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Mathematization of the theory and methodology of accounting in the first half of the twentieth century

Kolchugin S.V.
Novosibirsk State University of Economics and Management
Novosibirsk, Russian Federation
s.kolchugin@rambler.ru

Abstract — **This article examines the historical attempts to apply mathematical methods in the theory and methodology of accounting from the beginning of accounting as a practical activity until the first half of the twentieth century. The article analyzes the evolution of accounting from the component of the mathematical discipline to an independent scientific discipline, applying the mathematical apparatus. Mathematization of the theory and methodology of accounting in pre-revolutionary Russia, conducted by such scientists as N. Popov and A. Rudanovsky is observed separately.**

Keywords — accounting theory, accounting methodology, accounting history, mathematical method, axiomatic theory, formalization.

I. Introduction

Historically, accounting was recognized as part of mathematical knowledge. The eleventh treatise “On Accounts and Records” was included by the Franciscan monk and scientist Luca Pacioli in an encyclopedic work in mathematics “The sum of arithmetic, geometry, the theory of proportions and relations” (“Summa de arithmetica geometria. Proportioni: et proportionalita: ...") [1.] and published in 1494. In 1846, the famous logician and mathematician Augustus de Morgan included “Elements of Arithmetic” [2] in his work, the seventh appendix “On the basic principle of accounting” (“On the main principle of book-keeping”) [2, pp. 180-190] where he expounded a personalistic theory of accounts.

In the future, accounting becomes an independent scientific discipline where theories of mathematical direction appear. One of the first mathematical theories of accounting was the theory of Giovanni Rossi “Teorica matematica della scrittura doppia italiana. Metodo algebraico-Metodo gragico" (Mathematical theory of double-entry bookkeeping) (1889) [3.] And Antonio Masetti «Sulla teorica matematica del conto e dei metodi di scrittura (On the mathematical theory of the account and accounting methods)» (1901) [4.].

Over time, a skeptical attitude towards the use of mathematical methods in theoretical accounting appears in commonwealth of schientists. Nikolai Semyonovich Pomazkov, did not single out mathematical calculating theories as an independent direction in the development of a countable idea in his classification of countable theories. In the sixtieth paragraph "The mathematical direction in the development of countable theories" of "Countable theories. The duality principle and the double-entry method ”[5.] N.S. Pomazkov gives the following link to Austrian authors Reish and Craibig: “... it was stated many times that the presentation of a countable theory only in the shell of algebraic equations shows the correctness of this theory and only in this case reveals the scientific nature of the justification of the countable theory. We cannot overcome known doubts regarding this statement. The fact that representatives of the most controversial theories based on formally correct equations shows that the equation cannot play a decisive role in establishing the truth of a countable theory. Similarly, the relationship of algebraic symbols will remain completely incomprehensible unless the meaning and relationship of the Asset, Obligations, Gains and Losses and Net Capital are clarified in advance; so the formulas and their transformations are only repeated in the literal symbols of the known and the established and in no case define new concepts. Since the basic equations allow only certain transformations of them, based on the practical meaning of the symbolized values, in most cases the usual algebraic calculations now become absurd” [5, pp. 242-243]. And further, N. Pomazkov recognizes this criticism to be quite thorough: “Recalling all those negative aspects of the materialistic theories of one and two rows of accounts, that were mentioned above and that did not violate the formal correctness of the basic equations characteristic of all these theories, we have to admit the cited considerations of Gomberg, Reish and Craibig to have a sufficient degree of substantive” [5, p. 243].

Thus, the use of mathematical apparatus in accounting is a fundamental problem in the theory and methodology of accounting. The purpose of this study is to examine the main areas of application of the mathematical method in the theory and methodology of accounting until the first half of the twentieth century.

II. Basis

A. Mathematical description of fundamental accounting equations.

In the theory of accounting mathematical description of the fundamental accounting equations and derivation of the consequences of them gained considerable acceptance.

Thus, the materialistic theory of two rows of accounts, which became widely known in the works of Friedrich Gügli [6.] and Johann Friedrich Sher [7.], accepts mathematical identity of the following form as a fundamental equality:

$$\mathbf{A - O = C} \quad (1)$$

A is an asset, O are obligations, C is the capital of an enterprise.

