument in their respective case studies). However, the very same geometry that put such high demands on construction (given the existing state of technology) also suggested solutions to measurement problems that could not be solved by the mere following of fixed routines and procedures. Finally, users needed a considerable degree of expertise and training. But even expert weighers could not just rely on these routines. At various moments in the weighing process, they relied on their judgment to get precise and accurate results.

As Jevons ([1874] 1958, 270) remarked in the *Principles*: “Measuring apparatus and mathematical theory should advance *pari passu*, and with just such precision as the theorist can anticipate results, the experimentalist should be able to compare them with experience.” The balance served the same function for Jevons as it had for Galileo and Lavoisier: it was an engine of discovery.¹¹

11. Even though the notion of an “engine of discovery” is somewhat Whiggish. See Wise and Smith 1989a; also 1989b, 434.

Balancing Disturbing Causes: “A Serious Fall in the Value of Gold Ascertained”

We have seen that, for Jevons, the imperfection of the measurement instrument—and the consequent occurrence of measurement errors—was the “normal state of things.” In fact, he considered it even “one of the most embarrassing things” when “experimental results agree too closely” (357–58). In parallel to the usual argument in statistics—that small independent disturbances or errors will cancel out in the average—Jevons ([1874] 1958, 357) proposed in the *Principles* to “eliminate . . . the multitude of small disturbing influences . . . by balancing them off against each other.” In other words, for Jevons, averaging and balancing ideas are connected, as we can see in his discussion of the different methods of error reduction found in chapter 25 of the *Principles*. Even when he faced situations in his statistical work where he acknowledged that causes were interconnected, he still argued that it was legitimate to treat them as “noxious” measurement errors that averaged out when as many causes as possible were included.¹² His famous gold study is the best case in point.

Once we see the importance of the mechanical balance for Jevons's approach to the problem (his most discussed innovation in this context), the use of index numbers to prove his point becomes obvious. Jevons used the mechanical balance as a tool of investigation: it was first a thinking tool to structure the analysis of the causal influence of a gold influx on prices; second, it served as a virtual, not a material, measurement instrument to attribute a number to the fall in the value of gold.¹³ In using the balance in this way, he restructured the thinking of the political economists and statisticians of his day and made index numbers relevant in the computation of a measurement.

When Jevons undertook the gold study, it was considered to be impossible to give a numerical estimate of the influence of the new gold discoveries on prices. Cairnes's (1857, 95) views may serve as an example: “Now if Political Economy were an exact science, this question could be at once determined by calculating the effect of the causes assigned, and comparing the result of our calculation with the actual market price.”

12. Statisticians of the day might have considered this as illegitimate. It gave Jevons, however, a possibility to circumvent the problem of multiple causation, which could not be addressed at that time (Morgan 1997). With regard to Jevons, see Aldrich 1987, 1992; Peart 1995a, 1995b; and Sandra Peart's article in this volume.

13. See Klein 1999 for a similar notion of scientific tools in classical chemistry.

But political economy was not then such an “exact science,” so Cairnes considered this undertaking “impracticable.” Even had accurate statistics been available, there were simply too many other causes involved to separate out the effect of the gold influx. Jevons’s ingenuity lay in the use of the mechanical balance as an analytical tool first to circumvent the problem of multiple causation, and, second, to provide a numerical estimate for the fall of the value of gold.

Jevons ([1863] 1884, 18) started with the simple observation that “the comparative values of two articles are said to be altered when the proportion of the quantities usually exchanged in the market is altered.” The ingenuity lay in the sequel. Drawing an analogy between an exchange on the market with the balancing of two weights at once simplified dramatically the problem other authors had faced: “This alteration may arise from circumstances affecting the supply or demand of either article, just as a balance may be disturbed by an upward or downward force, applied to either arm. There is nothing in the simple motion to indicate from which side the change comes” (18).

Jevons’s recourse to the mechanical balance was, however, more than drawing an analogy or even invoking a metaphor; applying the balance argument restructured the way one should think about the problem of multiple causation in price formation, just as the analytical properties of the balance structured the way students at the Mechanics’ Institutes were trained to understand the laws governing material objects. There was no need to go into the causes of all separate changes in prices of all the innumerable commodities involved, for the situation could be simply pictured like this: the price of gold was in one pan and the prices of all other commodities were in the opposite. The mechanics of the balance provided for an immediate connection between a change on the one side of the beam and on the other side: “It is obvious, in short, that an alteration in any one article is shown in its rate of exchange with all other articles, so that the fact of an alteration may be ascertained with a continual approach to certainty” even though “there always remains the alternative of a concurrence of causes affecting all other articles” (19). The balance mechanism structured the way we should think about the cause of price changes in relation to gold.

