Mechanics Meets Economics, Once Again: On the Rationale of "Rational Economics" of the Guillaume Brothers*

Guido ERREYGERS

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Address for correspondence:

Guido Erreygers, Department of Economics, University of Antwerp, City Campus,

Prinsstraat 13, 2000 Antwerpen, Belgium; guido.erreygers@ua.ac.be

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1. Introduction

Much has been written about the complex relationship between economics and physics. One of the most well-known examples is Philip Mirowski's provocative book *More Heat than Light*, in which he went to great lengths to show "the wholsesale piracy of some physics by a doughty band of economists" (Mirowski, 1989: 4). One of the villains in his story is Léon Walras, who is presented as having very little mathematical skills and only a shallow knowledge of the theories of physics. Yet Walras repeatedly stressed the strong similarity between economics and physics. Perhaps the most explicit exposition of his views can be found in one of his very last papers, 'Economics and Mechanics' (Walras, 1987[1909]), written in 1907-8 and first published in 1909.[1] Here Walras argued that the psycho-mathematical science of pure economics, as he conceived it, used identical methods as the physico-mathematical sciences of rational and celestial mechanics.

A similar, but not entirely identical, position was defended by Édouard and Georges Guillaume, who in the 1930s launched an ambitious project of mathematical economics under the title of 'rational economics', a term coined explicitly as an echo of 'rational mechanics'. Mirowski did not mention the Guillaume project in his *More Heat than Light*, but in his more recent book *Machine Dreams* he included an anecdote which involves a publication of the Guillaume brothers (Mirowski, 2002: 104). The story comes, in fact, from Robert Leonard (1995: 736-8), who quoted extensively from a letter which John von Neumann in May 1935 wrote to Abraham Flexner, director of the Institute for Advanced Study at Princeton, who the month before had sent him a copy of their 1932 book *Sur les Fondements de l'Économique Rationnelle*. Although von Neumann had some sympathy for their methodological principles, he was of the opinion

[1] An English translation, with extensive comments and notes, is in Mirowski and Cook (1990).

that "the mathematical technique of the authors is not good enough, to carry all the theoretical and statistical structures, which they want to build on it". More generally, he had "the impression that the subject is not yet ripe (I mean that it is not yet fully understood, which of its features are the essential ones) to be reduced to a small number of fundamental postulates – like geometry or mechanics".

The work of Édouard and Georges Guillaume is not very well known among economists and historians of economics. In recent years Marianne Fischman and Emeric Lendjel (2000), Lendjel (2002: 21-33) and Michel Armatte (2005: 99-102) have examined some aspects of their writings. In this paper I explore the specific blend of physics and economics proposed by the Guillaume brothers, and in particular trace the connections between their theoretical work and its more practical manifestations. They rejected what they called the 'subjective' rational economics of Cournot, Jevons, Walras and Pareto, and instead aimed for an economic science based upon an 'operational' axiomatic system. After a short biographical sketch, I analyse the theoretical contributions of the Guillaume brothers, and present a survey of the activities of their research centre, the *Centre d'Analyse Économique*, and its collaborators.

2. Biographical Elements

Édouard and Georges Guillaume had Swiss roots. The Guillaume family, of which a reduced genealogical tree can be found on Figure 1, came from the village of Fleurier in the Val-de-Travers district of the canton of Neuchâtel. Business interests – some family members were prominent watchmakers – as well as political turmoil had pushed the family to maintain a settlement in London.[2] One of these watchmakers, George Guillaume (1817-1896), also owned of a printing shop in Neuchâtel, and served as a

[2] The English connection apparently explains why the (French versions of the) names of the English kings Edward, George, Charles and James were popular in the Guillaume family (Roth, 1965: 35).

Conseiller d'État of the canton of Neuchâtel from 1853 to 1886.[3] Around 1870, three of his sons had moved from Neuchâtel to Paris. His oldest son James (1844-1916) was a socialist and would later become a well-known historian of the Socialist International Movement (Vuilleumier, 1964). Édouard (1850-1897), on the other hand, was an aspiring painter, and Charles (1854-1903) a graphical artist. During the 1870s and 1880s Édouard and Charles operated a zinc engraving company in Paris, *Guillaume frères et Cie*. Around 1885 Édouard launched himself in the printing and publishing business, specializing in colourfully illustrated literary books. Using innovative marketing techniques he managed to sell enormous amounts of books – apparently more than two million volumes marketed under the heading of the *Collection Guillaume*, which included books by Alphonse Daudet, Emile Zola and Edmond and Jules de Goncourt, went over the counter in the period 1885-1893. In 1895, however, the Guillaume firm was declared bankrupt, and Édouard died soon thereafter.

It is from the marriage of this Édouard Guillaume with Nina Nacamulli from Venice that Édouard and Georges Guillaume were born. Édouard Guillaume *junior* was born in Paris on 25 January 1881; Georges Guillaume was also born in Paris, but more than 15 years later, on 25 August 1896.[4] Interestingly, they are also related to another, and more famous, member of the Guillaume family living in Paris in that period: the physicist Charles-Édouard Guillaume (1861-1938). He was director of the *Bureau International des Poids et Mesures* in Sèvres, and the surprise laureate of the Nobel

[3] The information on the Guillaume family comes from Rosny (1927: 201-23), Petitpierre (1955), Mollier (1988: 474-7), Ruedin (1996), and Stead (2007: 814-8).
[4] This information on Édouard and Georges Guillaume comes from their birth certificates in the *Archives de Paris*. Although the certificate of Georges mentions that his mother was called 'Stella' Nacamulli, there is little doubt that Nina and Stella Nacamulli are one and the same person.

Prize for Physics in 1920 for his work on nickel-steel alloys which remain almost invariant under different conditions (Genovesi, 2000).[5]

Édouard Guillaume was a physicist, too. In 1908 he obtained a PhD in Philosophy from the University of Zürich with a thesis entitled *Les phénomènes de Bose et les lois de l'électrisation de contact*. At that time he worked for the Swiss *Federal Office for Intellectual Property* in Bern, where Albert Einstein was one of his colleagues. Einstein and the theory of relativity seem to have been the focus of Édouard Guillaume's attention in that period: in 1913 he translated a booklet by Einstein into French, in 1920 he gave a series of lectures on the theory of relativity at the University of Lausanne (Guillaume, 1921), and throughout the 1910s and 1920s he published several articles on the topic in both physical and philosophical journals (e.g. two articles in the *Revue de Métaphysique et de Morale*; Guillaume, 1918, 1920). He was, however, not an uncritical admirer of Einstein and his work. In 1922, when Einstein visited Paris, Guillaume travelled from Switzerland to give a lecture in which he, according to the press, would show that Einstein's theory contained fatal mathematical flaws. But neither Einstein nor his colleagues were impressed by the value of his arguments, and the episode was widely perceived as a humiliating defeat for Guillaume.[6]. In his last contribution in this field – the edition of a number of writings of the French physicist Henri Poincaré, with an extensive introduction (Guillaume, 1924) – Guillaume

[5] In 1920 it was widely expected that Einstein would win the prize for his contributions to relativity theory, but he had little support in the Nobel Committee for Physics. In 1921 the Committee came to the conclusion that no one was worthy of the prize, and as a result the Royal Swedish Academy of Sciences did not award a Nobel Prize for Physics that year. In 1922, however, the Academy awarded two Nobel Prizes for Physics: Einstein received the 1921 prize for his discovery of the law of the photoelectric effect (not for his relativity theory), while Niels Bohr received the 1922 prize. More details can be found in Friedman (2005).

