Chapter 2

Historical Review

Partial Least Squares Path Modeling (PLS-PM), also known as Structural Equation Modeling by the Partial Least Squares approach, is integrated by two main concepts: (1) the concept of path modeling or structural equation modeling, and (2) the concept of partial least squares. Although the concept of partial least squares appears later than that of structural equation modeling, its history and development can be seen as a process over a long period of time that covers many fields of knowledge such as biometrics, psychometrics, econometrics, and sociology, among others.

The contributions from each discipline have created a comprehensive literature in which is not unusual to find different terms referring to the same concept and, conversely, find identical names used to designate different concepts. This lack of uniformity in terminology is the main cause for the generalized confusion many readers can experience within PLS-PM related literature. In order to clarify some of the doubts and confusions regarding PLS and structural models, while contributing to a better understanding on the topic, this chapter presents a historical review in the evolution process of the structural equation models and the subsequent development of the PLS approach.

We have tried to link the different disciplines and their associated methods with the purpose of providing the context in which they arose, as well as the practical problems they sought to solve. Although we have attempted to offer a review as comprehensive as possible, our presentation does not pretend to be a complete and exhaustive history of PLS; something that is virtually impossible. We have highlighted only some of the historical facts and events that we consider to be the most important or relevant in regards to the development of path modeling.

The first section contains a brief biography of the “father” of PLS: Herman Wold, followed by a description of each of the four different backgrounds related to structural equation modeling. The final sections will cover the antecedents of PLS, describe its evolution, and will mention some recent developments within the PLS field.

2.1 Brief Biography of Herman Wold

Herman Ole Andreas Wold was born at Skien, Norway, on December 25th, 1908; he was the youngest of a family of six brothers and sisters. In 1912 his family moved to a small town near Stockholm and he lived in Sweden for the rest of his life. It was there that he began his higher education at Stockholm University in 1927. He also obtained his doctoral degree in 1938 under the supervision of Professor Harald Cramér (Whittle, 1992). He continued as Docent in actuarial mathematics and mathematical statistics until 1942 when he was offered the chair of Statistics at the University of Uppsala. In the summer before presenting his doctoral dissertation he was appointed by a government committee to perform an econometric analysis of consumer demand from available Swedish statistics. That project took him almost 14 years to complete, from 1938 to 1952.

His interest in path models began by the late 1950s and led him to the organization of the Uppsala Symposium on Psychological Factor Analysis in 1953. However, during the 1950s and early 1960s his research focused on econometric models with directly observed variables, as well as on recursive and non-recursive systems of equations trying to estimate those equations by least squares methods.

While serving as visiting professor at Columbia University from 1958-1959, Wold suffered from “an intellectual turmoil” (Wold, 1982b) and decided to change some of his intellectual ideas and make a new start with causal modeling analysis. He dedicated most of his time to path models with latent variables and to the development of the partial least squares methodology from 1966 till his death. Wold continued in his position as chair at Uppsala until 1970, when he moved to Gothenburg University and became there, the chair of the Statistics Department. Upon retirement in 1975 he returned to live in Uppsala. He kept active doing research for the Volkswagen Foundation and spent some time at the University of Geneva. Herman Wold died on February 16th, 1992.

Professor Wold was Vice-President of the International Statistical Institute from 1957 to 1961, he was elected to membership of the Swedish Academy of Sciences in 1960, received an honorary fellowship of the Royal Statistical Society in 1961, was elected president of the Econometric Society in 1966, member of the Nobel Economic Science Prize Committee from 1968 to 1980, and honorary membership of the American Economic Association and the American Academy of Arts and Sciences in 1978 (Wold, 1982b). During his retirement he also received several honorary doctorates (Hendry and Morgan, 1994).

2.2 Econometrics and Simultaneous Equations

The rapid industrialization process experienced by the United States and some European countries during the last decades of the nineteenth century brought spectacular rates of economic growth together with some periods of crisis. These circumstances led to an increased interest among economists in demand analysis, production theory and business cycle analysis (Gilbert and Qin, 2005). According to Desrosières (2004), from these circumstances two main schools of thought emerged in Economics: one based on economic theories and the other based on observations and records of empirical data. The first, inspired in the model of physical sciences, assumed the existence of *a priori* general principles and laws pretending to describe a deterministic representation of economic phenomena. Conversely, the second school of thought stated that economical laws could only be extracted from regularities in data. In other words, there were two separated ideologies: the deductive one, and the inductive one.