This equality, in the materialist theory of two rows of accounts, describes two opposite rows of accounts. The accounts of the asset accounting and obligations constitute a series of accounts reflecting the property of an enterprise (“property accounts”), and the accounts of capital accounts constitute a series of accounts reflecting the capital of an enterprise (“capital accounts”). “This way accounts fall apart," wrote I. Sher, "in two essentially different types. One row of accounts marks the income, expense, and condition of the property — property accounts; another row of accounts marks the state of capital at the beginning of the period and its subsequent increase or decrease - capital accounts” [9, p.34]. The relationship between property accounts and capital accounts is described as follows: “... with proper record keeping, the balance of the debit of property accounts must be equal, as will be mathematically proved below, to the balance of a capital account credit, then *in this dual accounting of property produced in double-entry bookkeeping, there is a highly important control (highlighted by I. Sher)*” [10, p.61].

From the fundamental equality of the materialistic theory of two rows of accounts, according to mathematical rules, the following derivatives of identity are got:

$$\mathbf{A = C + O} \quad (2)$$

$$\mathbf{O = A - C} \quad (3)$$

In 1841, this mathematical identity was used in his work by Johns Thomas, one of the earliest American authors of accounting manuals.

The fundamental equation of the materialistic theory of two rows of accounts is given by T. Jones as the first statement (propositions I.): "If we can ascertain our Resources and Liabilities at any time, their comparison will determine the state of our affairs at this time" [12, p.48]. Then the author gives the following illustrative example:

TABLE I. REPORT ON OUR RESOURCES AND LIABILITIES, ON DECEMBER 31, 1840

Cash at our disposal	$ 15 000	Bills to pay	$ 3 000
Account receivable	$ 4 0 00	We owe John Spring	$ 6 000
William James owes us	$ 3 0 00		
Total resources	*$ 22 000*	*Total liabilities*	*$ 9 000*

From $ 22 000

We substract $ 9 000

Consequently, our present worth should be $ 13,000

When obligations exceed resources, this enterprise is considered insolvent [12, p. 21].

Thus, the amount of capital, the size of assets (property), the amount of liabilities, signs of solvency (insolvency), etc. are determined basing on the mathematical equation originally given.

In his late work “Accounting and balance on the economic, legal and mathematical basis for lawyers, engineers, merchants and students of business administration with an application ...” [13.] Johann Friedrich Sher uses mathematical equality everywhere. The author recognizes accounting as the science located at the junction of mathematics, law and economics. It's reflected in the title of his main work.

Except these scientists, in the world's practice early authors such as Léautey Eugéne and Adolf Guilbault (14.), Leo Gomberg (15.), Richard Reisch and Josef Kreibig [16.] and many others also used mathematical description of accounting equations.

The use of mathematical equations, to describe the fundamental identities of accounting, has been practiced in educational literature up to the present moment. As an example we can mention the work of Robert E. G. Nicol «The Accounting Equation Revisited: A Conceptual Accounting Model» [18.].

B. The use of the mathematical method in creating a scientifically based accounting theory in pre-revolutionary Russia.

At the end of the 19th and the beginning of the 20th century, an intensive search for the scientific foundations of accounting was carried out in pre-revolutionary Russia, scientific theories of accounting were created, and scientific schools were formed. One of the directions of the scientific substantiation of the theory of accounting is the formalization of the theory of accounting and the use of mathematical methods in accounting. Nikolay Popov can be considered the founder of this direction in Russia. He noted: "... the subject of my studies is a mathematical method in accounting as economic science" [17, p.5]