[6] As one prominent observer wrote: "Au bout de quelques instants il devint évident que ce ne serait point encore ce jour-là, ni de cette main, qu'Einstein mordrait la poussière. Quand l'orateur eut achevé, il ne fallut pas plus de deux secondes à ceux qui avaient compris, et tous les assistants étaient dans ce cas, pour ramener l'intervention tant claironnée à ses modiques proportions. (…) Quant à Einstein, souriant, il se réfugia dans une abstention charitable en prétextant n'avoir rien compris à ce que voulait dire son interlocuteur. Ainsi s'acheva cet incident dont on ne peut dire s'il fut plus bouffon que pénible." (Nordmann, 1922: 153). See also Biezunski (1987: 176-177; 1991: 21-22, 47-48, 90, 120-122, 138) and Moatti (2007: 143-146).

suggested that Poincaré had independently obtained the same results as Einstein, but by following a different and from his point of view more acceptable route. The Poincaré-Einstein issue was the subject of a protracted exchange of letters between Einstein and Guillaume (see Genovesi, 2000), and led to a debate about the priority of the theory of relativity, which continues until today.[7]

Through his work in physics Édouard Guillaume also developed an interest in probability theory (Guillaume, 1946: 53-4). In 1915 he moved from the *Federal Office for Intellectual Property* to the *Federal Office for Insurance*, and from 1916 to his retirement in 1946 he worked for the Swiss insurance company *La Neuchâteloise*, of which he became a director (Moatti, 2007: 143). In the decades that followed he regularly published articles on life insurance and actuarial subjects, but not as much as he did on physics. In the academic year 1936-7 he was appointed as "privat-docent" at the University of Neuchâtel, where he lectured on financial economics.[8]

Observing the usefulness of probability theory in the actuarial sciences, Édouard Guillaume began wondering whether it would be possible to bring more mathematical rigour to economics in general. At that point his brother's researches must have played an important role. In Édouard Guillaume's words:

> Survint la guerre mondiale de 1914/18. M. Georges Guillaume, qui était alors arbitragiste à la Banque de Paris et des Pays-Bas, faisait des observations extrêmement curieuses dans le domaine monétaire, et me les communiquait. Les booms et les dépressions économiques commençaient à se succéder à un rythme assez rapide, et l'on acquérait de plus en plus la conviction que nous étions tous pris dans un mécanisme inexorable, obéissant à des lois aussi précises qu'inéluctables. (Guillaume, 1946: 55)

Exactly at what date they started to collaborate is unknown. In any case, in 1932 Georges Guillaume obtained a PhD in Economics at the University of Neuchâtel, with a thesis entitled *Sur les fondements de l'économique rationnelle, avec une technique de la*

[7] One of the persons involved in this debate – on the side of Poincaré – is Maurice Allais (2005).
[8] See Guillaume (1937, 1943).

prévision.[9] This marked the beginning of a period of intense discussion of their economic work. They found a fertile audience at the *École Polytechnique* in Paris, where the *Centre Polytechnicien d'Études Économiques*, also known as *X-Crise*, gathered engineers, economists and others to discuss economic issues.[10] Georges Guillaume was closely associated to Jean Coutrot (1895-1941), a *Polytechnicien* and one of the driving forces of *X-Crise*.[11] The Guillaume brothers presented their work at different occasions, beginning in January 1933. The *X-Crise* group also supported the publication of their next book, *Économique Rationnelle*, which appeared in 1937 as Documents 6-7 of the centre's book series, with a postface by Jean Coutrot.[12]

In the 1930s Georges Guillaume also founded the *Centre d'Analyse Économique* and the *Centre de Gestion Guillaume* in Paris. The first presented itself as a scientific research institute where 'usable laws' were derived based on the theoretical work of Georges and Édouard Guillaume; the aim of the second was to proceed to 'experimental verifications' of these laws by means of a capital fund (*Le Centre d'Analyse Économique*, 1935: 8). The address of these two centres (9, rue Lincoln in the 8th arrondissement of Paris) in 1937 also became the seat of the journal *Humanisme Économique* and of the *Centre d'Études des Problèmes Humains*, an interdisciplinary association created by Jean Coutrot and supported by influential personalities like Alexis Carrel (1873-1944), winner of the Nobel Prize for Medicine in 1912, Aldous

[9] The published book version of the dissertation has the following on the page facing the inner front cover: "Le présent Ouvrage a fait l'objet d'une Thèse de doctorat présentée à la Faculté de Droit de l'Université de Neuchâtel et acceptée avec Félicitations du Jury. – Neuchâtel, le 28 janvier 1932." (Guillaume and Guillaume, 1932) The title page itself mentions: "par Georges Guillaume – Docteur ès Sciences Économiques – Secrétaire Général de la Société d'Économique Appliquée". It also states: "Avec une Théorie Mathématique – par Édouard Guillaume – Docteur ès Sciences"; since there is no separate mathematical theory in the book, it is unclear to what this statement refers precisely.
[10] On *X-Crise*, see: *De la Récurrence des Crises Économiques* (1982) and Ljendel (2002).
[11] On Coutrot and his influence in *X-Crise*, see Dard (1995; 1999: 55-98).
[12] "Ces extensions ont fait l'objet de diverses communications au Centre Polytechnicien d'Études Économiques, auquel nous devons tant, et nous sommes heureux de saisir cette occasion pour exprimer à ses animateurs les sentiments de notre gratitude." (Guillaume and Guillaume, 1937: 247) The year before, Georges Guillaume had written the preface of Coutrot's *L'humanisme économique*, Document 4 of the same series.

Huxley (1894-1963), the English writer, and Pierre Teilhard de Chardin (1881-1955), the Jesuit palaeontologist and philosopher.[13] During World War II Georges Guillaume's name was rumoured to be on the member list of the 'Synarchic' movement, a presumed conspiracy against the Vichy regime (Dard, 1995: 145).

It is not clear how and when the *Centre d'Analyse Économique* ceased to exist. As we shall see in Section 4, it still operated for a few years after World War II. Immediately after the liberation of France in 1944, it published the Guillaume's ambitious study *Construction d'une économie mondiale – Les conditions de l'harmonie – Le plan rationnel*.[14] This was followed in 1947 by the book *L'Arbitre Suprême*, in which they developed a 'general energetics' as a foundation for conflict resolution, a summary of which can be found in Guillaume and Guillaume (1949). This book signalled a mystical turn in their work, and it seems that they gradually lost contact with the mainstream of economic research and retreated into an esoteric world of their own.[15] This is perhaps best illustrated by the publication, in 1960, of George Guillaume's book *L'Accord par le Cosmisme*, an ambitious attempt to formulate a general theory of nearly everything which exists.[16] The book also contained a picture of Édouard Guillaume, who had died on 9 November of the year before in Delémont, Switzerland. Georges Guillaume, *attaché aux recherches scientifiques*, died on 14 July 1969 in his home, 25bis rue Franklin in the 16th arrondissement of Paris.[17]

[13] On this association and the role of Georges Guillaume in it, see Henry (2004: 54-64).
[14] Some copies of this study seem to carry the title *Construction d'une économie française*.
[15] In 1947 they apparently also wrote a report *Contribution à l'étude préliminaire sur le projet d'enquête de l'Organisation des Nations Unies pour l'éducation, la science et la culture sur "États de tension et compréhension internationale"* (Centre d'Analyse Économique, 1947, 38 pp.), of which I have been unable to find a copy. The biologist Julian Huxley (1887-1975), brother of Aldous, was at that time the first director of UNESCO. The Huxley association might explain their involvement in this UNESCO initiative.
[16] The outer cover carries a different title: *L'Arbitrage du Cosmisme*. It was published by the *Éditions de l'Adéquatorium*, located at the same address as the *Centre d'Analyse Économique*.
[17] The information on Édouard comes from the registry office of the *Arrondissement du Val-de-Travers* in Les Verrières, and that on Georges from his death certificate in the *Mairie du 16ème Arrondissement de Paris*.

3. Rational Economics

In the above-mentioned paper 'Economics and mechanics' Walras systematically designated the science of economics by the term *l'économique* rather than by the term *l'économie politique*, which he used in his earlier work. Walras shifted to the new term in the 1890s (see, e.g., Walras (1992[1897]), where he used *l'économique pure* and *l'économique appliquée*), following up on Jevons's suggestion to replace political economy, "the old troublesome double-worded name", by economics, "perfectly analogous in form to *Mathematics, Ethics, Æsthetics,* and the names of various other branches of knowledge" (Jevons, 1888[1871], Preface to the 2nd ed.: 5). Albert Aupetit, a young economist acting as Walras's first disciple and protégé in France at the beginning of the 20th century, also contributed to this terminological change. In 1901 Aupetit had written a PhD thesis in which he formulated a general theory of money along the lines sketched by Walras. He distinguished two parts in his work: an abstract and theoretical part which he called *Économique rationnelle* and an empirical part entitled *Économique expérimentale*.[18] The distinction was motivated by the way things were done in physics, where 'synthetic or rational' research existed side by side with 'analytical or experimental' research (Aupetit, 1957[1901]: 23-24). As much as rational mechanics studied an ideal world based upon a number of abstractions, rational economics studied a non-existent world based upon abstractions such as the *homo œconomicus* and perfect competition. (*ibid.*: 28-29). Gaetan Pirou (1929: 113-5) stressed that this was not the same as the distinction of pure and applied economics, but simply two different approaches of the same problem. He pointed out that similar

[18] An abridged edition, containing only the Introduction and the *Économique rationnelle* part, was reissued in 1957.

distinctions were made by Marcel Lenoir (1913), Jacques Rueff (1922), Charles Bodin (1926) and François Divisia (1928).