Jevons made only loose reference to probability arguments, since he supposed that everyone would agree that the odds were clearly against all the weights (prices) in one pan having altered in the same direction; it was far more likely that all these different changes would average out.

Thus, the cause of a movement of the beam must lie in the other pan—that is, in the factors affecting gold. Indeed, the more commodities involved, the more confidence one could have in this kind of reasoning.

Jevons then used the analytical properties of the balance to compute a numerical estimate of the fall in the value of gold. To ascertain this fall in value, one needed to ascertain the general rise in prices based on the idea that, departing from an initial equilibrium, all or at least a preponderance of prices would have risen against the price of gold. At this point, an average was needed. But of what kind? Jevons chose the geometric mean, a choice that lay at hand when calculating the average change in the ratios of prices. Perhaps this also followed naturally from his use of the mechanical balance to structure his investigation, since the balance measures ratios.¹⁴

Jevons's choice of the geometric mean to determine the fall in the value of gold was then, and has remained, something of an enigma.¹⁵ Etienne Laspeyres interpreted Jevons as making an index number argument and queried the use of a geometric mean in that context. Jevons ([1865] 1884, 122) linked his choice for the geometric mean especially to his balancing argument in answer to Laspeyres's stated preference for the arithmetic mean:¹⁶

[The geometric mean] seems likely to give in the most accurate manner such a general change in price as is due to a change in the part of gold. For any change in gold will affect all prices in an equal ratio;

14. At the turn of the nineteenth century some controversy arose as to whether measuring a ratio could be considered a measurement. See, for example, Carter 1907. I owe this reference to Judy Klein.

15. Arguments for the choice of the mean today are sought in the distributional characteristics of the observations. In the nineteenth century, errors were considered to average out with zero mean due to the "Law of Error." Only in the twentieth century has explicit recourse been taken to the distributional characteristics of observations. See, for example, Krüger et al. 1987 and Morgan 1990. In relation to Jevons, see Stigler 1982; Aldrich 1987, 1992; Kim 1995; Peart 1995a and this volume. Aldrich (1992, 674) rightly points out that "the overall impression from [Jevons's] writing is that the use of the geometric mean was divorced from any consideration of the distribution of price changes," but this does not make Jevons's choice the result of a "jumble of reasons."

16. Jevons passed over Laspeyres's argument for weighting the price changes in the arithmetic mean rather quickly. He had two other arguments for choosing the geometric mean. The first was that the geometric mean was to be preferred over the arithmetic or the harmonic (unweighted) averages because it lay in between the two, an argument that—as Marcel Boumans pointed out to me—would be repeated by Irving Fisher. The second argument was only for convenience. Jevons had a strong predilection for using logarithms, making the choice for the geometric mean the most natural.

and if other disturbing causes may be considered proportional to the ratio of the change in price they produce in one or more commodities, then all the individual variations of prices will be correctly balanced off against each other in the geometric mean, and the true variation in the value of gold will be detected.

Jevons's "proof" for the fall in the value of gold began with the average rise in prices of 39 commodities, and he subsequently enlarged the group of commodities to 118. Taking account of intricacies—such as the commercial tide—which could bias the outcome, Jevons's calculations led him to conclude that there had been a fall in the value of gold "by about 9 1/3 per cent" (54). This result convinced Jevons that he did not have to worry too much about causes on the other side of the balance, because the fall in the value of gold was so considerable that Jevons hardly doubted the influence of the new gold influx.

In his gold study, Jevons relied on common arguments used in his own experimental practices. Since he had shown that on average prices had risen, he argued that this rise "*is and constitutes* the alteration of value of gold asserted to exist" (21). Notwithstanding remaining problems—of which he was fully aware—Jevons had no doubt that his computations effectively established a fall in the value of gold, and they enabled him to give numerical evidence for the amount it had fallen in value.