In his work N. Popov, for the first time in Russia, attempts to formalize accounting methodology mathematically (building a mathematical model of accounting). The basis of this model is the mathematical law of equality, and the language of the model is the language of mathematics: “Through the entire content of the General Accounting Manual, the idea was to trace the economic foundations and mathematical essence of each account and each group of accounting records in as many different accounting systems as common (for various enterprises and institutions) and private, for special (for homogeneous farms),… and, if possible, translate all these types of the countable part into an algebraic language” [17, p.15]. The algebraic language is considered by the author as the language for the analysis of theoretical accounting positions: "The solution of accounting problems through the mathematical method is the following: the task is divided into conditions, the nature of the values taken into account is studied, each part of the solution, according to the conditions, is expressed by a formula, and a general one is made up of particular formulas. The last one serves for determining the type of each account, the accounting system, recording methods and graphical construction, and other means of the most favorable solution” [17, p.14]. The result of this analysis is the identification of principles, rules and accounting formulas: “The results of the united economic and mathematical research and the generalization of works on the countable part are principles, rules, theorems, formulas and graphical constructions which then serve to group, comparing and analyzing objects of accounting" [17, p.20]. Revealed principles, rules and formulas within the framework of a formalized mathematical model are universal for theoretical accounting: "Axioms, theorems, formulas and principles that are subject to the mathematical method of accounting, should be common for all objects of accounting; otherwise, the accounting may fall into one-sidedness, which, as it must be admitted, already happened" [17, p.24]. From our point of view, one of the most important functions of the mathematical formalization of the accounting methodology, which N. Popov only touches upon, is the function of analyzing and comparing existing accounting models ("accounting systems"): "... when comparing the conclusions from the study of types of bookkeeping, I pointed out the comparative merits of the systems and sometimes paid attention to detectable deficiencies; but at the same time, it was usually stipulated that I referred them not to the essence of the system, but exclusively to that manual or material that I used to characterize the species in question" [17, pp. 15–16]

One of the significant shortcomings of the mathematical formalization of the accounting methodology conducted by N. Popov is the fact that the author considers his mathematical apparatus as a tool for analyzing the existing methodological provisions of accounting (accounting systems), but not for their self-construction: "Thus, general accounting with its axioms and theorems common to all systems cannot be taken as a general accounting system. It cannot create systems itself" [17, p.16].

Next attempt to formalize the methodology of accounting, building accounting models and introducing the theory of accounting for mathematical methods was made to Alexander Pavlovich Rudanovsky.

According to A. Rudanovsky's mathematization of the theory of accounting will make it possible to move from accounting as art or craft to accounting as science. The idea of creating a special science "balancing", by mathematizing the accounting methodology, is one of the main motives of the work of A. Rudanovsky: "I hope that this analysis, being simple itself and based on the most elementary and well-known accountants, will draw their attention to the more general accounting questions that I put forward in my previous studies, all with the same and with the hope of turning bookkeeping into science and giving grounds for building a theory of accounting, which should serve as the missing and mediating link between political economy and value theory" [21, p. XX].

The object of special science, the theory of balance accounting, is the balance of an economic entity in which all its economic activities are represented in terms of value. The balance sheet, according to A. Rudanovsky, objectively exists: "So, the accounting balance exists in speculation before and independently of the applied forms of accounting for the economic activities of any given economy" [22, p.179 (part II)].

The balance sheet is determined as follows: *" the balance is a term determined on the one hand, by inventory, representing a set of economic relations that have a certain value; on the other hand, by the state economy, representing a set of legal relations that dictate a certain value; at that, the relationship between inventory and state power stems from the monetary turnover of the given economy, leading to such financial relations, as a result of which one or another rent is obtained, from the relationship between the income and expenditure of the economy*" (*highlighted by A. Rudanovsky - S.K.*) [22, p.34-35 (part II)].

In the above definition of the balance sheet, A. Rudanovsky relies on three independent areas of the theory of accounting: simple accounting, logismography and simple cameral accounting. Even in earlier works, such as "New Direction of Accounting" [20.] and "Principles of Public Accounting" [19.] the author identified three main schools of accounting: Italian (rationalistic school of Italian professor Fabio Besta, school of logismographic accounting of Rossi Giovanni, French (represented by Léautey Eugéne) and Guilbault Adolphe) and the German school (primarily the cameral school

of accounting of Friedrich Gügli). Regarding this, when determining the balance sheet, A. Rudanovsky synthesizes three independent areas of accounting: simple accounting, logismography and cameral accounting.

Due to the fact that the general balance in the theory of balance accounting consists of three independent balances, the author calls it "differential balance", that: "... is very close by its content to the generally accepted balance, but represents the combination of Léautey commercial balance accounts with the Cherboni logistic balance and the Gügli cameral balance" [22, p.71 (part II)]. A. Rudanovsky separately emphasizes the opposite nature of the three separate balances of a single overall balance: "The analysis of the logismographic, cameral and commercial directions of accounting, as the ones giving the balance accounting in full is interesting as it draws a balance from three well-studied points of view that differ sharply and are opposite" [22, p.74 (part II)].