From Walras's correspondence we know that in 1907 Albert Aupetit had agreed to write a book *Économique Rationnelle* for the applied mathematics section of the massive *Encyclopédie Scientifique* series edited by Édouard Toulouse (Jaffé, 1965: III, letters 1660 and 1674). Aupetit's book was never published, and one had to wait to the year 1928 when François Divisia published his book with the same title in the series. According to Divisia (1951: 12) the term rational economics had been invented by Walras, but Divisia did not provide a specific reference. Whatever the source of the term may be, it is clear that it was used by those who claimed to be working in the tradition of Walras.

When the Guillaume brothers chose this term to designate their project, they did not imply to be continuing the Walrasian tradition, and they did not refer to Aupetit's or Divisia's previous use of the label. They simply wanted to express their ambition to create an economic science "semblable à un corps de doctrine comme l'est la Mécanique rationnelle" (Guillaume and Guillaume, 1937: 3). Édouard Guillaume described the specific meaning which they attached to the term 'rational' as follows:

> Une doctrine nous apparaît comme rationnelle – telle la Mécanique – lorsqu'elle repose entièrement sur un *petit* nombre de principes – d'axiomes – fondamentaux, dont elle développe les conséquences à l'aide de l'instrument mathématique. (Guillaume, 1935: v)

The number of axioms had to be small so that one could 'easily dominate them by a geometry' (Guillaume and Guillaume, 1937: 14). The role of mathematics would be to show that the set of principles was free of internal contradictions, and to derive the logical consequences of the principles adopted. Empirical verifications would reveal whether the chosen principles were true.

According to the Guillaume's, economics had not yet reached this status of a scientific, i.e. axiomatic, discipline. In their view, the history of economic research could be seen as exploring four different methods (*ibid.*: 9-17). Political economy, akin to law, was based on the dialectical method: it used mainly verbal logic and common sense to derive economic laws. Business cycle studies used both historical and statistical methods to discover correlations between different factors. The school of Cournot, Jevons, Walras and Pareto relied on mathematics and the hedonistic method to formulate a general economic theory. But this 'subjective rational economics', as the Guillaume's called it, had one basic flaw: its axiomatic system was not operational. Here they referred explicitly to the views of Percy Williams Bridgman.[19] Their main criticism was that the subjective concept of value did not obey the principle of conservation.

> L'usage des mathématiques suppose, en effet, que l'objet de l'analyse – en l'occurrence la valeur – obéisse à un *principe de conservation*. C'est grâce à l'énoncé d'un tel principe que la Physique et la Chimie ont pu faire, depuis Lavoisier et Mayer, les progrès fabuleux que l'on connaît. Malheureusement la valeur étant, pour les hédonistes, une grandeur essentiellement *subjective* et *qualitative*, l'analyse ne pouvait porter que sur des fonctions psychologiques dont la détermination quantitative est inextricable. (Guillaume and Guillaume, 1937: 13-14)

Their alternative, rational economics *tout court*, was based on the axiomatic method and operational concepts. It purged economics of the variable and psychological concept of value and replaced it by an objectively defined and numerically expressed value concept obeying the principle of conservation. Their ambition was to derive a general theory formulated in objective and numerical terms. They typically elaborated 'small models' (*ibid.*: 39-42), starting from a single-agent world which was then successively made more complex. The principles of their value theory, for instance,

[19] P.W. Bridgman (1882-1961) was a physicist who was awarded the Nobel Prize in Physics in 1946. Fischman and Lendjel (2000: 370-2) have analysed the influence of Bridgman's concepts on the work of the Guillaume brothers; they also suggest a strong similarity with the views of Paul Samuelson (*ibid.*: 381n).

were clarified by first studying 'Robinson on his island' (*ibid.*: 46-53), and then introducing more individuals, money etc. (*ibid.*: 53-63). The two crucial principles were (i) the conservation of flows of goods (*flux de commodités*), and (ii) the conservation of flows of values (*flux de valeur*). In mathematical terms, they can be expressed as follows (*ibid.*: 248-57). Let q_H denote a quantity of good *H*, and dq_H the production of good *H* between time *t* and time *t+dt*. Suppose that this production requires the amounts $dq_A^H, dq_B^H, ..., dq_N^H$ of the *n* different goods *A*, *B*, …, *N*, with the services of capital and labour also treated as goods. Using the shorthand notation $\dot{x} = \frac{dx}{dt}$, the basic principle of the conservation of flows of goods can then be expressed as a system of *n* equations:

$$\dot{q}_L = \sum_{H=A}^{H=N} \dot{q}_L^H \quad (L = A, B, ..., N) \tag{1}$$

(In the case of lags these equations have to be modified.)

Let the prices of the *n* goods be equal to $p_A, p_B, ..., p_O, ..., p_N$, with p_O representing the price of gold. The second principle expresses that, in equilibrium, the prices must be such that every producer earns exactly what he needs to cover his costs. For instance, the producer of good *A* earns a flow of value equal to $p_A \dot{q}_A$; this should be equal to the flows of value which he has to pay for the productive services which he uses. The principle of the conservation of the flows of value therefore defines a second system of *n* equations:

$$p_L \dot{q}_L = \sum_{H=A}^{H=N} p_H \dot{q}_H^L \quad (L = A, B, ..., N) \tag{2}$$

Since there is one degree of freedom, the Guillaume's suggested to use gold as the numéraire, i.e. to put the price of gold, p_O, equal to 1.[20]

[20] Systems (1) and (2) are similar to those of other linear economic models presented in the first half of the 20th century. Gilibert (2000) has compared the Guillaume equations with those of Remak, von

The two conservation principles were seen as counterparts of the two conservation principles of physics, with the first corresponding to the conservation of matter and the second to the conservation of energy (Guillaume, 1946: 58-61). In this perspective, prices obtain the character of energetic values, indices revealing the amount of effort required to produce different goods. With some pride they reproduced a letter written by Albert Einstein on 24 August 1946 in which he expressed support for their work:

> TO WHOM IT MAY CONCERN!
>
> Dr. G. Guillaume, whose family was well known to me in Switzerland, has explained to me a method for mechanized determination of the relative values of the various commodities (in function of time). I believe that the use of this method may be practical and useful in providing an objective way to obtain an incontestable measure of economic values. (Guillaume and Guillaume, 1947: 62)

For the Guillaume's, rational economics had to be based on a twofold accounting system, one with regard to goods and the other with regard to values. The small models analysed by the Guillaume's therefore have a core consisting of variants of the two systems of equations expressing the two conservation/accounting principles. Various adaptations ensured that these models could also be used to analyse non-equilibrium situations such as price adjustments, economic crises, etc. In particular, they claimed that they by using probability theory they were capable of forecasting rates and prices of different assets. As we will see in the next section, it appears that they were effectively using this information.

