Use R !

J. Christopher Westland

Audit Analytics

Data Science for the Accounting Profession

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Foreword by Erik Brynjolfsson

I have known my colleague Chris Westland for nearly 25 years, and during this time, he has contributed a wealth of innovations in areas relevant to my own research. So it gives me great pleasure to write this foreword for his new book Audit Analytics which offers substantial contributions toward automation of the accounting profession. Audit Analytics addresses a number of topics that have been pivotal in my own research as Director of the MIT Initiative on the Digital Economy. I have investigated productivity contributions of information technology and the key roles of organizational capital and intangible assets all the while wishing that the accounting data on which I was so dependent had been more complete, informative, and reliable. Westland's book puts forth many of the tools and concepts that will allow accounting to provide future economists with more relevant, complete, and reliable data.

Chris is well-equipped to write this book. He is a Certified Public Accountant who has worked professionally as an auditor for Touche Ross (now Deloitte Touche Tohmatsu); he has been a prolific researcher in information technology, in statistics, in data science, and in financial accounting. He is the author of seven well-received books and is editor-in-chief of our top journal in electronic commerce. I can think of no one better suited to write a path-breaking book that brings together the latest innovations in data science, statistical information technology, and the practice of auditing.

This book is both timely and needed. Technological progress through improvements in computer hardware, software, and networks has been so rapid, and so surprising, that accounting and auditing, along with many other industries, are not keeping up. Accounting is now both global and technology-centric, yet accounting rules and regulations change slowly. Any change yields winners and losers—a difficult prospect in times of rising income inequality. Technology's promise of cost-effective audit automation accompanies wrenching change: jobs and skillsets transform, and wages diverge even as productivity and profits soar. The accounting profession is not spared this transformation.

Audit Analytics is directed toward today's practicing auditor, and consequently, its structure parallels that of an audit. It includes several topics that I have not seen previously in accounting texts—analysis of the complex statistical distributions of accounting transactions, and methods for using accounting reports in predicting future adverse events through statistical time-series and machine learning models, as well as an entertaining history of double-entry accounting prior to Pacioli. Chris's presentation of blockchain technology, along with R-code to implement a blockchain, is a welcomed reprieve from the vendor hype surrounding blockchain. This book is not just theory—Westland provides a wealth of software code to implement machine learning models, blockchains, "test decks," interactive scripts for management of the audit, and software to implement nearly all of the important tasks and decisions in an audit. The book provides a solid and concise founding in audit theory, along with practical implementations of auditing tasks and decisions using R-code.

Audit Analytics invokes a scientific perspective to support accounting and auditor opinions, based on treating audits as natural experiments. This perspective creates a statistical foundation for auditor hypotheses, evidence collection, and integration into decisions. Audit Analytics innovates in applying the latest machine learning models to identify subtle patterns in audit evidence that might escape traditional auditing methods. Rather than subjecting audits to intuitive assessments that can vary widely and inconsistently across auditors and audits, Westland applies modern methods in data science to make auditing a more rational, replicable, and reliable practice. In the best sense of the concept, Westland has learned how auditing can better race with the machines, using computers as allies rather than adversaries, concentrating on ways to accelerate organizational innovation and enhance human capital.

The growth of the digital economy has many consequences, among them a need for new and extended accounting systems. Income inequality and the rise in income of the world's top earners are controversial consequences of our move to a digital economy. Governments, tax policy, corporations, and social institutions will never be effective in addressing these without complete and reliable accounting data. We are not there yet.

I conveyed in my books with Andy McAfee, Race Against the Machine and The Second Machine Age, as well as my articles with Tom Mitchell, the dangers to policymakers and managers when they “fly blind” without good data. This has consequences when knowledge and skills divides lead to ever-widening wage gaps and lifestyles. Challenges confronting contemporary economists—intangible assets, network effects, wage, and skills inequalities—present significant research problems precisely because there is so little reliable data.

Over the years, my own research agenda has faced the challenge of a paucity of reliable economic evidence on the value of technology and information assets. I have needed to construct alternative non-accounting metrics, procure datasets from independent survey and investigative organizations, and put forth conjectures on underlying economic mechanisms to fill gaps created by underreporting of financial information in corporate accounting reports. Yet, any scientific study in economics and finance will benefit from reliable accounting data. Auditors are key arbiters and guarantors of that reliability—they verify that accounting systems are functioning, and that transaction capture reliably mirrors reality.

I believe that our future is bright, but only if it is inclusive, scientific, and informed. Otherwise, we will choose unrealistic futures based on convenient fictions, invented lies, and debunked ideas. The danger is that we will manage ourselves toward larger wage and skills gaps, wasteful “investments,” and counterproductive policy. Reliable accounting and auditing are the first steps in realizing this future.