The next important point in the theory of balance accounting that allows to go to the application of mathematical analysis methods in accounting theory is the spatial separation of economic relations. Once independence and opposition of the asset and liability of the balance sheet is established , A. Rudanovsky makes a spatial distinction between asset and liability in the area of economic phenomena: "The essence of accounting is reduced to defining the area of internal, money-measurable and general-measurable relations of the whole space of economic phenomena, that is the consideration of the balance" [23, p.56].

The balance sheet is understood as a synthesis of internal, external and border field of economic phenomena. Spatial separation of economic phenomena to the internal, external, and boundary areas allows the use of elements of higher mathematics that describe relationship between the internal, external, and boundary areas of spatial relations when describing the accounting methodology. When translating the accounting provisions into the language of a mathematician A. Rudanovsky uses the following principles, theorems and laws of higher mathematics and physics: Dirichlet's principle [23, p.28], Steklov's theorem [23, p.28-29], the Galoit principle [23, p.29], Bär's principle [23, p.29], Lorentz's law of relativity [23, p. 29], Jordan's theorem [23, p.30]. All the principles, theorems and laws mentioned describe the spatial relations of the inner and outer areas: "From a previous study of the interconnection between various principles of mathematical analysis, that are: the Dirichlet principle, the Steklov theorem, the Galoit principle, the Bär principle, the Lorentz law of relativity, it is clear that they are reduced to the interrelation of the internal and external area" [23, p.28].

The division of the space of economic phenomena into mutually exclusive areas (internal and external), as well as the selection of the border area, as already noted, allows mathematizing the accounting methodology by creating a scientific accounting theory - the theory of balance accounting. But in this case there is the problem of translating the language of mathematics into the language of accounting or the problem of the metalanguage of accounting. Indeed, all the principles, theorems and laws mentioned above are formulated into the language of mathematics and their direct translation into the language of accounting is impossible. Rosetta Stone is needed, i.e. special semantics that allows to translate the language of mathematics into the language of accounting: metalanguage of accounting.

A. Rudanovsky consistently introduces a meta-language of accounting theory in the second part of [22.]: "... if we agree, when translating into a counting language, a delimited area of economic phenomena, that is, separate isolated farms, to determine by balance, then the *balance*, as an object of accounting, should be applied to the same method of building all its properties, that is dictated by the duality principle and the theory of complexes" [22, p.3 (part II)]. Further, A. Rudanovsky translates the concepts of the theory of complexes (creates a meta-language of accounting) into the language of accounting: "Disvariant - Static part of balance. Covariant - The dynamic part of the balance. Invariant - Accounts with changes on the inner (left) debit side of the balance and cannot transfer to the other side. Exvariant - Accounts with changes on the outer (right) credit side of the balance and cannot pass to the other side "[22, p.5 (part II)], etc.

Introducing the metalanguage of accounting allows translating theorems, principles and laws of higher mathematics that describe the spatial relations of the internal and external areas into the language of accounting. This translation is carried out according to the scheme "Language of Higher Mathematics - Metalanguage - Language of Accounting (more precisely, we can speak of the balance accounting language of A. Rudanovsky)". Particular importance in this regard has the law of relativity of Lorentz.

A. Rudanovsky formulates the following way Lorentz's law of relativity and its necessity when translating the language of mathematics into the language of accounting: "Just as the latter, by assuming the dependence of spatial relationships on time, go beyond purely geometric relationships," this further *generalization, dictated by Lorentz's law, should lead to the conclusion that laws established within any area of phenomena or relationships by proper coordination of the latter can receive a new interpretation in the field of completely different phenomena, if a form of transformation of the coordination of the first region into the coordination of the second area is found, that is, coordination is only the language of the phenomenon of each area and knowledge of the alphabet, that is, composing elements, allows you to translate all the concepts of the first and parallel to the laws established in the first area into the language of another area, to establish the laws of the second area (highlighted by A. Rudanovsky - S.K.)*" [23, p.23]. In other words, by virtue of Lorentz's law of relativity (in A.P. Rudanovsky's terminology), mathematical principles and theorems describing the relationship between the internal and external areas of spatial relations (in a geometric sense) are also applicable in the space of economic relations when describing an asset as an internal area and liabilities as an external area of economic relations. From our point of view, the introduction of Lorentz's law of relativity the transition from the field of mathematics to the field of accounting is the key point of the theory of balance accounting of A. Rudanovsky. It is the law of relativity Lorentz that allows to translate mathematical theorems and principles relating to the internal and external areas of the geometric space, through the metalanguage, into the language of accounting.