It would be exaggerated to say that the work of the Guillaume brothers made much of an impact on the economics profession. Apart from their direct collaborators, very few authors have tried to develop their ideas, and those who did had limited success. In 1935 Maurice Bouytaud published his *Essai d'Économique Rationnelle,*

Neumann, Leontief and Sraffa. There is also a similarity with some variants of Maurice Potron's economic models; see Bidard and Erreygers (2007, 2010) and Bidard, Erreygers and Parys (2009).

with a preface by Édouard Guillaume. Ostensibly inspired by the Guillaume approach, Bouytaud presented a very formal kind of general equilibrium model, but without abandoning all references to utility and preferences as advocated by the Guillaume brothers. The market for these fairly abstract mathematical economic models must have been pretty thin, since both the book and its author have left hardly any traces in the economic literature. The same cannot be said of the Austrian art historian Robert Eisler (1882-1949), who often wrote about value and money. In his writings he repeatedly recommended the ideas of the Guillaume brothers. For example, in a 1946 review essay of Ludwig von Mises's *Omnipotent Government: The Rise of the Total State and Total War*, he wrote:

> (…) a complete plan for an entirely free, uncontrolled and throughout competitive liberal economy has been drawn up in a newly published French book by two Swiss economists, Dr. Georges and Edouard Guillaume, *Le Plan Rationnel* (Paris, 1944). It is the indispensable counterpart of Professor von Mises' *Omnipotent Government*. (Eisler, 1946: 247)

And in the book *Winning the Peace. A Comprehensive Policy*, a section was devoted to the views of the Guillaume brothers (Eisler and Hart, 1948: section 79).[21]

A remarkable affinity exists between their work and the esoteric economic writings of the mineralogist André Amstutz (1901-1981) and the chemist Arnold Borloz (1899-1960), both from Switzerland. First in a series of short papers published during World War II in the *Compte rendu des séances de la Société de Physique et d'Histoire Naturelle de Genève*, and then in a longer article in the *Revue suisse d'économie politique et de statistique* (Amstutz and Borloz, 1945), they expounded a mathematical economic model in which gold played the role of standard of value. Making use of datasets of the League of Nations, the US Department of Labor and Bureau of Census, and data made available by the economist Carl Snyder (1869-1946), they proceeded to

[21] The connection between Eisler and Georges Guillaume dates from the 1930s; see Fisher (1935: 102) and Gibrat (1936: 26).

elaborate empirical calculations. Both Edouard Guillaume (1943: 103) and Amstutz and Borloz (1945: 591) acknowledged the resemblance between the two approaches, but a promised in-depth comparison of the two was apparently never published.

As already mentioned, their theories were intensively discussed during the meetings of *X-Crise* (Gibrat, 1936), but even there the reception was not uniformly positive. Their 1937 book provoked a rather critical reaction by Divisia (1938), to which Georges and Édouard Guillaume (1938) duly replied. Divisia maintained that by purging economics from its hedonistic content, the Guillaume's were performing an amputation which entailed the loss of "tout ce qui fait de l'économique une science morale" (Divisia, 1938: 191).

Of the main economics journals, only the *Economic Journal* published a review, by Michal Kalecki (1940). He noted several deficiencies, but nevertheless concluded that "their work represents a serious contribution to this field of thought, and abounds in original and stimulating ideas" (*ibid.*: 278). In their native Switzerland the *Bulletin Technique de la Suisse Romande* published three reviews of their books: one by the mathematician Gustave Juvet (1932), one by the engineer Charles Jaeger (1937a), and another one by J.C. (1938). Jaeger (1937b) also published a much longer article on mathematical economics in the *Schweizerische Bauzeitung*. Harold T. Davis (1938) published a joint review of the 1937 book by the Guillaume's and of Jan Tinbergen's *An Econometric Approach to Business Cycle Problems* in the *Bulletin of the American Mathematical Society*.

4. The *Centre d'Analyse Économique*

It is very difficult to find information about the Parisian research centre of the Guillaume's. Our main source is a brochure published in 1935 by the centre itself: *Le*

Centre d'Analyse Économique – Son Organisation – Son Utilité (henceforth: CAE). Apart from that, we have two internal reports by the department of economic and financial studies of the *Crédit Lyonnais*[22], and a few sporadic remarks in other publications[23].

The centre was founded and directed by Georges Guillaume. The main purpose of this non-profit organisation with scientific aim was to transform the principles of rational economics of the Guillaume's into propositions which could be applied to real-world problems.[24] The centre was divided into five sections: (I) Business cycles (*La Conjoncture Générale*); (II) Sectors and markets (*Les Branches de l'Activité Économiques*); (III) Assets with variable revenues (*Les Valeurs Mobilières*); (IV) Assets with fixed revenues, and interest rates (*Les Valeurs à Revenu Fixe et les Taux*); and (V) The Guillaume management technique (*La Technique de Gestion Guillaume*).[25] This last section elaborated and refined a financial technique described as the 'Guillaume Technique' of generalized systematic arbitrage. The centre seemingly attached great importance to data collection and graphical illustrations; it boasted of continuously updating a series of 'atlases' with data and diagrams (CAE: 26-7).

[22] The first report "Centre d'Analyse Économique (Visite à M. G. Guillaume)" (Note N° 8447) is dated 18 November 1935, and the second "Centre de Documentation Économique. Atlas International de Valeurs" (Note N° 8656) 17 June 1938. Together with related correspondence and appendices they are conserved in the *Archives Historiques du Crédit Lyonnais*, file numbers DEEF 44503/2 and DEEF 59907.
[23] See Marjolin (1937), Picard (1937) and Guillaume and Guillaume (1937: 246-7 and passim).
[24] After the inner title-page, there is a page with two photographs, one of Georges Guillaume and another of Édouard Guillaume. At the bottom of this page it is stated: "Auteurs des travaux à la base des applications du Centre d'Analyse Économique" (CEA: 2)
[25] In 1935 these sections were headed by Stéphane Leven, Antoine Pourquié, Jacques Bourcier-Omètre, René Guignard – all former students of the *Ecole Polytechnique* – and J. Mertens, *expert-comptable*. The adminstrative director was Pierre Mauclère, a chemical engineer. Other members of staff mentioned by name in the brochure were the actuarian Max Borel, the statistician M. Dewek, and P. De La Porte De Vaux, *Directeur honoraire de la Société Générale*. The centre also employed a lawyer, L. Guillaume, and a librarian, S. Neikrug.

It is unclear how the centre managed to finance its operation. Presumably it made revenue by selling information and data to interested parties.[26] The contacts with the *Crédit Lyonnais* were clearly meant to explore the possibilities for future cooperation. The bank's report of the visit stated:

> M. Guillaume a passé, avec une 'importante' société suisse d'assurances, un contrat réservant à cette dernière l'exclusivité de ses travaux concernant les travaux à revenu fixe; il fait également certaines recherches pour des banquiers (Rothschild, B.N.C.I., etc.), des industriels (raffinerie de sucre, etc.) et des particuliers. Il estime que des études analogues concernant les prix des principales matières premières seraient susceptible d'intéresser le Crédit Lyonnais, auquel il serait prêt à en réserver l'exclusivité moyennant le droit d'utiliser la documentation des Etudes Financières du Crédit Lyonnais et le versement d'une somme annuelle qu'il évalue 'au maximum à 300.000 frs par an' (frais d'entretien du bureau spécialisé). ("Centre d'Analyse Économique (Visite à M. G. Guillaume)", 1935: 3)[27]

Probably the centre also benefited from the profits made by its sister organisation, the *Centre de Gestion Guillaume*, which had the task of empirically verifying the propositions established by the *Centre d'Analyse Économique* by means of a capital fund (*Groupement de capitaux*) brought together for this purpose (CAE: 8). The capital apparently belonged to Georges Guillaume, his collaborators and their families ("Centre d'Analyse Économique (Visite à M. G. Guillaume)", 1935: 1). It was claimed that the two centres operated in harmony:

> Loin de se mal trouver des opérations dictées par les nécessités d'enregistrement des travaux du **Centre d'Analyse Économique**, le Groupement de capitaux a montré, au contraire, qu'il en profite grandement. L'ensemble a pu ainsi se développer harmonieusement. Il présente une cohésion qui lui confère la puissance investigatrice et la compétence voulues. (CAE: 8)

[26] E.g., it published a bulletin which was only available to subscribers (Lemaître, 1937: 343); both Marjolin (1937: 221) and Picard (1937: 251-2) saw the centre mainly as providing business cycle information.

[27] My guess is that the 'important Swiss insurance company' is *La Neuchâteloise*, of which Édouard was director. The *Crédit Lyonnais* seems to have declined Georges's offer. The report was sceptical about his methods and warned that "l'application systématique des mathématiques supérieures à des raisonnements qui ne reposent en fait que sur des tissus d'hypothèses risque de donner une apparence de rigueur à des conclusions qui peuvent être dangereuses" (*ibid.*: 4).

A number of examples were given which purportedly showed the superiority of the Guillaume arbitrage technique in comparison to other financial techniques (CAE: 21-8).