Westland’s book will not be the final word in this quest, but it provides a first step by addressing shortcomings, gaps, and weaknesses in our audit systems. These, in turn, assure that accounting data feeds the larger universe of financial and economic analysis with reliable data, assuring accurate, reliable, credible predictions and policy recommendations. With accounting reports that are accurate, reliable, and complete, economics can do what it does best—provide the big-picture, strategic insights that yield a richer, more inclusive and more meaningful world for all.

Peter Drucker observed over a half-century ago in the Effective Executive that “Working on the right things is what makes knowledge work effective. This is not capable of being measured by any of the yardsticks for manual work.” Audit Analytics offers a cornucopia of yardsticks, implementing technology that makes them accessible to auditors—guarantors of the data that fuels much of our knowledge work. Westland’s prose is entertaining, with stories and insights to keep you turning pages. The software implementations may be challenging, but to auditors as well as researchers like myself, who regularly confront large, sparse, poorly formatted business datasets, the advances proffered by this book promise a future completeness of reporting and reliability of accounting data that in the past would not have been conceivable.

Audit Analytics epitomizes the future of auditing. We can no longer afford to pave the old cow-paths by computerizing audit methods that originated in the nineteenth century. Rather the fundamental tenets of accounting and auditing must be revisited in light of advances in data science and information technology, to address the needs of modern investors and stakeholders. Both in structure and content, Audit Analytics does an excellent job of defining the new tenets of accounting and implementing software solutions. Read it, run the code, and apply the ideas to your own work!

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Preface

I began my career in 1973 as a staff accountant in the Chicago office of Touche Ross (a predecessor firm to Deloitte Touche Tohmatsu). Computers were new to accounting in those days. IBM had introduced its System 360 in 1964 (S/360 referred to the architecture's wide scope: 360 degrees to cover the entire circle of possible uses). By 1973, these were becoming fixtures in the accounting systems of large corporations. Prior to Touche Ross, I had earned a large portion of my college expenses providing assistance in the use of the Compustat tapes (they were actually physical 9-track tapes in those days and also came as decks of 80-column Hollerith punched cards) on a Control Data 6600. Touche Ross decided I was well-suited to teach and develop applications for their bespoke auditing software—STRATA (System by Touche Ross for Audit Technical Assistance) and this is largely what I did during the rest of my tenure at Touche Ross.

My Compustat work provided me a prescient foundation in statistical computing which I would later apply to my auditing work. In those days, people were still calling computers "electronic brains" reminiscent of today's use of "artificial intelligence" to refer to machine learning. Applications of statistical computing to accounting were poorly taught, and reading matter on the subject was non-existent.

The Compustat story is itself worth retelling, as it played an important role in my education and has strong ties to Chicago. Compustat was the brainchild of Alfred Cowles III who came from an established publishing family; his father and uncle founded the Chicago Tribune and Cleveland Leader, respectively. For a short time after the First World War, Cowles successfully ran a Chicago investment firm that acquired and restructured small railroads. His firm also published a stock market newsletter providing fundamental analysis and recommendations on railroad stock issues as well as other investments. This was long before the Securities and Exchange Commission existed, let alone required annual audits and reliable financial reports. Ford Motor Company at the time, for example, only produced a balance sheet (unaudited) but not an income statement, despite being one of the largest firms in the USA. It was difficult to be a financial analyst in those days.

Diagnosed with tuberculosis in the late 1920s, Cowles consolidated his investments (just prior to the 1929 crash) and moved to Colorado Springs to improve his health. There, he filled his time developing linear regression models that simultaneously compared the predictions of 24 stock market newsletters to actual stock performance. Cowles quickly came to the conclusion that forecasters were guessing; that they offered little useful investment information and were more often wrong than right (he also applied his regression skills to investigate whether good climates, like Colorado Springs, improved the outcome of tuberculosis, with somewhat more optimistic results). The pen and paper calculation required at the time, for the regression formulas he used, soon exceeded his capabilities as a lone researcher. At this point, he made a decision to invest some of his fortune to create the Cowles Commission, an institution dedicated to linking economic theory to mathematics and statistics. To that end, its mission was to develop a specific, probabilistic framework for estimating simultaneous regression equations to model the U.S. economy. The Cowles Commission moved from Colorado Springs to the University of Chicago in 1939, where economist Tjalling Koopmans developed the systems of regression tools that Cowles originally had sought. This period also expanded Cowles personal files into what ultimately became the Compustat and CRSP databases and created the market index that eventually became the Standard & Poor's 500 Index. Cowles researchers developed many new statistical methods such as the indirect least squares, instrumental variable methods, full information maximum likelihood method, and limited information maximum likelihood. Eleven Cowles associates ultimately received the Nobel Prize in Economics.

The days of bespoke auditing software have passed; platforms, systems, and standards are too varied and change too quickly for this small market to be attractive to developers. The good news is that readily available open-source software now has much more power, flexibility, and ease-of-use than has ever been available, and these can be applied in the support of audit tasks. Circa 2020, Python, Java, and the R statistical packages are widely used open-source platforms for data analytics; TensorFlow and PyTorch are open-source packages for machine learning; and open-source packages such as LibreOffice provide spreadsheet capabilities. There currently are no comprehensive texts for their application in auditing, a fact which motivated the writing of this book. This book and its methods have grown out of an Audit Analytics course that I have taught at the University of Illinois—Chicago and previously at the Hong Kong University of Science and Technology. I have switched software platforms several times over the years but have settled on R, which has become my software package of choice for data analytics (I talk about motivations for my choice later in this book).