Many of Jevons's contemporaries missed the novelty of his approach to the issue of multiple causation and argued that the causes of the change in prices for all commodities should be investigated one by one. Cliffe Leslie was one of them. Against Jevons's argument that "the average must in all reasonable probability represent some single influence acting on all the commodities," he countered: But why not a "plurality of causes"? (quoted in Peart this volume). Kevin Hoover and Michael Dowell (this volume) rightly compare the alternative method political economists like Cliffe Leslie suggested with Mill's Method of Residues. Such an approach stood in opposition to the setup of Jevons's inquiry. Jevons fully admitted that it would be possible to give causes for price changes in all individual cases. But if, on these grounds, one were to throw out the commodity in question from the inquiry, "the whole inquiry would be thrown into confusion by any such attempt . . . the impartial balance of the inquiry" would be "overthrown" ([1865] 1884,

58).¹⁷ The reference to the impartial balance should here be taken literally. If one changes the weights in the balance during the process, the whole outcome is thrown in disarray, proving the investigator to be an inaccurate weigher.

Cairnes, in contrast to Leslie, acknowledged Jevons's accomplishment. He referred to it in a letter in the *Times* and used Jevons's results to substantiate his own conclusions in the same direction. In correspondence with Jevons, however, he underlined the complete differences in the methods they used to get the same results. Cairnes considered these differences advantageous—the argument was strengthened when similar results were obtained by completely dissimilar ways. Both Cairnes and Jevons were well aware that they used “entirely distinct methods of inquiry” (Jevons 1972–81, 3:17–18). In this case, it gave Cairnes no reason to dismiss Jevons's results. The situation changed, however, when it came to the use of the balance as a tool of investigation in the *Theory*.

Balancing Pleasures and Pains

In the middle of the nineteenth century it was a widely held opinion that tools and methods like mathematics and experiments, which could be so fruitfully applied to nature, were inapplicable to the phenomena of the mind, including political economy. Whewell, for example, had limited the sciences to the study of the natural, but not the moral, world even though he himself pioneered the use of mathematics in political economy. John Stuart Mill's famous essay on method (1836) and his *Logic* (1843) had made political economy as respectable as the natural sciences, yet its tools and methods were thought to exclude experiments and mathematics. In short, political economy was considered primarily as one of the moral or mental sciences, making a marriage with the tools and methods of the natural sciences hardly conceivable.

By the time Jevons began to devise a new approach to political economy, Mill's view had lost its status as self-evident truth. Developments within psycho-physiology, and the engineering type of mechanics that lead to the discovery of the conservation law in physics, created doubts over the categorical distinction between the phenomena of mind and matter. Physiologists such as William Carpenter argued for the so-called

17. To be able to make this argument, Jevons implicitly assumes uncorrelated price changes even though he knows they do not exist. This clearly made Jevons's argument flawed. See, for example, Aldrich 1987, 1992; Kim 1995; Peart 1995a.

principle of the “correlation of forces,” in which motives were considered forces, just as forces work on matter. Similarly, the very idea that human labor could be examined in the same terms as the work performed by inanimate machines gained wide currency.¹⁸ Margaret Schabas (1990, 84–89) rightly highlighted Jevons’s consideration in the *Principles* that “the time may come . . . when the tender mechanism of the brain will be traced out, and every thought reduced to the expenditure of a determinate weight of nitrogen and phosphorus. No apparent limit exists to the success of scientific method in weighing and measuring, and reducing beneath the sway of law, the phenomena both of matter and mind” (Jevons [1874] 1958, 735–36). White (1994) examined extensively how Jevons’s reading in the new developments in psychophysiology influenced his *Theory*. White in particular noted the influence on Jevons of Richard Jennings’s *Natural Elements of Political Economy* ([1855] 1969), an eclectic mixture of associationist psychology and reflex physiology. Jevons wrote his new theory of exchange against this background.

The analogy of exchange with balancing of utilities is clearly expressed in Jevons’s early version of the theory:¹⁹ “Whether the exchange will take place or not can only be ascertained by estimating the utility of the objects on either side, which is done by integrating the appropriate functions of utility up to the quantity of each object as limits. A balance of utility on both sides will lead to an exchange” (1866, 284).