As a result, a number of quantitative studies of business cycles were developed trying to understand business fluctuations and cycle lengths. However, the unsophisticated methods employed to study economic phenomena gave poor results and only partial explanations were given for the distinct irregularities in business fluctuations (Gilbert and Qin, 2005). Although simple correlation, basic statistics, and regression analysis were known and applied by some, these methods could not fill all the gaps between data and theory. In other words, there was no well established framework for synthesizing data evidence and economic theory. The need for this general mathematical framework to help conceptualize and describe the economy became increasingly clear in the initial decades of the twentieth century when early innovations were proposed as *ad hoc* methods to handle particular problems.

In 1930 the Econometrics Society was founded with the objective of analyzing economic phenomena while integrating statistical methods and mathematical modeling. As Morgan (1990) mentions, there were three main objectives of the Econometrics Society: (1) to make economics more scientific, (2) to express theories more exactly, and (3) to provide stronger, empirically based knowledge. Two years later, Alfred Cowles created the Cowles Commission for Research in Economics in 1932. Cowles was a businessman and an investment counselor, who after the stock market crash of 1929, decided to support academic research in order to understand the workings of the economy (Christ, 1994).

Also in the 1930s, the statistical concepts and the apparatus of hypothesis testing came into econometrics with the Neyman-Pearson method of rejection. This approach inspired econometricians who began combining economic theory, statistical methods, and observed data to model particular aspects of economic behavior, such as the price of food, consumer demand, or consumer income. The idea was to describe economic phenomena as the result of interactions among many agents, i.e., as the result of the *simultaneous* interaction of different agents. These relationships were expressed by a system of simultaneous equations capable of describing the workings of the economy (Christ, 1994).

One of the econometricians inspired by the theory test modeling approach was the Norwegian Trygve Haavelmo (Nobel Prize in 1989). He focused on the formulation of *a priori* theories as a set of admissible hypotheses and the integration of the Maximum Likelihood principle into econometrics. Haavelmo dismissed ordinary least squares (OLS) regression as inconsistent when applied to simultaneous equations and instead recommended estimation by Maximum Likelihood. However, Wold and Bentzel in 1946 distinguished the conditions under which a system of simultaneous equations can be estimated by OLS.

Many important developments in econometrics took place during the 1930s and 1940s due in part to the incorporation of the recently established probabilistic framework, as well as economic events such as the stock market crash of 1929, the implementation of public policies to maintain full employment, the studies on supply-demand analysis, and the studies on rationing policies and regimes of regulated prices during the wartime and after World War II (Wold, 1982b).

Much of the econometricians work was centered in model building with suitable systems of equations, and the development of methods for estimating them. New estimation methods were needed and the maximum likelihood approach took the attention in the econometrics environment. It is important to note that there had been some early successes with other estimation methods like *path analysis* proposed by Sewall Wright, the son of economist Philip Wright. Unfortunately, this method went unnoticed by most economists.

2.3 Sewall Wright's Path Analysis

As mentioned above, various *ad-hoc* methods were proposed to solve different economic problems. One of those methods, Path Analysis, was presented under circumstances that unfortunately nullified its impact on the econometrics field, having to wait for a couple of decades to be rediscovered by sociologists. The econometrics application of this method appeared in the form of an appendix in a study made by Philip Wright in 1928 about market equilibrium, and supply and demand curves. The appendix was written by his son Sewall Wright, a geneticist at the University of Chicago, who some years earlier had seen that market equilibrium could be analyzed using the method he had developed to study certain problems in heredity (Epstein, 1989).