I am honored to be able to contribute my ideas and work in Gentleman, Hornik, and Parmigiani's *Use R!* series. Robert Gentleman and Ross Ihaka developed the R programming language at The University of Auckland in the mid-1990s. Hadley Wickham, who holds adjunct professorships at University of Auckland, Rice University, and Stanford University, has played a major role in developing the `tidyverse` packages, which I use throughout this book, and J.J. Allaire's `RStudio` has put the tools of data analytics within easy reach of nearly everyone. Researchers such as myself, who regularly confront large, sparse, poorly formatted business datasets, owe all of them multiple debts of gratitude for not only making our lives infinitely easier but also for making some of our research even possible at all.

The *Use R!* series is designed to make statistical computing tools and relevant algorithms readily available to practitioners. Since these books are written in `LaTeX` and R's `Bookdown`, code for figures and tables are easily placed on a website for sharing. I assumed, in writing this book, that the reader has a basic background in statistics (for example, as would be offered in Dalgaard's *Introductory Statistics with R*) and in data analytics (for example, as would be offered in Grolemund and Wickham's *R for Data Science*) and with basic principles of accounting (for example, as would be offered in Walther's *Principals of Accounting*). For the most part, I focus on the tasks faced by an auditor in public accounting, though offer some material that addresses other important topics in auditing.

How to Use This Book

The R language is not a typical language with a single core of developers and guidelines; rather, it is a sharing platform for a wide range of state-of-the-art data analytic functions—features which make it useful, dynamic, and sometimes messy. The effort put into familiarizing oneself with the R ecosystem will pay off many times over in access to the latest, most sophisticated algorithms that exist anywhere in industry.

The reader is assumed to have a basic knowledge of the R language, to be familiar with `help` screens, with online package support and documentation sites, and to be linked in with the large group of R experts at Internet resources like `Stack Overflow` and `R-bloggers`. These will be essential resources as the reader customizes the code examples offered in this text to their own particular needs. Much of the code in this text, particularly that presented in the Analytical Review chapter, depends on an ever-changing set of databases, streams, and standards. In some cases, packages will need to be loaded from `GitHub` rather than the official Comprehensive R Archive Network (CRAN) repositories; it is important that the reader consult these resources as well as CRAN.

In writing this book, I hope to provide the reader with an inventory of basic algorithms which can be easily expanded and customized to fit an auditor's specific challenges. Accessible and comprehensive tools for these additional approaches are covered in this book, as are research approaches to take advantage of the additional explanatory power that these approaches offer to auditing. Coverage of software, methodologies, and fit statistics provide a concise reference for the conduct of audits, helping assure that audit opinions and decisions are defensible, fair, and accurate.

The book files and chapter code are available at https://github.com/westland/auditanalytics and this can be installed as an R package as well.

Chicago, IL, USA J. Christopher Westland
January 2020

Contents

Fundamentals of Auditing Financial Reports

Auditing

An audit is an independent examination of the records of an organization to ascertain how far the financial statements as well as non financial disclosures, present a true and fair view of the concern. It also provides assurance that the systems of record-keeping are well-controlled and accurate as required by law. Auditing has become such a ubiquitous phenomenon in the corporate and the public sector that academics started identifying an "Audit Society" (Power 1997).

The earliest surviving mention of a public official charged with auditing government expenditure is a reference to the Auditor of the Exchequer in England in 1314 (Matthews 2006). The Auditors of the Imprest were established under Queen Elizabeth I in 1559 with formal responsibility for auditing Exchequer payments. Modern concepts of "auditing" grew out of practices from the sixteenth century English manorial accounting. The medieval Latin term was "auditus compoti" from Latin auditus "a hearing," at a time that literacy levels were low, and an official examination of accounts was presented orally.

Auditing initially existed primarily for governmental accounting and was concerned mostly with record-keeping rather than accounting procedures (Matthews 2006). It was not until the Industrial Revolution in the eighteenth century that auditing began evolving into a field of fraud detection and financial accountability.

The early twentieth century saw the standardization of 'auditors' testing methods and reporting practices and a growing role by banks and shareholders for public companies. Auditors developed a system for examining a representative sample of a company's transactions, rather than examining each transaction in detail, allowing audits to be completed in less time and at lower costs. By that time, audit findings were regularly presented as standard "Independent Auditor's Reports" accompanying a firm's financial statements.