By the year 1938 a third centre had been created at the same address, the *Centre de Documentation Économique*. This appears to have been mainly a financial service centre, collecting, processing and selling information on quoted stock companies. Its main output was the *Atlas International de Valeurs*, consisting of *Les Planches Guillaume* with detailed information and graphs on individual firms.[28] The theoretical foundations of the *Atlas* were said to be the 'Models' of rational economics and a 'Manual' with general explanations. Specific information relative to each firm was grouped into two files, a *dossier général* and a *dossier matrice*, and Guillaume invited the bank to come and consult these files.[29]

During the 1930s and 1940s several theoretical and applied studies of the Guillaume brothers were published by the *Centre d'Analyse Économique* (see, e.g., Guillaume and Guillaume, 1947), but most of them are nowadays very hard to find.[30] Although they claimed that its members were also engaged in personal research, some of which they used for their theories (Guillaume and Guillaume, 1937: 246-7)[31], little traces of this can be found. One exception is a very broad and non-technical paper on dynamics by Octave Gélinier (1946)[32], heavily inspired by the work of the Guillaume's and the centre. At the end of his study Gélinier mentioned that it had been written at the

[28] The second report by the *Crédit Lyonnais* staff had in appendix a leaflet on the *Atlas* and two of its *planches*, one on the *Crédit Lyonnais* itself and another on the *Crédit Commercial de France*, sent to the bank by Georges Guillaume.
[29] Once again the bank seems to have declined Guillaume's services. The report mentioned several inaccurate and arbitrary elements in the *planches* ("Centre de Documentation Économique. Atlas International de Valeurs", 1938).
[30] Some confusion may be possible with another Paris-based *Centre d'Analyse Économique*, the one headed by Maurice Allais since 1946.
[31] They mentioned explicity the 'remarkable researches' of Stéphane Leven on the construction of a leading indicator (*ibid.*: 246), and the work of Antoine Pourquié on the laws of price variations (*ibid.*: 313-4). Much later Leven (1971) wrote a book on monetary instability, but he did not mention his work at the Guillaume institution.
[32] Octave Gélinier (1916-2004), a civil mine engineer, later became one of France's leading management experts. In 1947 he moved to Cegos, where he would spend the rest of his career.

Institut d'Analyse, de Synthèse et d'Orientation des Activités (I.A.S.O.A., 9, rue Lincoln, Paris) – probably a spin-off of the other Guillaume centres at the same location, about which I have been unable to find further information. Interestingly, he pointed out that the centre had used four different techniques:

> Pour construire pratiquement des modèles économiques conformes aux caractéristiques précédentes, diverses techniques ont déjà été utilisées: modèles mathématiques, qui se prêtent à l'étude des propriétés formelles; modèles graphiques commodes pour illustrer un exposé de principe; modèles numériques, reproduisant quantitativement les flux de matière et de valeurs réels mesurés à un instant donné, mettant en évidence les tensions-valeur et permettant la prévision pratique; enfin modèles électriques qui, substituant aux flux de valeur des courants électriques (qui obéissent au même principe de conservation), et figurant les contraintes matérielles par des liaisons électriques appropriés, constituent une image souple et mouvante douée d'une évolution spontanée parallèle à l'évolution du milieu réel. (Gélinier, 1946: 264)

This is the first mention of the use of electrical models by the centre; I will explore this branch of activity in the next section.

5. Electric Models and Devices

When applied at the level of the nation-state, the conservation and accounting laws which the Guillaume's considered to be the hard core of their rational economics models eventually led to the construction of tables of national accounts, representing flows of goods and value between different sectors. For instance, in one of their publications they included a number of folding pages with a detailed table of this kind representing the economy of Switzerland in 1939 (Guillaume and Guillaume, 1947: 61). They also claimed to have invented a device which enabled them to trace the dynamics of the economic system:

> Nous avons construit une calculatrice électrique qui permet de suivre, d'une façon quasi-continue, les intervalles entre les tableaux dressés à des instants aussi rapprochés qu'on le désire. Cette machine reproduit ainsi une *synthèse dynamique de l'évolution* en fonction du temps. (*ibid.*: 34)

This raises two interesting questions: were the tables of the Guillaume similar to the input-output tables constructed by Wassily Leontief since the early 1930s, and what exactly was the electrical calculator to which they referred?

A partial answer to these questions can now be given. Just a couple of weeks after the Liberation of Paris in August 1944, Raymond Alphonse Marie Barbey submitted a patent application to the French authorities for a *Dispositif électrique pour l'étude des variations corrélatives de grandeurs liées entre elles par un système de relations mathématiques formant tableau à double entrée*.[33] In 1945 he submitted the same application for an electric calculator also in the UK, the USA and Switzerland.[34] The application file started with a simplified representation of economic transactions in a national economy by means of a double-entry table arranged according to the method of Georges and Édouard Guillaume of the *Centre d'Analyse Économique* (see Figure 2). Barbey then noted that the entries of this table are such that for each sector i (i = 1, 2, 3, 4), the following equation holds:

$$\sum_{j=1}^{j=4} Q_{ij} + P_i = M_i + P_i = \sum_{j=1}^{j=4} Q_{ji} = N_i \qquad (3)$$

His invention was based on the idea that it should be possible to translate this information on economic exchanges between sectors into flows of electric energy:

> The invention has for its object to device an electrical apparatus permitting to instantaneously and continuously compute correlative variations of the quantities $Q_{11}, Q_{12} \ldots M_1, M_2 \ldots N_1, N_2 \ldots P_1, P_2 \ldots$, when one or several of them are adjusted or undergo a variation.
> The invention has further for its object to devise an electric integrator adapted to integrate variations of these quantities in function of the time, so as to totalize the exchanges between the groups as well as the profits or losses of any one of these groups. (Patent US2509718, column 3)

[33] Patent number FR992866, applied for on 18 September 1944, delivered on 11 July 1951, and published on 24 October 1951. All patent information comes from the EPO Database (for European patents), the USPTO Database (for American patents) and the CIPO Database (for Canadian patents).
[34] Patent numbers UK600795, US2509718 and CH253045.

He went on to describe the technical details of the system of instantaneous and totalizing meters which he had in mind.

On 6 March 1946 Barbey informed Leontief that he had developed an "Overall Surveying Machine", called the "Grid" (see Figure 3), which would allow "easy handling of statistical data and economic information".[35] Without going into technical details, he explained that the Grid was an electric device that functioned "much like a telephone exchange". He was convinced that it would make economic calculations much easier:

> This electrical coordination, flexible, instantaneous, and complete, is a revolutionary change for statistical work. Its consequences are bound to be far reaching, and will prove to be [an] asset to the organizations who will be first to use it. A development equipment is built on a semi-industrial scale for a private investment trust in France. (Barbey to Leontief, 6 March 1946, Appendix: 2)

The investment trust to which Barbey referred in his letter was the *Centre d'Analyse Économique* of the Guillaume brothers. In another letter to Leontief Barbey inserted a note on the history and development of the Grid, and there he explained:

> At the beginning of 1944 the author saw the double-entry tables of the Center [sic] d'Analyse Économique, Paris, on the national product.
> He was struck by the difficulty of mutual adjustment within the frame of double-entry accounting, of large numbers of statistical or tentative figures. He wondered whether electric currents would not spontaneously give the answer to such large systems of linear equations and he built a first very small electric "Grid" of four accounting units exchanging through sixteen points.
> The Centre d'Analyse Économique bought it, and asked the inventor to design and build a more important "Grid". With the collaboration of the Centre, the inventor developed a thoroughly changed structure of the double-entry table, in order to make it more comprehensive, explicit, practical. All the economic functions should appear on a well-designed table. At the expense of the Centre, he built the Grid which has been finished just now. (Barbey to Leontief, 14 June 1946, Appendix: 5)

Barbey was obviously trying to make money from his invention. Leontief was not interested, however. In two letters he maintained that the computational work for his

[35] Barbey to Leontief, 6 March 1946, Appendix, p. 2. The Barbey-Leontief correspondence comes from the Papers of Wassily Leontief, *Harvard University Archives*.

input-output tables could be accomplished without any serious difficulty by the existing techniques.[36]

The exact relation between Barbey and the Guillaume's remains a bit of mystery. When the previously mentioned patent application was submitted in Canada, the inventor was listed as Raymond Barbey but the owner as Georges Guillaume.[37] In 1946-7, Barbey submitted patent applications in France and the USA for an "electric calculating machine for studying the variations of linear functions of several variables and for solving systems of equations with several unknowns".[38] He reproduced the same table as in his previous application (Figure 2), but he dropped the reference to the Guillaume's and instead claimed that it had been prepared in accordance with the methods of Leontief's input-output analysis. To make things even more complicated, a few years later Georges Guillaume also submitted patent applications for electric calculating machines, entitled *Appareil électrique de mesure, permettant notamment de faire des previsions économiques* and *Appareil électrique de mesure, permettant notamment de determiner l'équilibre dans un système d'échange*.[39] In the first he referred explicitly to the *Économique Rationnelle* book which he and his brother had published in 1937. He claimed that he had found a way to construct an electric device which established an exact correspondence between economic variables and electric variables. The main terms of correspondence are given in Figure 4. In the second, clearly a variant of the first, he suggested that the patent which Barbey had applied for in 1945 was, in fact, his. It is uncertain whether any of the devices invented by Guillaume has ever been built.