Path analysis was developed by the American geneticist Sewall Wright in the 1920s as a method for dealing with a system of interrelated variables (Wright, 1972). In 1911, Sewall Wright was a graduate student of Biology at the University of Illinois. In 1915, Wright was working at the Animal Husbandry Division of the United States Department of Agriculture, where he was investigating the role of genetics in the determination of color inheritance (Denis and Legerski, 2006). In particular, he was interested in ascertaining how the genes of the parents (the causes) influenced the offspring's traits (the effects); more concisely he wanted to estimate the sizes of the effects from each parent to the offspring (Murayama, 1998). He came up with a solution by establishing a system of equations in which each equation was expressed in terms of the correlations among the various variables. He started to develop a quantitative method called Path Analysis designed to estimate the degree to which a given effect was determined by each of a number of causes. The first use of this methodology occurred in 1918 in an article titled *On the Nature of Size Factors*. Basically, what Wright proposed in this article was that growth factors of different broadness (e.g., general size, size of skull, size of leg, etc.) may have an effect on the size of diverse bones (skull, tibia, femur, etc.) and induce variability among them (Tomer, 2003) . In concrete, Wright was able to establish the importance of the size factors by calculating the proportion of variation determined by a factor (cause) in the size of a body part or bone (effect).

This method was motivated by the question of whether a set of variables had a causal structure that could be determined from a matrix of simple correlation coefficients. The fundamental contribution of path analysis, and the reason for its name, is the graphical representation of the relationships among the variables by means of a path diagram. As an example of a simple path diagram let us consider a system with three variables X_1, X_2 and X_3, where X_2 is a linear function of X_1, and X_3 is a linear function of X_1 and X_2. This simple system, represented in figure 2.1, is modeled by: $X_2 = bX_1$ and $X_3 = aX_1 + cX_2$.

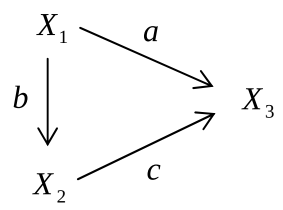

Figure 2.1. *Path diagram example*

The way to think of a path diagram is as if it were the causal flow in a system of interrelated variables. Wright's 1918 article did not contain the conceptualization of path coefficients nor the path-analytic diagrams. It was until 1920 when the notion of path coefficients and path diagrams appeared in a second article written by Wright titled *The Relative Importance of Heredity and Environment in Determining the Piebald Pattern of Guinea-Pigs*. Wright not only used his path analysis for genetics and econometrics applications in the estimation of supply and demand equations, but also in psychometrics factor analysis (Bollen, 1989).

2.4 Psychometrics and Factor Analysis

Psychometrics is a branch of Psychology devoted to the development, evaluation, and application of mental tests with the purpose of measuring knowledge, attitudes, personality traits, and abilities (Rust and Golombok, 1999). One of the statistical data analysis techniques that originated within psychometrics is Factor Analysis. This technique was developed by the British psychologist Charles Spearman at the beginning of the XXth century in order to measure intelligence in an objective way. The idea was to study how mental ability is organized by analyzing correlation matrices for sets of cognitive test variables. Spearman hypothesized that the correlations could be described by a single underlying variable called the factor of "General Intelligence".

Spearman's assumed factor of general intelligence was soon found to be inadequate and the model was then modified in order to include more factors. This modification was not immediate but took place over the four decades following Spearman's initial work. The result was the development of an enormous variety of different factor analysis methods (Kotz and Johnson, 1983). Among the psychologists who contributed to this modification was Louis Thurstone who postulated seven, rather than one, primary mental ability, and developed multiple factor analysis.

Currently, the purpose of factor analysis is to explain most of the variability among a number of variables that are directly observable in terms of a smaller number of unobservable variables called factors. The observable variables are modeled as approximately linear functions of the factors (Loehlin, 1987). One of the main contributions of factor analysis is the concept itself of a factor which is an unobservable variable or latent variable (LV). The interest in LVs is that, although they represent theoretical constructs (unobserved), they can be measured indirectly by observable or manifest variables (MV).

Different estimation procedures were proposed during the 1920s and the 1930s but it was not until 1940 that efficient statistical methods were introduced by Lawley using the method of maximum likelihood (ML). However, there were two problems that had to be solved before ML was to become a feasible method of estimation. First, the estimating equations for the ML estimates are obtained from the derivatives of matrix functions which are very complex and difficult to treat at the level of scalar algebra. Thus it was necessary to simplify the notations for matrix derivatives. Second, the likelihood equations cannot be solved algebraically, rather they require iterative numerical algorithms. In addition, electronic computers were not available before the 1950s.