Statistical sampling of transactions is now the industry standard in performing audits. As a consequence, computer tools to conduct statistical samples and opinions based on them are an integral part of modern auditing. It is only when gross errors or fraudulent activities are uncovered that comprehensive audits are performed. As businesses have increased in complexity, such "risk-based" auditing has evolved to make auditing more efficient and economical. Risk-based auditing starts by assessing whether an audit is even needed, based on a review of information in the financial statements. If the review finds adverse trends or irregularities, audit scope may be expanded accordingly. Through audits, stakeholders may effectively evaluate and improve the effectiveness of risk management, control, and corporate governance.

In the USA, audits of publicly traded companies are governed by rules laid down by the Public Company Accounting Oversight Board (PCAOB), which was established by Section 404 of the Sarbanes–Oxley Act of 2002. Such an audit is called an integrated audit, where auditors, in addition to an opinion on the financial statements, must also express an opinion on the effectiveness of a company's internal control over financial reporting, in accordance with PCAOB Auditing Standard No. 5.

Computers in Auditing and the Birth of Audit Analytics

When I received my undergraduate degree in statistics in 1971, the job market offered very little employment in statistics. Mainframe computers had just been introduced, and data resided on 80-column Hollerith cards. All data analyses were done on paper ledgers with adding machines. Microcomputers, cloud computing, and remote storage were yet to be invented. What a difference 50 years has made. For a growing number of people, data analysis is a central part of their job today.

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Increased data availability, more powerful computing, and an emphasis on analytics-driven decision in business has created a plethora of jobs in data science. There are around 2.5 million openings (and increasing) for data analytics jobs in the USA at any time.

A significant share of employees analyze data with Microsoft Excel or other spreadsheet programs like Google Sheets. Others use proprietary statistical software like SAS, Stata, or SPSS that they often first learned in school. While Excel and SAS are widely used tools, they have serious limitations. Excel conflates metadata (headings and descriptions) with formulas and data; and all are called "cells" in Excel. Furthermore Excel is horrendously slow, cannot handle datasets above a certain size, and does not easily allow for reproducing previously conducted analyses on new datasets. The main weaknesses of programs like SAS are that they were developed for very specific uses in the mainframe era of the 1970s and 1980s and have missed out on many of the newest developments in analytics. Nor do they have a large community of contributors constantly adding new tools.

For those who have reached the limits of Excel, SAS, and their ilk, there is a next step: learn R or Python. R and Python are the two most popular programming languages used by data analysts and data scientists. Both are free and open source and were developed in the early 1990s—R (an open-source version of the "S" language) for statistical analysis and Python (after Monty Python) as a general-purpose programming language. For anyone interested in machine learning, working with large datasets, or creating complex data visualizations, both have become standard tools for analysis.

Corporate computing offers more data analytics jobs requiring Python. In contrast, in academe, consulting, and finance, R offers an expanded set of data cleaning and analysis tools that are useful in one-off data analysis. Learning either requires a significant time investment—particularly if you have never coded before. Python is better for data manipulation and repeated tasks, while R is good for ad hoc analysis and exploring datasets.

Python tends to be in demand in companies run by computer scientists and with a code base, partly because it is easy to learn once you know other languages. Python is most useful for relatively routine, predictable processes. From pulling data, to running automated analyses over and over, to producing visualizations like maps and charts from the results, Python is the better choice.

R tends to be in demand in consulting fields where every report is ad hoc. Neither is a particularly efficient language from a purely operational standpoint; for that you would turn to C++. Over the past 5 years there has been substantial competition in offerings of interactive development environments (IDEs) to promote the use of either language. The R IDE is called R-Studio and is managed by J. J. Allaire (originally from South Bend, IN, and who developed the ColdFusion web development software many years ago). Python is supported on NetBeans and Eclipse IDEs through plugins; but the go to Python environment is Anaconda, which has its own version of Python, and supports R as well as other programs.

R is good for statistics-heavy projects and one-time analyses of a dataset. R is also more difficult to learn, as many of its conventions assume you have a solid background in statistics. Python conceptually uses the same control structures and data types that you will find in other languages, which is why computer scientists prefer Python. They see R as being more of a statistical tool that also happens to have a language, rather than a well-designed language before anything else (as Python arguably is). R has `Reticulate` that allows any program written in Python to be used in R; it also has `Rcpp` (written and maintained by Chicago's Dirk Eddelbuettel) that allows C++ programs to be used in R. Although powerful, R as a programming language may seem very unfamiliar and quirky to developers in more general-purpose languages.

No matter how brilliant your analyses are, if you cannot communicate them, they are worthless. Report writing, publication on webs, GitHub, and other outlets are all essential parts of being a data analyst. In support of this, R has the report writing tool called `knitr` (the author himself spells it with a lower case letter k). Python has its counterpart, `Jupyter notebooks` (which can be used with R now), and although they are conceptually similar, their intended purpose is quite different. Though not particularly well suited for exploratory analysis, `knitr` is a powerful tool for dynamic data report generation so much so that it is a worthy addition to any programmer's toolbox.