[36] Leontief to Barbey, 14 March and 19 June 1946. Interestingly, in the first letter he mentioned that his 1934 article in the *Quarterly Journal of Economics* "has been translated into French by Mr. Stephane Leven of the French Economic Mission in Washington".
[37] Patent number CA484584; the application date is unknown, but it was issued on 1 July 1952.
[38] Patent numbers FR1002557 and US2503932; the quote is from the US application (columns 8-9).
[39] Patent numbers CH297068 and DE910906 for the first and CH297465 for the second.

6. Concluding Remarks

In this paper I have tried to show that the Guillaume brothers have gone quite far in their attempt to reconcile economics and physics. They elaborated rational economic models inspired by the principles of rational mechanics; applied their theoretical knowledge to the real world and offered information and advice to parties willing to pay for it; were apparently capable of making a profit by investing their own funds according to what they identified as lucrative investment opportunities; and stimulated the development of electric devices which would facilitate the calculations needed to construct and use tables of national accounts. Their work constitutes a fascinating but hitherto largely unknown episode in the history of economics-as-if-it-were-physics.

References

Archival sources

Archives Historiques du Crédit Lyonnais, *Archives Historiques Groupe*, Crédit Agricole S.A., Paris.

Archives des Mairies de Paris, *Archives de Paris*, Paris.

Office Régional de l'État Civil de Val-de-Travers, *Arrondissement du Val-de-Travers*, Les Verrières (Neuchâtel).

Papers of Wassily Leontief, *Harvard University Archives*, Cambridge (MA).

Service de l'État Civil, *Mairie du 16ème Arrondissement de Paris*, Paris.

Internet Sources

CIPO Database, Canadian Intellectual Property Office, http://patents.ic.gc.ca/cipo/cpd

EPO Database, European Patent Office, http://ep.espacenet.com

USPTO Database, United States Patent and Trademark Office, http://www.uspto.gov

Published sources

ALLAIS, Maurice (2005), *Albert Einstein. Un Extraordinaire Paradoxe*, Paris, Editions Clément Juglar.

AMSTUTZ, André and Arnold BORLOZ (1945), "Endettements, productions, compréhension économétrique", *Revue Suisse d'Économie Politique et de Statistique*, 81(6): 585-606.

ARMATTE, Michel (2005), "La notion de modèle dans les sciences sociales: anciennes et nouvelles significations", *Mathématiques et Sciences Humaines*, 43(4): 91-123.

AUPETIT, Albert (1957[1901]), *Essai sur la Théorie Générale de la Monnaie – Économique Rationnelle*, Paris, Marcel Rivière.

BIDARD, Christian and Guido ERREYGERS (2007), "Potron and the Perron-Frobenius theorem", *Economic Systems Research,* 19(4): 439-52.

BIDARD, Christian and Guido ERREYGERS (eds) (2010), *The Analysis of Linear Economic Systems. Father Maurice Potron's Pioneering Works*, London: Routledge.

BIDARD, Christian, Guido ERREYGERS and Wilfried PARYS (2009), "'Our Daily Bread': Maurice Potron, from Catholicism to mathematical economics", *European Journal of the History of Economic Thought*, 16(1): 123-54.

BIEZUNSKI, Michel (1987), "Einstein's reception in Paris in 1922", in: Thomas F. Glick (ed.), *The Comparative Reception of Relativity*, Dordrecht, D. Reidel, pp. 169-188.

BIEZUNSKI, Michel (1991), *Einstein à Paris,* Saint-Denis, Presses Universitaires de Vincennes.

BODIN, Charles (1926), *Principes de Science Économique: Cours Elémentaire d'Economie Simple*, Paris, Sirey.

BOUYTAUD, Maurice (1935), *Essai d'Économique Rationnelle*, Paris, Gauthier-Villars.

COUTROT, Jean (1936), *L'Humanisme Économique. Les Leçons de Juin 1936*, Paris, Éditions du Centre polytechnicien d'études économiques.

DARD, Olivier (1995), "Voyage à l'intérieur d'X-Crise", *Vingtième Siècle. Revue d'Histoire*, 47: 132-46.

DARD, Olivier (1999), *Jean Coutrot. De l'Ingénieur au Prophète*, Besançon, Presses Universitaires Franc-comtoises.

DAVIS, Harold T. (1938), "[Book review]", *Bulletin of the American Mathematical Society*, 44(11): 761-2.

De la Récurrence des Crises Économiques (1982) [*X-Crise. Centre Polytechnicien d'Etudes Économiques. Son Cinquantenaire, 1931-1981*], Paris, Economica.

DIVISIA, François (1928), *Économique Rationnelle*, Paris, Doin.

DIVISIA, François (1938), "L'économique rationnelle de MM. Georges et Édouard Guillaume", *Revue d'Economie Politique*, 52(1): 187-93.

DIVISIA, François (1951). *Exposés d'Économique. Introduction Générale: L'Apport des Ingénieurs Français aux Sciences Économiques*, Paris, Dunod.

EISLER, Robert (1946), "Omnipotent government", *The Nineteenth Century and After*, 139-140(837): 239-247.

EISLER, Robert and Eric George HART (1948), *Winning the Peace. A Comprehensive Policy*, London: Frederick Muller.

FISCHMAN, Marianne and Emeric LENDJEL (2000), "X-Crise et le modèle des frères Guillaume", in: Pierre Dockès, Ludovic Frobert, Gérard Klotz, Jean-Pierre Potier, André Tiran (eds), *Les Traditions Économiques Françaises, 1848-1939*, Paris: CNRS Editions, pp. 369-82.

FISHER, Irving (1935), *Stable Money. A History of the Movement*, New York: Adelphi.

FRIEDMAN, Robert Marc (2005), "Einstein and the Nobel Committee: Authority vs. expertise", *Europhysics News*, 36(4): 129-133.

GÉLINIER, Octave (1946), "De la dynamique économique à la dynamique générale", *Revue Philosophique de la France et de l'Etranger*, 137(7-9): 257-88.

GENOVESI, Angelo (2000), *Il Carteggio tra Albert Einstein ed Édouard Guillaume. "Tempo Universale" e Teoria della Relatività Ristretta nella Filosofia Francese Contemporanea*, Milano, Franco Angeli.

GIBRAT, René (1936), "La science économique. Méthodes et philosophie", in: *Actes du Congrès International de Philosophie Scientifique, Sorbonne, Paris 1935. II. Unité de la Science*, Paris, Hermann & Cie, pp. 22-31.

GILIBERT, Giorgio (2000), "Un decennio di modelli circolari (1927-1937)", in: Massimo Pivetti (Ed.), *Piero Sraffa. Contributi per una Biografia Intellettuale*, Roma, Carocci, pp. 461-9.

GUILLAUME, Édouard (1918), "La théorie de la relativité et le temps universel", *Revue de Métaphysique et de Morale*, 25(3): 285-323.

GUILLAUME, Édouard (1920), "La théorie de la relativité et sa signification", *Revue de Métaphysique et de Morale*, 27(4): 423-69.

GUILLAUME, Édouard (1921), *La Théorie de la Relativité. Résumé des Conférences Faites à l'Université de Lausanne au Semestre d'Eté 1920*, Lausanne: F. Rouge & Cie.

GUILLAUME, Édouard (1924), "Introduction", in: Henri Poincaré, *La Mécanique Nouvelle. Conférence, Mémoire et Note sur la Théorie de la Relativité*, Paris, Gauthier-Villars, pp. v-xvi.