In the early 1950s Herman Wold had met with the famous psychometrician Louis Thurstone and his wife Thelma in Stockholm. Wold was so inspired by their work on factor analysis that he decided to organize in 1953 the Uppsala Symposium on Psychological Factor Analysis. A few years later, the young student Karl Jöreskog, after completing his studies to be a grammar school teacher, decided to help out a friend during a summer by replacing him in the statistics laboratory at the University of Uppsala. At the end of the course, due to his aptitude for statistics, professor Wold invited Jöreskog to stay at the university and continue as a PhD student in the statistics department. In 1958 Wold suggested that Jöreskog do a dissertation on factor analysis (Jöreskog, 2004).

By the late 1950s a number of computer programs were available for performing factor analysis however none of these provided the correct maximum likelihood estimates for the common factor model. Major advancements in solving the problems concerning factor analysis and the ML approach came from the efforts of Karl Jöreskog. When he moved to the United States at the Educational Testing Service in the middle 1960s, he developed an efficient algorithm for the computation of the ML estimating equations (Mulaik, 1986).

2.5 Sociology and Causal Models

By the 1950s, the concept of causation had been reintroduced into the main discourse of the philosophy of science through several independent and almost simultaneous publications by different sociologists and economists such as Paul Lazarsfeld, Herbert Simon and Herman Wold (Sobel, 1992). The notions of model and causality attracted many researchers who were trying to model sociology after the physical sciences, that is, they were searching for theoretical universal laws of society that would mimic those of physical sciences. As Nollmand and Strasser (2005) have commented: “There was a wish for sociological scientism… A strong concern with methodology promised to cure sociology’s inferiority complex on its way into academia and to provide equal strength in the competition of scientific disciplines”

Herbert Simon, consultant of the Cowles Commission and Nobel prize winner in Economy 1978, was one of such researchers who thought that the social sciences “needed the same kind of rigor and the same mathematical underpinnings that had made the hard sciences so brilliantly successful” (Simon, 1996). Simon was familiar with Sewall Wright’s path analysis and during the period from 1950 to 1955 he focused on the concept of causal ordering, i.e. the directionality of variables when proposing a model. During this time he came in contact with the work of Herman Wold who impressed him with the use of the concept of causality (Bernert, 1983). Basically, Simon was interested in establishing the conditions under which a correlation between two variables provides sufficient evidence for inferring causal relations between them.

In 1954 Simon published his seminal article *Spurious correlation: a causal interpretation* in the *Journal of the American Statistical Association*. Inspired on

Wright's path analysis, Simon showed how, under certain assumptions, correlation might indicate causation. The idea was to check whether a particular causal model was consistent with a particular pattern of correlations. The importance of this article was its significant impact on sociological thinking regarding issues of causality, and its influence on other members of the sociological community.

Among the various sociologists influenced by Simon's thoughts was Hubert M. Blalock (Tomer, 2003) who was interested in establishing causation among variables by means of using statistical modeling. One of the contributions of Blalock was the expansion of Simon's work by considering more complex models and by examining partial correlations. By the early 1960s, Wold's causal modeling was incorporated into Blalock's theory and he began writing on causal models placing great emphasis on the prior theorizing that it is central to causal analytic methods. In 1964 Blalock published his book on *Causal Inferences in Nonexperimental Research*, considered one of the most influential works in the sociological field. In *Causal Inferences*, Blalock outlined methods for making causal inferences from correlational data as well as outlining problems in confirming these relationships. The concepts of Simon and Blalock were combined in the approach known as the Simon-Blalock method which is a technique of hypothesizing a theory and then testing it with correlational data, serving as an appropriate method for rejecting proposed models (Hackler, 1970).

A somewhat separate evolution of causal method culminated in Dudley Duncan's introduction of path analysis to sociology. In 1963, Otis Dudley Duncan and Robert Hodge were concerned with relating factors of education and occupational mobility. Their research examined antecedents of success in attaining education and jobs, by measuring variables such as social class of the family, past academic achievement, and social support as predictors of success. Their paper titled *Education and Occupational Mobility: A Regression Analysis*, can be considered the first application of Path Analysis in sociology although it was just a "primitive version of a path diagram" (Duncan, 1974).