For example, assume you have a CSV file with some entries that you want to present to someone (or yourself) in some graphical way on regular basis. You can open it in Excel, add a pivot table and graphs; but assume then that you need to combine this data with one or more XML files and some more data in a database—this becomes a scripting task. Excel can still help, but it would be laborious. Python can also accomplish this, but you will need to learn quite a few libraries before you are ready. But `knitr` and `R Markdown` can easily generate PDF reports with all the graphical and data-processing tools of R included. Additionally, R segues statistics with machine learning, which is important since the concepts of machine learning and artificial intelligence derive from statistics. Much of the Python-based literature on machine learning completely misses underlying statistical concepts and consequently fails to be as effective as R in developing machine learning algorithms. It is written by computer scientists who understand well the Python scientific stack, and who will demonstrate the steps in rote manner of how to achieve a certain goal, but would not be able to impart much insight into what happens behind the scenes.

Much of the popular press "artificial intelligence" news you may read is a product of hackers who may understand "how" to program something, but along the way seem to have missed the "why?" and "what?" In contrast, books by authors who actually teach statistical curricula on which the machine learning practice is based and which skillfully elucidate deep theoretical foundations, all seem to exclusively presume basic to intermediate knowledge of R. If you are planning to work in machine learning, R is a much more worthwhile investment than Python.

The preceding are some of my admittedly biased opinions. I think R is the better language; but with the caveat that "your mileage may vary" and you should choose your own path. I firmly believe, though, that the extra effort in learning R will be rewarded tenfold if you intend to work in data analytics.

The Roots of Modern Financial Accounting and Auditing

Accounting and auditing are ancient, with many modern practices that are rooted in traditions that date back millennia. This section details the evolution of accounting, with explanations of how historical developments live on in idiosyncrasies of accounting and auditing today.

The earliest extant record of humans keeping track of numbers are the Lebombo Bones (several dozen have been found to date), which have been carbon dated to about 35,000 BCE. These are arguably the oldest known accounting computers. They are tally sticks with counting notches carved into a baboon's fibula, found in the Lebombo mountains located between South Africa and Swaziland.

In the middle of the ninth millennium BCE, communities began coalescing around marketplaces that eventually became the cities of antiquity. Accounting was practiced in the ancient Middle East by means of small counters—tokens modeled in clay in different shapes, each symbolizing a particular commodity. Their shapes include spheres, flat and lenticular disks, cones, tetrahedrons, and cylinders. These forms seem fully arbitrary and were decided based on the requirement of least production effort. They were easy to identify and replicate and embodied daily life commodities.

With stylized signs, all information could be recorded directly on clay tablets, which were cheaper and more portable than tokens. The earliest scribes served as lawyers and accountants in the early cities. They would record trade transactions, debts, and advances, in duplicate on clay tablets to be retained by the parties to the transaction. The earliest texts were pictographs on tablets written with a stylus, with accounting-specific writing systems evolving into more expressive systems that described politics, religion, and news.

Many commodities were exchanged in the early barter communities—silver, grain, and so forth based on standardized weighs, and thus establishing an absolute value for any particular item was complex and inexact. Under King Croesus of Lydia (in modern Turkey), the *touchstone* (mined from local riverbeds) was used to standardize the content of gold alloys, allowing standardized coinage and a single denomination for the price of any item. The earliest coins were blank droplets of metal of standard weight, issued by the treasury; later coins were stamped with punches for easy accounting. It was the custom of unmarried ladies in Lydia to sell their virtue in exchange for coins, in order to accumulate a dowry sufficient for them to marry. In this regard, accounting can credibly lay claim to being "the oldest profession."

The Kingdom of Lydia was short lived; but their idea of standardized coinage lived on, first in the Athenian silver drachma, and later the Roman Solidus, which provided Mediterranean trade with an unprecedented assurance of quality and value for a numéraire commodity—one which could be traded with all others. Issuing standardized coinage was a profitable business for government. Governments essentially take out non-interest bearing loans on the money they mint; in turn, this begot profitable industries in money changing, accepting deposits, and lending money at interest. Rome developed sophisticated financial and contracting systems for transport and trade, far-reaching tax collection, and a vast bureaucratic network.

Parallel developments in Asia saw China evolve from Cowry shells as standard coinage in the fifth century BCE, to copper coins in the Qin Dynasty period (third century BCE). Qin coins were practical—round with a square hole in the middle (for stringing together), which remained the common design for most Chinese copper coins until the twentieth century. Because of the low value of the coinage, seigniorage and government profits were substantial, as was the tax on transactions. The Qin Dynasty took a no nonsense attitude toward executing anyone caught making transactions with local coins, or any currency not sanctioned by the government; a policy revived in the Tang Dynasty when they introduced paper (tree bark) currencies.