Thus, the Dirichlet principle leads to the delimitation of an asset, as an internal area of economy, and a liability, as an external area of economy. Steklov's theorem implies a strict delineation of the internal (asset) and external area (liability) and recognition of the border area (income and expenditure or budget). The principle of Galoit allows to move from material accounts to personal accounts and from static to dynamic accounts. Bär's principle sets the highest and lowest balance sheet estimates. Jordan's theorem affirms the need of the existence of a border area or budget of any economy, that allowed A. Rudanovsky to assert the falsity of double records on the postulate of Pacioli and the need for double records on the postulate of Pisani. But the most important thing is that the provisions of the theory of accounting are scientifically grounded in the above principles and theorems, and the theory of balance accounting by A. Rudanovsky, according to its creator, acquires a scientific status.

So, in the theory of balance accounting, A. Rudanovsky introduces a meta-language of accounting theory, in order to translate the language of higher mathematics into the language of accounting (or in other words, to conduct mathematization of accounting methodology). Unlike N. Popov and other authors who attempted mathematical formalization of the accounting methodology, A. Rudanovsky translates mathematical principles and theorems with use of a metalanguage into the language of accounting. This is the uniqueness of the theory of balance accounting. The authors before and after A. Rudanovsky mathematized the accounting methodology by translating the postulates and concepts of accounting theory into the language of mathematics, but not vice versa.

Summing up the analysis of the theory of balance accounting, we can draw the following conclusion. The theory of A. Rudanovsky is an original work in which there are deep and fruitful ideas on the mathematical formalization of accounting methodology. Therewith, the way to conduct mathematization of accounting theory, from our point of view, has a significant drawback. The translation of mathematical principles and theorems that establish the relationship between the internal, external and boundary areas of spatial relations in the field of economic phenomena through Lorentz's law of relativity is not justified. In our opinion, Lorentz's law of relativity is applicable in the field of physical phenomena in the transition from one inertial reference system to another, but the application of this law in the transition from the field of physical phenomena to the field of logical concepts by A. Rudanovsky is not proven. Regarding this matter, the theory of balance sheet accounting A. Rudanovsky has a significant methodological flaw.

III. Conclusions

At an early stage of development, accounting was perceived as part of mathematical knowledge. An example of this approach to accounting is the work of Luca Pacioli and Augustus de Morgan, that includes accounting in the structure of mathematical knowledge.

Further, accounting gets separated from mathematical knowledge as an independent type of practical activity, and then, as an independent scientific discipline. At the same time, mathematical methods are used in the theory and methodology of accounting. Particularly, in the theory of accounting, fundamental identities, that gave basis to one or another accounting theory, became widespread. The fundamental identities themselves were described using mathematical symbolism and obeyed the mathematical rules of transformation. These attempts of applying mathematics to the theory and methodology of accounting were limited, in particular, many scientists noted that some theories, sometimes directly opposite, use formally correct mathematical identities.

In pre-revolutionary Russia, attempts were made to conduct a consistent mathematical formalization of the theory and methodology of accounting. Among the most prominent representatives of this direction are N. Popov and A. Rudanovsky. In his studies N. Popov tried to use a mathematical apparatus to analyze various accounting models in order to identify their advantages and disadvantages. A. Rudanovsky who studied mathematics at the university, introduced elements of higher mathematics into the theory and methodology of accounting adapting the theorems of higher mathematics to theoretical accounting.

Summing up the study, it can be noted that the full use of mathematical methods in the theory and methodology of accounting in the period under review did not happen. Except for the description with the help of mathematical symbolism well-known accounting equations and primary mathematical formalization, the mathematical method in theory and accounting methodology has not received its development.

In the second half of the twentieth century, the ideas of using mathematical and digital methods in accounting, received a powerful impetus thanks to the work of Richard Mattessich [24, 25, etc.], Yuji Ijiri [26, 27, 28, etc.], and many others. In the theory of accounting, attempts are made to apply formal-axiomatic accounting methodology.

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