Later, in 1964, after reading Blalock's book, Duncan decided to study Wright's path analysis seriously. As Duncan (1974) himself recognizes "It occurred to me that the specification of the Simon-Blalock approach was the same as the one Wright used". Duncan started to work in his paper *Path Analysis: Sociological Examples* that was finally published in 1966 which also included some suggestions made by the same Sewall Wright. By this time, Duncan had initiated correspondence with the econometrician Arthur Goldberger who had noted the similarity between sociological causal models and the simultaneous equation models used in econometrics. They began to collaborate and after various discussions they established that there were no real differences between Wright's approach and the one used in econometrics. Moreover, Duncan convinced Goldberger that sociologists were using methods that in fact were in both econometrics and psychometrics. Finally, they showed that path analysis models were closely related to the simultaneous equations models of econometrics, and the confirmatory factor analysis of psychology (Bernert, 1983).

It can be seen that around the 1960s there was a growing interest among sociologists for developing approaches that moved towards the causal understanding and modeling of non-experimental data. As Tomer (2003) indicates "methodological (errors in variables, multiple indicators, causality, testing theories) and philosophical considerations (measurement of theoretical concepts) intertwined" to generate an increasing interest in causal models that allow the development of a methodical framework to these topics.

Different publications on the application of path analysis began to bring together the confirmatory models of sociologists and the simultaneous equations models of econometricians. However, these first applications lacked a global approach for general application (Bentler, 1986).

The overall framework for general applicability was reached by Karl Jöreskog. Together with Duncan and Goldberger, Jöreskog had also seen that generalizations of the confirmatory factor analysis model led to a more general class of models involving analysis of covariance structure models. The collaboration of Duncan and Goldberger involved the organization in 1970 of a conference in Madison, Wisconsin, to which Karl Jöreskog was invited (Wolfe, 2003). It was in this conference that Jöreskog (1973) presented the first formulation of the Covariance Structure Analysis (CSA) for estimating a *linear structural equation system* which came to be known later as LISREL. The papers of the conference were published in Goldberger and Duncan's (1973) *Structural Equations Models in the Social Sciences* which included Jöreskog's (1973) paper in which he unified factor analysis, analysis of covariance structures, and linear structural equations modeling in a single general model (see Mulaik, 1986).

2.6 Development of PLS

As stated before, most of Wold's econometric work was related to estimation methods for simultaneous equations. However, unlike most of his contemporary colleagues, he always preferred to use methods based on least squares rather than maximum likelihood. Wold studied different estimation techniques using iterative procedures from which he developed a special method called the *fix-point algorithm* (Wold, 1973). Generally speaking, the fix-point (FP) method consists of an iterative algorithm of ordinary least squares (OLS) regressions to estimate the parameters of multi-equation systems.

In 1964, after one of his seminars on the FP method at the University of North Carolina, Wold decided to modify his algorithm in order to expand it for calculating principal components. As he himself recognized, this modification was accomplished through the remarks made from one of the participants of a conference, which gave Wold "the clue for computing principal components by an iterative procedure" (Wold, 1982a). Then, as an immediate step he also applied the algorithm to compute Hotelling's canonical correlations. This new method was first called NILES (Nonlinear Iterative Least Squares) (Wold, 1966a) but some time later it was changed to Nonlinear Iterative Partial Least Squares (NIPALS) (Wold, 1973a). With this algorithm Wold showed how to calculate principal components by means of an iterative sequence of simple ordinary least squares (OLS) regressions, as well as how to calculate canonical correlations with an iterative sequence of multiple OLS regressions.

In 1971, inspired by the results presented by Jöreskog on path models with latent variables, he realized that principal components and canonical correlation analysis could also be interpreted as path diagrams. He then started to analyze the possibility of estimating such models by adapting an appropriate generalization of his algorithms for principal components and canonical correlations. It took him five years of experimenting before PLS took its definitive shape which he called *Soft Modeling*. Herman Wold gives the end of 1977 as the birth date of PLS (Geladi, 1988). Wold presented his "soft model basic design" (Wold, 1982b) for the PLS estimation algorithm as an alternative to LISREL avoiding many of the restrictive hypotheses underlying maximum likelihood estimation techniques, i.e. multivariate normality and large samples (*hard modeling*). The concept of soft modeling technique refers to the overall situation for which PLS Path Modeling (PLS-PM) was conceived: working with non-experimental data, with complex information and data matrices with a large number of variables, with a lack of a solid prior theoretical knowledge and which was intended for causal-predictive modeling (Wold, 1969).