The Roman Empire sank into medieval chaos after about the third century. Predicting the collapse of civilization, Boethius and Cassiodorus in the sixth century collected existing studies in mathematics (including accounting) into the quadrivium, comprising the four subjects of arithmetic, geometry, music, and astronomy. These were to be taught to Roman patricians in the monastic schools, which before Saint Benedict of Nursia were more or less safe country estates for offspring of the Roman elite. Until the fifteenth century, European accounting was static and unchanged from the Roman practices. Meanwhile in the Middle East, firstly the Umayyad Caliphate, and then the Abbasid Caliphate of Baghdad rapidly gained power over Central Asia by adopting our modern Arabic number system from India. This was a substantial improvement over the cumbersome notation of the Romans. It allowed easier additions and subtractions, as well as allowing accounting to extend itself to multiplication (for prices and cost allocations) and division (for rates). Baghdad became the world's center of accounting innovations.

Al-Khwarizmi Algebra of Double-Entry

In the Islamic world, the word account took on religious significance, relating to one's obligation to account to God on all matters pertaining to human endeavor. According to the Qur'an, followers are required to keep records of their indebtedness. Thus Islam provides general approval and guidelines for the recording and reporting of transactions. The Islamic law of inheritance defines exactly how the estate is calculated after death of an individual. The power of testamentary disposition is basically limited to one-third of the net estate (i.e., the assets remaining after the payment of funeral expenses and debts), providing for every member of the family by allotting fixed shares not only to wives and children but also to fathers and mothers. Clearly this requires ratios, multiplication, and division that were well beyond the scope of Roman numerals and abaci.

The complexity of Islamic inheritance law served as an impetus behind the development of algebra by medieval Islamic mathematicians. Al-Khwarizmı's "The Compendious Book on Calculation by Completion and Balancing" devoted a chapter on the solution to the Islamic law of inheritance using linear equations. In the twelfth century, Latin translations of al-Khwarizmı's "Book of Addition and Subtraction According to the Hindu Calculation" on the use of Indian numerals, introduced the decimal positional number system to the Western world. Hindu–Arabic numerals and algebra were introduced to Europe from Arab mathematics at the end of the tenth century by Pope Sylvester II and in the twelfth century by Fibonacci.

Al-Khwarizmı (Latinized as *Algorithmi* from which we derived the word "algorithm") introduced algebra (from the Arabic *al-jabr* meaning "restoration") to accounting, leading to three fundamental $accounting - algebreic$ concepts:

1. $Debits = Credits$: The "Bookkeeping equation" for error control, which is the accounting equivalent of algebraic manipulations on the left-hand and right-hand side of an equation.
2. $Assets = Liabilities + Owner's\ \ Equity$: "Real" accounts for tracking wealth, and the "basic accounting equation." An elaborate form of this equation is presented in a balance sheet that lists all assets, liabilities, and equity, as well as totals to ensure that it balances.
3. $Closing\ \ process$ where "Nominal" accounts for tracking activity are closed to $Owner's\ \ Equity$: Closing out these accounts at year end yields the *net income* (the owner's increment in wealth)—arguably the most important single statistic produced in the accounting process.

Algebra manipulates formulas around an equal sign, the only constraint being the formula on the right of the equal sign must have the same value as the formula on the left. Double-entry bookkeeping manipulates debit and credit balances around an equal sign, the only constraint being that the debits must have the same value as the credits. Accounting is applied algebra.

Though not specific in this regard, Al-Khwarizmı's book hinted at what were to become the standards for later accounting: error control (through double-entry), nominal accounts (which appear on the Income Statement) and real accounts (which appear on the Balance Sheet). Nominal accounts are revenue or expense accounts that are closed to a zero balance at the end of each accounting period. They start with a zero balance at the beginning of a new accounting period, accumulate balances during the period, and return to zero at the year end by means of closing entries. Nominal accounts are income statement accounts and are also called "temporary accounts" in contrast to balance sheet (asset, liability, and owners' equity) accounts that are called "permanent accounts" or "real accounts." Real accounts are asset, liability, reserve, and capital accounts that appear on a balance sheet. The balances of real accounts are not canceled out at the end of an accounting period but are carried over to the next period.

Al-Khwarizmı's method was an immediate hit and was widely disseminated throughout the educated world. In 756, the Abbasid Caliph Al-Mansur sent 4000 Arab mercenaries to assist the Chinese Tang Dynasty in the An Shi Rebellion. After the war, they remained in China and established an alliance with the Tang court where they were known as the Black-robed Arabs. The Tang Dynasty brought in Arab scholars and adopted Abbasid innovations in money and accounting. Trade flourished: the Tangs reopened the Silk Road and hugely expanded their maritime presence into the Persian Gulf and the Red Sea, into Persia, Mesopotamia, (sailing up the Euphrates River in modern-day Iraq), into Arabia, Egypt, Ethiopia, and Somalia in the Horn of Africa. They established the most extensive taxation system to date. Each citizen was taxed on iron and salt usage and owed the Dynasty corvée labor of 20 days a year. The state practiced the "equal-field system" in which most land was state owned and granted to individual farmers to prevent the formation of large estates. This allowed greater government control over the individual farmers but required a huge professional bureaucracy, including accountants selected by Imperial examination. The banknote was first developed in China in the Tang Dynasty during the seventh century, with local issues of paper currency. Its roots were in merchant receipts of deposit as merchants and wholesalers desired to avoid the heavy bulk of copper coinage in large commercial transactions. The Tang Dynasty paid local merchants with money certificates called “flying cash,” because of its tendency to blow away. These certificates bearing different amounts of money could be converted into hard cash on demand at the capital. Since they were transferable, they were exchanged among merchants almost like currency. The threat of penalties and possibly execution also encouraged merchants to use “flying cash.”