For Jevons, the laws of supply and demand were founded on the “laws of human enjoyment,” and these laws obeyed the causal mechanism of the balance, leading to the surface event of exchange. Though Mill did not believe that the laws of human enjoyment bear upon market exchange, Jevons found these laws, as he said, in Jeremy Bentham’s “springs of human action,” our feelings of pleasure and pain. In the

18. A general account of this development can be found in Rabinbach 1990. For the physical context of this development, see Grattan-Guinness 1990, especially chap. 16, and Vatin 1993 with regard to French engineering; Wise and Smith 1989a, 1989b, and 1990 with regard to the developments in Victorian physics; and Mirowski 1989 for an account of the importance of the energy concept for the developments in economics. For the debates among Victorian physiologists and psychologists on the relation of mind and matter, see Daston 1978; Jacyna 1981 and 1983. Jevons’s theoretical position in these physiological debates is examined in White 1994 and in the physical debates in White 1999.

19. The theory was part of *Notice of a General Mathematical Theory of Political Economy*, an essay that was read at Section F of the British Association for the Advancement of Science in 1862 and published in 1866 as the *Brief Account*.

Theory, Jevons wrote that Bentham had “thoroughly” understood the mathematical character of the subject and quoted his description of how to estimate the “tendency of an action”: “Sum up all the values of all the pleasures on the one side, and those of all the pains on the other. The balance, if it be on the side of pleasure, will give the good tendency of the act . . . with respect to the interests of that individual person; if on the side of pain, the bad tendency of it upon the whole” (1871b, 12, quoting Bentham).

Bentham's balancing process, however, fell short in providing a genuine mechanism. This can be illustrated with a similar balancing procedure found in Benjamin Franklin's so-called *Moral Algebra*. In a letter to Joseph Priestley, Franklin had described his method of making difficult decisions by making up a balance of motives:

To get over this [the uncertainty that perplexes us], my way is, to divide half a sheet of paper by a line into two columns; writing over the one *pro*, and over the other *con*; then, during three or four days' consideration, I put down, under the different heads, short hints of the different motives, that at different times occur to me, *for* or *against* the measure. When I have thus got them altogether in one view, I endeavour to estimate their respective weights; and when I find two (one on each side) that seem equal, I strike them both out. If I find the reason *pro* equal to some *two* reasons *con*, I strike out the *three*. If I judge some *two* reasons *con* equal to some *three* reasons *pro*, I strike out the *five*; and, thus proceeding, I find out where the balance lies; and if, after a day or two of further consideration, nothing new that is of importance occurs on either side, I come to a determination accordingly. And though the weights of reasons cannot be taken with the precision of algebraic quantities, yet, when each is thus considered separately and comparatively, and the whole lies before me, I think I can judge better, and am less liable to take a false step; and, in fact, I have found great advantage from this kind of equation, in what may be termed *moral* or *prudential algebra*. (Bain 1859, 463, quoting Franklin)

At first sight, Franklin's balancing procedure is about the care taken by a weigher when making measurements, adding new weights and quietly waiting until a new equilibrium is reached.²⁰ However, in contrast

20. I thank Mary Morgan, Hasok Chang, and Marcel Boumans for pushing me on this subject.

with a mechanical balance, the weights added are not homogeneous by nature. This highlights the importance of man's power of judgment. The estimation of weights relative to one another is in need of the constant interference of man's judgment. Franklin provides a prescriptive routine to aid judgment, not motive forces that drive the mind to equilibrium in accordance with mechanical principles. Franklin's procedure may be a useful routine, but it lacks the mechanics of a material balance. It is not, therefore, suited for applying the geometry of the balance, let alone the calculus, to demonstrate its properties.²¹

Jevons (1871b, 38–39) interprets Franklin's balancing procedure as if pleasures and pains are homogeneous quantities: "The algebraic sum of a series of pleasures and pains will be obtained by adding the pleasures together and the pains together, and then striking the balance by subtracting the smaller amount from the greater." To provide for a mechanism, however, it is not sufficient just to consider feelings of pleasures and pains as homogeneous quantities. Rather, pleasures and pains have to be considered as feelings that move the mind automatically, without the interference of judgment, in the same way that forces move the balance. To introduce the calculus in economics, Jevons not only considered feelings of pleasures and pains as homogeneous quantities, capable of "more or less"; he also considered man's deliberation process as moved by forces that escaped the interference of man's judgment.