Despite the of advantage flexibility claimed over Covariance Structure Analysis, PLS-PM was not extensively used in econometrics nor in social sciences. Even though both approaches were developed at nearly the same time, their subsequent evolution was rather far from being parallel. The main reason for the divergence between both techniques is related with their software availability. CSA was provided with the LISREL program since the early 1970s and improved versions were released with ease-of-use interfaces. In contrast, PLS-PM lacked of a computer program for many years until Lohmöller's *LVPLS ver1.8* program appeared in 1987.

During the 1980s Jan-Bernd Lohmöller spent many years under Wold's advice and guidance, focused on the study of the PLS-PM methodology and its capabilities. As a result of his research, Lohmöller (1989) published a comprehensive treatise on PLS titled *Latent Variable Path Modeling with Partial Least Squares*. Also in the 1980s, research interests in PLS shifted from social sciences to applications in chemistry into what is now known as chemometrics (application of statistical methods to chemical data). The person responsible for this transition was Svante Wold, the son of Herman Wold. Svante together with Harald Martens developed yet another branch of the PLS techniques in analytical chemistry known as PLS regression (PLS-R).

2.6.1 The American Trend: Bookstein, Fornell, and Chin.

Although Professor Herman Wold visited different American universities and he dictated various seminars, the initial spread of PLS in USA was mainly carried out by Fred Bookstein. Professor Bookstein, an American biometrician, is the principal creator of morphometrics, a specialty that combines techniques of geometry, computer science, and multivariate statistics for analysis of biological shape variation, shape difference, and body parts (Bookstein *et al*, 1985). Being familiar with the work of Sewall Wright, Bookstein got involved with PLS through the study of path analysis, becoming interested in the geometrical aspects of PLS (Bookstein, 1982; 1990) and the singular value decomposition (Bookstein, 1986). He had developed a special PLS method called PLS singular vector analysis, which is considered to be an intermediate technique between PLS-PM and PLS regression.

While working as a professor at the University of Michigan, Bookstein introduced Claes Fornell (Fornell 2007, pp. 24), a business professor, to the PLS-PM methodology. Professor Fornell, a Swedish economist, was already working with structural equation models by CSA approach and he was especially interested in marketing applications. In 1982, Bookstein and Fornell published an article on marketing applications in customer satisfaction with a comparison of LISREL and PLS-PM. Since then, professor Fornell has been working on marketing applications of PLS-PM particularly in the topic of customer satisfaction measurement with the creation of the American Customer Satisfaction Index (ACSI).

Another important researcher related to the evolution of PLS-PM in USA is Professor Wynne Chin, who received his PhD in Computers and Information Systems

(Graduate School of Business Administration) from the University of Michigan. Together with Fornell, Chin is one of the leading references on PLS-PM with applications in marketing and Information Science. He developed the *PLS-Graph* software which is a windows-based package (based on Lohmöller's *LVPLS*) provided with a graphical user interface.

2.6.2 PLS and the French-style Data Analysis

Besides the direction taken by PLS-PM in the USA, a rather different evolution took place in Europe. As previously mentioned, a different version of PLS was developed by the Scandinavian chemometrics community with the development of PLS regression by Svante Wold and Harald Martens among others. Its widespread use and success in the chemical industry, accompanied by a powerful software, eclipsed the PLS structural equation modeling background. The multidimensional approach of PLS-R and its capability to deal with multiple data tables, large number of variables, prediction purposes, and missing data, attracted the attention of French statisticians in the beginnings of the 1990s. Professor Michel Tenenhaus was one of those statisticians and he became the primary researcher involved with the study of PLS techniques. During his research project on PLS, and due to his interests in business and management applications of data analysis techniques, Tenenhaus was referred to the work of Claes Fornell about the applications of PLS-PM in marketing and customer satisfaction. As a result of his amazing research, he published his book *La Régression PLS* in 1998.