Abbasid and Tang innovations in accounting would have been much less influential were it not for the rise of the Mongol conqueror Genghis Khan and later his grandson Kublai Khan who were deeply influenced by the bureaucracy of the Tang Dynasty. Genghis and his progeny nearly conquered the known world in the thirteenth century. Germany lost nearly a million soldiers (most of its adult males) defending Europe against their invasion. Genghis Khan gave his accountants an unprecedented position of power in the Mongol Empire. When a city was sacked by Mongols, the accountants were the first to enter, tallying up the total asset value of the city (before soldiers could loot or pillage) from which the Mongols took 10%, to be allocated between the troops on well defined principles. Conquered cities were subjugated, then encouraged to remain going-concerns, so that they could be reliably tithed—in this the accountants also played a pivotal role.

The Caliphate of Baghdad had provided fertile ground for the advancement of mathematics at a time that Europe was stuck in the quadrivium. Many of the ancient libraries of Rome and Greece had been transferred to Baghdad, where scholars integrated the Hindu numerical notation into geometry and the algebra of linear and quadratic equations. These works were disseminated throughout the Abbasid Caliphate, including into Moorish Spain, making this body of knowledge accessible to Europeans in the colleges at Granada, Cordova, and Seville around the beginning of the twelfth century. The Italian mathematician Fibonacci became exposed to this knowledge traveling extensively throughout Egypt, Syria, Greece, and Sicily. He eventually returned to Italy to publish his *Liber Abbaci* (book of calculation), which promoted the use of Arabic numerals for calculations. The book was written in Latin during the year 1202 and was influential and widely read.

The introduction of double-entry bookkeeping into Europe is an interesting one in itself. Arabic numerals were known in Europe, but it was considered sinful to use them. For example, the statutes of the *Arte del Cambio* of 1299 prohibited the bankers of Florence from using Arabic numerals (even though they had been slipping them into documents since the tenth century just to ease calculations). Pope Sylvester II who reigned for three years at the turn of the millennium, endorsed and promoted study of Arabic arithmetic, mathematics, and astronomy, reintroducing the abacus to Europe. After his death, he was widely denounced as a sorcerer in league with the devil for exactly this reason.

It was into this politically and religiously charged atmosphere that the innovations in Fibbonaci’s *Liber Abbaci* started with merchants and bankers synthesizing alternatives to the abacus and daybooks of unwieldy Roman numerals. Fibbonaci himself was a merchant as well as a mathematician. He traveled extensively throughout the Mediterranean as a merchant prior to 1200. Not only did he encourage adoption of the Hindu–Arabic numerals for commercial accounting, but he actually set out an account contrasting completely the Roman figures versus the Arabic numerals.

Importantly, the Hindu–Arabic system mathematics also covered systems of equations, and these were in addition introduced into Spain by the Moors. From an accounting perspective, the conceptualization of debits and credits provided a generalization at the accounting systems (financial statement) level in addition to details at the transaction (journal entry) level. Equations—by definition—require an equality of two sides of the equation—on one side dependent variables, on the other independent. In an exchange transaction there is a natural dichotomization into independent variables (assets) and dependent variables (claims). These are reflected in the Latin words *debere* (to owe) and *credere* (to entrust), which are the basis for our modern words, *debit* and *credit*.

The Hindu–Arabic systems of equations were focused on equilibrium—in the balance sheet at any date, an equilibrium of exchange transactions is preserved. The use of an equilibrium device may at first have been pro forma. But it is easy to see how the change from ad hoc single-entry to equilibrium bookkeeping could lead to a complete double-entry system (particularly given European bankers’ early penchant for slipping Arabic numerals into their financial records, despite the fact that they might be accused of colluding with the devil). Once figures began to be disposed in a single column, instead of being scattered all over the page and reduced to order only outside the account-book on the abacus or in the mind, then the advantages of having two clearly separated columns, simply to facilitate computation, would quickly become apparent (De Roover 1956, 1955, 1938).

The Renaissance

For two centuries, during the rise of the great Italian banking centers of Genoa, Florence, and Venice, Italian banking recorded transactions, made loans, issued scripts, and carried on with numerous other financial activities that we would recognize today. Initially they used single-entry recording (date, and account affected), but this proved error prone as transaction volume increased. Fibbonaci's Liber Abbaci was widely read, and influential. Giovanni di Bicci de' Medici introduced double-entry bookkeeping for the Medici bank in the fourteenth century. By the end of the fifteenth century, merchant ventures in Venice used this system widely.