GUILLAUME, Édouard (1935), "Préface", in: Maurice Bouytaud, *Essai d'Économique Rationnelle*, Paris, Gauthier-Villars, pp. v-vi.

GUILLAUME, Édouard (1937), *Quelques Lois Économiques Fondamentales: Leçon Inaugurale du Cours Libre d'Economie Financière Donné au Semestre d'Hiver 1936-1937*, Neuchâtel, La Baconnière.

GUILLAUME, Édouard (1943), "La théorie quantitative de la monnaie représente-t-elle les faits?", *Journal de Statistique et Revue Économique Suisse*, 79(2): 89-105.

GUILLAUME, Édouard (1946), "De la science actuarielle à la science économique. Conférence faite à Bâle, lors de l'assemblée annuelle du 13 octobre 1945", *Bulletin de l'Association des Actuaires Suisses*, 46(1): 53-87.

GUILLAUME, Édouard and Georges GUILLAUME (1947), *L'Arbitre Suprême*, Paris, Centre d'Analyse Économique.

GUILLAUME, Édouard and Georges GUILLAUME (1949), "La détermination des valeurs par synthèse et l'instance arbitrale", in: E.W. Beth, H.J. Pos and J.H.A. Hollak (eds), *Actes du X^me Congrès International de Philosophie (Amsterdam, 11-18 Août, 1948)*, Amsterdam: North-Holland, Vol. I, part 2, pp. 1034-1037.

GUILLAUME, Georges (1960), *L'Accord par le Cosmisme*, Paris, Editions de l'Adéquatorium.

GUILLAUME, Georges and Édouard GUIILLAUME (1932), *Sur les Fondements de l'Économique Rationnelle, Avec une Technique de la Prévision*, Paris, Gauthier-Villars.

GUILLAUME, Georges and Édouard GUIILLAUME (1937), *L'Économique Rationnelle. Des Fondements aux Problèmes Actuels*, Paris, Hermann & Cie.

GUILLAUME, Georges and Édouard GUIILLAUME (1938), "Controverse au sujet d'une nouvelle économique rationnelle: réponse aux commentaires de M. F. Divisia", *Revue d'Economie Politique*, 52(4): 1220-3.

GUILLAUME, Georges and Édouard GUILLAUME (1944), *Construction d'une Économie Mondiale – Les Conditions de l'Harmonie – Le Plan Rationnel*, Paris, Centre d'Analyse Économique.

HENRY, Odile (2004), "De la sociologie comme technologie sociale. La contribution de Jean Coutrot, 1895-1941", *Actes de la Recherche en Sciences Sociales*, 153: 48-64.

JAEGER, Charles (1937a), "[Book review]", *Bulletin Technique de la Suisse Romande*, 63(12): 163.

JAEGER, Charles (1937b), "Quelques aspects recénts de l'emploi des mathématiques en économie politique", *Schweizerische Bauzeitung*, 110(5): 45-51.

JAFFÉ, William (Ed.) (1965), *Correspondence of Léon Walras and Related Papers*, Amsterdam, North-Holland, 3 Volumes.

J.C. (1938), "[Book review]", *Bulletin Technique de la Suisse Romande*, 64(7): 98-99.

JEVONS, William Stanley (1888[1871]), *The Theory of Political Economy*, London Macmillan.

JUVET, Gustave (1932), "[Book review]", *Bulletin Technique de la Suisse Romande*, 58(23): 307-308.

KALECKI, Michal (1940), "[Book review]", *Economic Journal*, 50(198/199): 276-8.

Le Centre d'Analyse Économique – Son Organisation – Son But (1935), Paris, Centre d'Analyse Économique.

LEMAÎTRE, Henri (1937), "Les centres de documentation", in: Raymond Aron e.a., *Les Sciences Sociales en France. Enseignement et Recherche*, Paris, Paul Hartmann, pp. 324-79.

LENDJEL, Emeric (2002), *X-Crise (1931-1939): Entre l'Atelier de* Modèles *et le Bureau des* Méthodes. Université de Marne-la-Vallée, UFR de Sciences Économiques et de Gestion, Mémoire pour l'Habilitation à Diriger les Recherches, Vol. II.

LENOIR, Marcel (1913), *Études sur la Formation et le Mouvement des Prix*, Paris, Giard & Brière.

LEONARD, Robert J. (1995), "From parlor games to social science: von Neumann, Morgenstern, and the creation of game theory 1928-1944", *Journal of Economic Literature*, 33(2): 730-61.

LEONTIEF, Wassily (1934), "Pitfalls in the construction of demand and supply curves: A reply", *Quarterly Journal of Economics*, 48(2): 355-61.

MARJOLIN, Robert (1937), "La statistique", in: Raymond Aron e.a., *Les Sciences Sociales en France. Enseignement et Recherche*, Paris, Paul Hartmann, pp. 200-23.

MIROWSKI, Philip (1989), *More Heat than Light. Economics as Social Physics, Physics as Nature's Economics*, Cambridge, Cambridge University Press.

MIROWSKI, Philip (2002), *Machine Dreams. Economics Becomes a Cyborg Science*, Cambridge, Cambridge University Press.

MIROWSKI, Philip and Pamela COOK (1990), "Walras' 'Economics and mechanics': Translation, commentary, context", in: Warren J. Samuels (Ed.), *Economics as Discourse. An Analysis of the Language of Economists*, Boston, Kluwer, pp. 189-215.

MOATTI, Alexandre (2007), *Einstein, un Siècle contre Lui*, Paris, Odile Jacob.

MOLLIER, Jean-Yves (1988), *L'Argent et les Lettres. Histoire du Capitalisme d'Edition. 1880-1920*, Paris, Fayard.

NORDMANN, Charles (1922), "Einstein expose et discute sa théorie", *Revue des Deux Mondes*, Année 92, Période 7, Tome 9, pp. 129-166.

PETITPIERRE, Jacques (1955), "La famille Guillaume", in: Jacques Petitpierre, *Patrie Neuchâteloise*, Neuchâtel, H. Messeiller, Vol. IV, pp. 181-217.

PICARD, Roger (1937), "Les sciences économiques", in: Raymond Aron e.a., *Les Sciences Sociales en France. Enseignement et Recherche*, Paris, Paul Hartmann, pp. 224-55.

PIROU, Gaetan (1929), *Doctrines Sociales et Science Économique*, Paris, Sirey.

ROSNY, J.-H. (Aîné) (1927), *L'Académie Goncourt. Les Salons – Quelques Editeurs*, Paris, G. Crès et Cie.

ROTH, Dorothea (1965), “James Guillaume : seine Jugend in Neuenburg (bis 1862), sein Studium in Zürich (1862-1864) und seine Begegnung mit dem Sozialismus (1868)”, *Schweizerische Zeitschrift für Geschichte*, 15(1): 30-86.

RUEDIN, Pascal (1996), “Ernest Biéler illustrateur des Goncourt dans la ‘Collection Édouard Guillaume’ à Paris (1880-1892)”, *Art + Architecture en Suisse*, 47(4): 389-403.

RUEFF, Jacques (1922), *Des Sciences Physiques aux Sciences Morales*, Paris, Alcan.