In the *Theory*, Jevons interchangeably considers feelings of pleasure and pain as motives or as forces. In fact, this marks a major conceptual change. An individual acts not on an array of different motives that each have to be judged, but on forces that automatically move the individual in one of two directions. Jevons's term "feelings" applied equally to "physical pleasure or pain" and "mental and moral feelings of several degrees of elevation" (1871b, 29). When Jevons, in his original 1878 criticism of Mill's utilitarianism, refers to Bentham's procedure to estimate the "values of pleasures and pains," he adds that Bentham "obviously" meant by "*values* the quantities or forces" ([1890] 1971, 276, emphasis in the original). Jevons persistently framed the "laws of human enjoyment" in terms of natural forces instead of motives.²²

21. One might argue that a system of double entry bookkeeping provides such a mechanism, but that was neither on Bentham's nor Franklin's mind.

22. Warke (2000) recently examined, from a different perspective than is pursued here, the mathematical fitness of Jevons's rendering of Bentham's felicific calculus.

Figure 4 Jevons's diagrammatic representation of the utility adjustments of one individual (or trading body) to its optimum at m . The vertical axis (not drawn) depicts utility; the horizontal, two different commodities, apparently measured in the same quantities. The two curves represent the utility functions for the respective goods, where the dotted one ($p'qr'$) is superposed and inverted on the other (pqr). The ratio of exchange is fixed at 1:1. From Jevons 1871b, 97.

Jevons's graphical illustration of how these different forces were inter-related for one person is reproduced in figure 4. In the diagram two utility curves are superposed and inverted upon one another; utility is measured on the vertical axis, commodities on the horizontal. Jevons showed how this person would make a net gain in utility by extending trade from a' in the direction of m and would lose in utility when trading beyond that point. He constructed thus a genuine mechanism, akin to a mechanical balance. An equilibrium would automatically emerge for this individual at m . Jevons described our will, in consequence, with some justification as a "pendulum" moved by pleasures and pains, "and its oscillations are minutely registered in the price lists of the markets" (14).

Whether such an equilibrium would arise was, of course, dependent on the form of the curves. Here the developments within psycho-physiology came to Jevons's aid, most notably Jennings's *Natural Elements* but also the writings of physiologists like Carpenter (White 1994). For Jevons, the "laws of human wants," in which "the basis of economy" was to be sought, seemed to be grounded in mankind's "chemical and physiological conditions" (1871b, 158). His own experiments on the exertion of muscular force convinced him that he was on the right track

for his theory of labor. From these sources Jevons took the idea that additional increments of commodity would lead to ever smaller gains in utility, an idea that was reflected in the form of the curves in the diagram. In a situation of exchange of one thing for another, such curves furnish a functional relation between the different sides of the individual's balancing of pleasures and pains. Jevons believed he had discovered a genuine mechanism explaining commodity exchanges, a "*mechanics of utility and self-interest*," in contrast to authors like Mill who made reference to the "laws of supply and demand" without providing for a genuine mechanism explaining their workings.

Jevons's theory both provided for a mechanism of exchange based on the "laws of human enjoyment" and resolved the issue of how one might get at numerical estimates for utility, or feelings of pleasures and pains. Limiting himself to the static case, in which equilibrium was reached, Jevons rightly argued that there were in fact no numbers needed at all. Just as someone could roughly perceive the equilibrium of a balance with the eye, so the individual was able to judge the equivalence of pleasures and pains by paying attention only to their marginal increase or decrease. No assumption was needed as to whether the mind was able to judge accurately numerical quantities of utility. It was only necessary to assume that the mind could perceive a rough equivalence (or inequality) between them.²³ For the static case, Jevons's utility theory rested on measurement without numbers.²⁴

The issue of the measurement of utility may need some extra discussion, if only for the extraordinary amount of intellectual energy that has been devoted to it in the past century. Many questions were immediately raised in response to the *Theory*. However, the measurement of utility only has an impact in those cases where equilibrium is not settled. In that case one should be able, one way or another, to assess the form of the individual (or average) utility functions in figure 4. This problem was intractable to Jevons, though he made several attempts to overcome it.²⁵

23. See Peart 1995b for an extensive discussion of Jevons's approach to the measurement of utility in the *Theory*.

24. In this context, another set of experiments Jevons pursued are worth mentioning. In 1871 Jevons published a short note in *Nature* on the power of numerical discrimination. The upshot of his argument was that "the mind is unable . . . to estimate any large number of objects" but does better when a smaller number is involved (1871a, 281).