The reason that explains the interest in the PLS techniques among the French data analysts is found in the general framework of the so-called French-style data analysis developed by Jean-Paul Benzécri. Data analysis *à la française* was developed based on a philosophical basis that accentuates the development of models that fit the data, rather than the rejection of hypotheses based on the lack of fit. Therefore, there are no statistical significance tests that are customarily applied to the obtained results. French-style data analysis (1) works with large amounts of data (large sets of variables), (2) it focuses not only on the variables but it also emphasizes the importance of individual observations, (3) it has an exploratory approach with geometric tools, and (4) it summarizes the information contained in data into new variables called components. These goals are accomplished by using dimension reduction techniques with multivariate projection methods such as component-based methods and cluster analysis among others. The idea is to reduce the complexity (dimensions) of highly dimensional data and provide the means with which to identify patterns or subjects in the data. In other words, data analysis is based on an inductive scheme. The underlying philosophy of the French standpoint can be summarized in one of the five data analysis principles of Benzécri (1973): "the model must follow the data, not the other way around" (i.e, the model must fit the data, and not vice versa). It is remarkable that these techniques rely exclusively on simple mathematical tools (linear algebra, regarding data from a geometrical point of view, without requiring a probabilistic model).

However, the strong descriptive and exploratory focus of French data analysis was not enough to have a complete understanding of reality. Explanation was also needed and it was important to take into account causal assumptions which are usually extracted from prior experience and/or some previously established theory. Thus, French analysts saw that the gap between exploration and explanation could be covered by PLS techniques without giving up the inductive scheme, geometrical context, and component-based (projections) methods. Hence, the connection between PLS and the general framework of the French style data analysis (multidimensional exploratory analysis) facilitated the rediscovery of the PLS approach of structural equation models with latent variables. It can be said that this situation gave a new impulse to the PLS techniques which have received further acknowledgement since the late 1990s. This impulse is reflected in the establishment of International Symposia on PLS and Related Methods in Jouy-en-Josas, France, in 1999; Anacapri, Italy, in 2001; Lisbon, Portugal, in 2003; Barcelona, Spain, in 2005; and As, Norway, in 2007. The first Symposium on PLS and Related Methods was organized by Michel Tenenhaus (HEC management school) and Alain Morineau (DECISIA group). Initially it was supposed to be a one time conference but Vincenzo Esposito Vinzi and Carlo Lauro from the University of Naples Federico II proposed to establish the tradition of holding the PLS symposiums every two years. In addition to the PLS symposia, another proof of the impulse on PLS-PM is the existence of several PLS-PM software solutions (*SmartPLS, XLSTAT-PLS, PLS-Graph, SPAD-PLS, PLS-GUI, VisualPLS*) that offer user friendly interfaces and interesting methodological capabilities.

2.7 Some remarks

The development of partial least squares path modeling was a long process, in which different aspects of the method were extracted from other methods and refined over a long period of trial and error. In the 1960s Herman Wold developed his NIPALS algorithm to calculate principal components and canonical correlations, and began applying different versions of the algorithm to various types of problems. This process took several years through which Wold and his research team experimented with different models before acquiring its definitive shape. The term *NIPALS modeling* can be found in the first applications of path models with latent variables (Wold, 1973), however, when the final version was presented at the end of 1977 Wold changed the *NIPALS modeling* term to the term of *Soft Modeling* (Wold, 1982a).

The name NIPALS was then used only to designate the algorithm for calculating principal components, whereas the application of the PLS algorithm to path models with latent variables was called soft modeling. However, during the 1980s some publications on soft modeling appeared under different names like *Partial Least Squares in Structural Modeling* in Fornell and Bookstein (1982), or *Partial Least Squares Path Analysis* in Noonan and Wold (1988). Also in the 1980s, the PLS techniques took a separate development in chemometrics with Heman’s son Svante Wold, and Harald Martens (Wold, 2001). The result of this new application was the PLS Regression (PLS-R).

The present term of “PLS Path Modeling” has been accepted following a suggestion from Harald Martens, in order to differentiate PLS-PM from PLS-R. Additionally, Svante (Wold *et al*, 2004) has given another conception to the PLS acronym: “Projection to Latent Structures”, in an attempt to clarify what PLS does in a geometrical sense (no matter which method is considered). Nowadays PLS is a highly developed body of methods, all based on the least squares (LS) optimization principle. It comprises of regression and classification tasks as well as dimension reduction techniques and modeling tools. The underlying assumption of all PLS methods is that the observed data is generated by a system (or process) which is driven by a small number of latent variables or factors (not directly observed or measured).