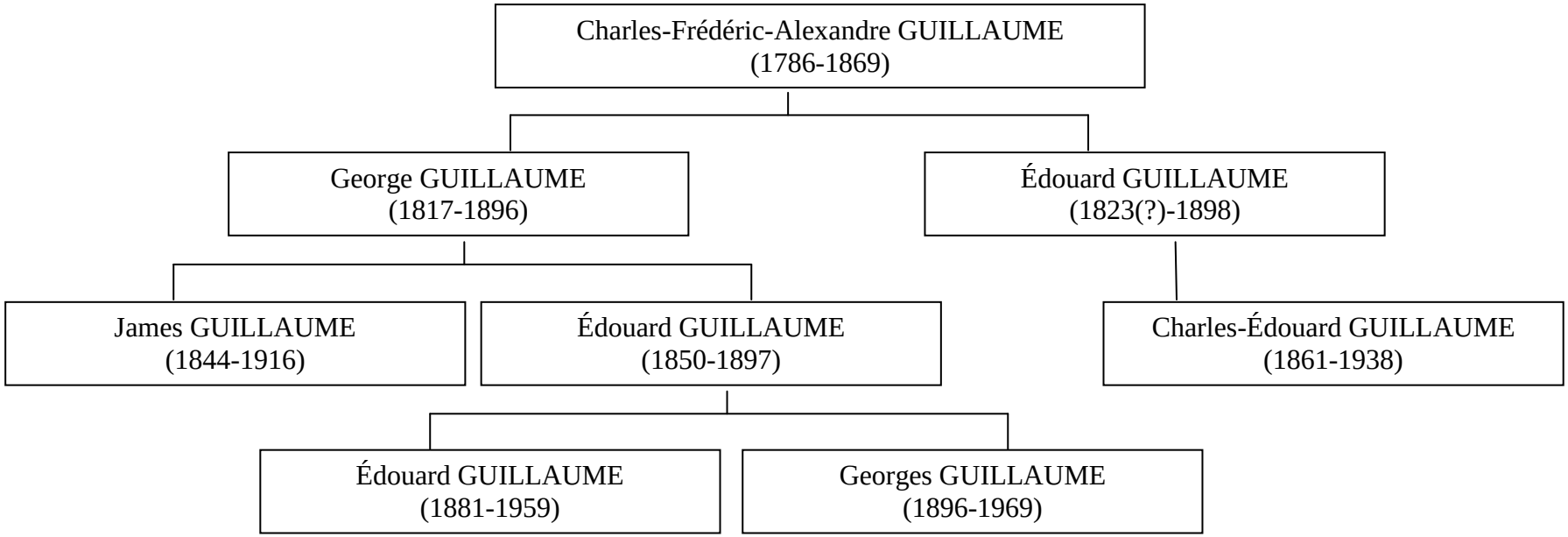
STEAD, Évanghélia (2007), “De la revue au livre: notes sur un paysage éditorial diversifié à la fin du XIXe siècle”, *Revue d’Histoire Littéraire de la France*, 107(4): 803-23.

VUILLEUMIER, Marc (1964), “Les archives de James Guillaume”, *Le Mouvement Social*, 48: 95-108.

WALRAS, Léon (1992[1897]), “L’économique appliquée et la défense des salaires”, in: Léon Walras, *Etudes d’Economie Politique Appliquée* (Auguste ét Léon Walras Œuvres Économiques Complètes, Vol. X), Paris, Economica, pp. 245-61.

WALRAS, Léon (1987[1909]), “Économique et mécanique”, in: Léon Walras, *Mélanges d’Economie Politique et Sociale* (Auguste ét Léon Walras Œuvres Économiques Complètes, Vol. VII), Paris, Economica, pp. 330-41.

Figure 1: Reduced genealogical tree of the Guillaume family



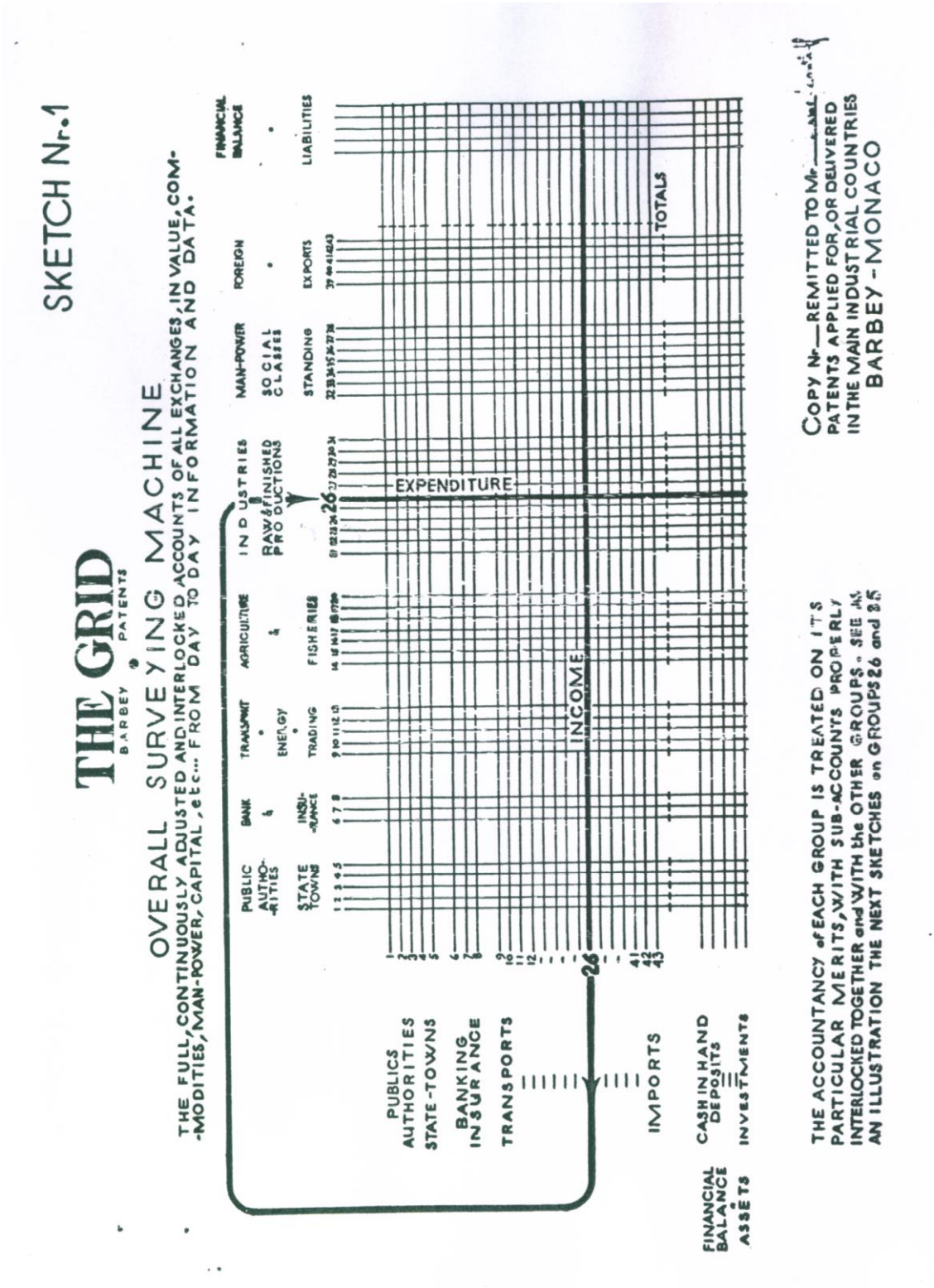
Source: Petitpierre (1955) and own research

Figure 2

	State	Transports and Credit	Agriculture	Industry	Totals	Profits and Losses
State	Q_{11}	Q_{12}	Q_{13}	Q_{14}	M_1	P_1
Transports and Credit	Q_{21}	Q_{22}	Q_{23}	Q_{24}	M_2	P_2
Agriculture	Q_{31}	Q_{32}	Q_{33}	Q_{34}	M_3	P_3
Industry	Q_{41}	Q_{42}	Q_{43}	Q_{44}	M_4	P_4
Totals	N_1	N_2	N_3	N_4		

Source: Patent number US2509718, columns 1-2.

Figure 3



Source: Barbey to Leontief, 6 March 1946, Appendix: 5 (Papers of Wassily Leontief).

Figure 4

Intensité du courant	=	quantité de matière ou de valeur par unité de temps.
Tension	=	prix par unité *a)* de quantité (cotation dite incertaine), *b)* de cotation dite certaine.
Puissance (watts)	=	flux de valeur par unité de temps.
Quantité d'électricité:		
a) charge des accus ${}_{A}M, {}_{B}M...$	=	stocks de biens en magasin,
b) charge des accus ${}_{A}C, {}_{B}C...$	=	contre-valeur de ces stocks.
Alternance positive:	=	quantités de biens ou services,
a) ligne	=	service des ventes, sortie des biens et services,
b) colonne	=	service des achats, entrée des biens et services.
Alternance négative:	=	quantités d'unités monétaires correspondant à la quantité de biens ou services,
a) ligne	=	service des ventes, entrée des valeurs,
b) colonne	=	service des achats, sortie des valeurs.
Conductances 6 et 7 plus valves 9 et 10	=	dispositif déterminant la ration de bien ou service versé ou livré par la ligne à la colonne.
Autotransformateurs 8	=	coefficients de structure.
Capacité de l'accu M (magasin) permettant la marche optimum de l'individu producteur/consommateur	=	stock-outil.

Source: Patent number CH297068, p. 7.