25. As Grattan-Guinness (2000) points out, Jevons was well acquainted with analysis of functional equations in which Augustus De Morgan, his mathematics teacher at University College, was an expert. In my view, Jevons's discussion on the King-Davenant "Law" of Demand

It is well known that Jevons's mechanics only worked when the ratio of exchange was fixed. As Fleeming Jenkin rightly pointed out in his famous letters on this issue, he saw “no motive power” tending to move two individuals toward an equilibrium rate of exchange, and he challenged Jevons to show how such an equilibrium rate would come about (Jevons 1972–81, 3:167–78). In the *Theory* Jevons circumvented the problem by taking recourse to his so-called law of indifference, which effectively amounted to saying that individuals adjusted their desired exchanges to a given exchange rate. His explicit “analogy” of the equation of exchange with the theory of the lever in the second edition implicitly clarifies the problem. If the ratio of exchange was not fixed, the fulcrum was not fixed, and the balance was essentially a defective instrument. Nevertheless, in using the mechanical balance as a thinking tool to disclose how exchange might be related to the laws governing the deliberations of an individual, Jevons paved the way for his successors.

Conclusion

In the introduction to the *Theory*, Jevons (1871b, 11) approvingly quoted Augustus De Morgan, his teacher in mathematics at University College London:

Had it not been for the simple contrivance of the balance, which we are well assured (how, it matters not here) enables us to poise equal weights against one another, that is, to detect equality and inequality, and thence to ascertain how many times the greater contains the less, we might not to this day have had much clearer ideas on the subject of weight, as a magnitude, than we have on those of talent, prudence, or self-denial, looked at in the same light. All who are ever so little of geometers will . . . remember the steps by which this vagueness became clearness and precision.

It is perhaps hardly surprising that Jevons, who was a chemist and natural philosopher by training, made the balance his most important tool of research. It is surprising, I think, that this simple fact has escaped the attention of historians of economics for so long. This is no doubt because economists don't think of their subject as an “allied branch” of

relates to this issue of functional form and is therefore less of a digression than suggested in Creedy 1986. See also White 1995 and chapter 6 of my thesis (Maas 2001).

chemistry. Jevons did. In this essay we have seen how Jevons used the balance as a tool of investigation to enforce clearness and precision in economics. The result can be truly termed a revolution.

In his gold study, Jevons used the balance as a thinking and calculating tool to measure a fall in the value of gold and to make an inference as to the cause of the fall as well. Thinking with the balance structured the way one might conceive of the causal influence of the new gold influx on prices and focused attention on the rise or fall in the average level of prices as a numerical indicator for the amount by which gold had fallen in value. In his *Theory of Political Economy*, Jevons used the principles of the balance to reconstruct the process of human deliberation. He was thus able to relate the marginal utility considerations of individuals to exchange on the market. The balance thus restructured economists' thinking about the laws of supply and demand: by connecting exchange to the mechanics of the individual's mind, Jevons provided, in outline, an equilibrating mechanism for market exchange resting on what we today would call a preference ordering. These accomplishments fundamentally changed the research strategies of economists on both the theoretical and practical plane. From Jevons's work onward, it became feasible to ask for numerical estimates in answer to empirical questions. It became equally feasible to consider human deliberation in relation to price formation in terms of the calculus.

In the case of the gold study, Jevons's approach was extremely successful and widely approved. To understand mental deliberation itself as made by a mechanical balance involved, however, a shift in perspective on the phenomena of the mind that many of Jevons's contemporary economists were not prepared to make. An anonymous reviewer of the *Theory*²⁶ quickly spotted that the novelty of the book rested not primarily on Jevons's use of mathematics, but on his persistent comparison of man with an instrument:

In what then, does Mr. Jevons's originality consist? First, in the fact that he approaches the subject from a new point of view; and, secondly, that this method enables him to express his conclusions in mathematical symbols. To explain the first statement we may remark that, for scientific purposes, human society may be considered as a vast

26. In the *Saturday Review* of 11 November 1871, possibly written by the mathematician George Wirgman Hemming, fellow of St. John's College, Cambridge, though the reviewer was in general quite sceptical to Jevons's undertaking in the *Theory*.

piece of machinery, in which the actions of the various parts is determined by the various forces which affect the will. Each man is regarded as an instrument moved by pain and pleasure; and the arrangements of society at large are determined by the aggregate impulses of all its individual members. (Jevons 1972–81, 7:152–53)

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