The fifteenth century also saw the invention of the printing press in Germany, and affordable, widely available reading glasses from Venetian glassmakers. Leo X's Vatican was an enthusiastic customer, where printing presses were used to churn out indulgences, and subsequently, Italy became a center of printing, book publishing, and literature. One of the first great texts on mathematics was published by a close friend of Leonardo da Vinci, Venetian Luca Pacioli, in 1494. *Summa de Arithmetica, Geometria, Proportioni et Proportionalita* (Everything About Arithmetic, Geometry and Proportion) formally described the widely used but still controversial system of double-entry for a much wider audience. Pacioli's Summa included one chapter titled, Details of Accounting and Recording that popularized the Method of Venice for accounting (an evolution of Al-Khwarizmi's method). Pacioli's Summa described the components of bookkeeping as: a memorandum book, journal, and ledger, with the journal and ledger similar to modern equivalents. A trial balance was used when the books were closed. The profit or loss was entered into the capital account to balance the balance sheet. Thanks to Gutenberg's printing press, Summa was published throughout Europe.

Pacioli's Summa was translated into the most commonly read vernaculars in Europe and was influential not only in investment and merchant ventures but in accounting in the great estates of Europe. Over the next 400 years it became the standard, in only slightly modified form, for accounting in all realms of business in Europe. Before the Industrial Revolution, China and India were the wealthiest economies in the world. Mughal India's annual revenues were twenty times that of France. In China, Qianlong demanded that Britain's ambassador Lord McCartney kowtow and informed him that China was in need of nothing from the West.

The Industrial Revolution

Europe was only a minor economic player in the world at the start of the Industrial Revolution in the late eighteenth century. England, and specifically Charles II, set out to change that. After the death of Oliver Cromwell in 1658, which resulted in his restoration, one of Charles II first tasks was to set up a body to move mathematics and the science forward in England. The Royal Society of London for Improving Natural Knowledge, known simply as the Royal Society, was founded in November 1660. Members of the Royal Society were initially chosen almost evenly from Parliamentarians, and Monarchists (leading some to believe that the Royal Society may have been a Masonic society). England was the first European country to place science and mathematics at the center of national policy. This was not merely an abstract goal. As a country with growing colonial and industrial ambitions, it needed better tools for navigation (clocks, sextants), for business (accounting, patents, methods), and government (statistics).

Modern businesses grew out of the cottage industries of the day. Home sewing grew into textile mills; mines became larger and more efficient. Goldsmiths' safes were used to hold the monetary deposits of merchants and others, using gold notes as receipts. These receipts evolved into banknotes and these new bankers loaned money and performed other banking tasks. Adam Smith chronicled the merits of specialization. Stock in businesses allowed operations to grow without limit as the technology became available for greater scale. The Bank of England was founded as a joint stock company and became the central bank of Britain.

Much of Britain's wealth depended on textiles and specifically the wool trade. The wool of British sheep was highly priced, and sheep owners in the Cotswolds and other areas became rich. Instead of selling all wool to continental merchants, the domestic system of textile manufacturing developed. Small farmers did the spinning, cleaning, and weaving in their homes. About half of the manufactured cloth was exported and a wealthy merchant class developed.

At this time manufacturing productivity levels were similar around the world and changed little over time. But the Industrial Revolution inched Britain's productivity growth up an average about 2% a year, pushing it to the largest economy in the world at the end of the nineteenth century. The factory system was invented for the textile industry. Power-driven machines required an army of laborers, working long hours at monotonous tasks in unsafe conditions for low wages. By 1800 most cotton manufacturing was done at factories. Cotton provided about half of Britain's exports well into the nineteenth century. By 1850 over 1900 factories were in the cotton industry with 330,000 workers, about 85% using steam and 15% using water power. The human toll was excruciating—the average age of death for a factory worker in 1800 was 17 (Bryson 2010).

The potter Josiah Wedgwood was keenly interested in the scientific advances of his day. It was this interest that underpinned his adoption of its approach and methods to revolutionize the quality of his pottery. His unique glazes began to distinguish his wares from anything else on the market. He was perhaps the most famous potter of all time. He built a successful business, but the depression years of 1770–1772 were financially difficult for Wedgewood—demand dropped, inventories rose, and prices had to be cut. He also found that his clerks were embezzling funds, while ignoring debt payments and other paperwork.

Wedgwood turned his creative genius toward a detailed examination of his company's transactions. He was interested in developing a system that would allow him to quickly discover inefficient operations and to identify sources of overhead. In the process, he discovered a long history of embezzlement by his head clerk. This resulted in a new clerk and weekly accounting reviews. Eventually, Wedgwood was able to calculate detailed costs for materials and labor for each step of manufacturing for each product. Overhead costs were analyzed and allocated to specific products. Wedgwood's early work in cost accounting influenced the understanding of industrial economics, as businessmen discovered that costs to produce some products were considerably more than for others, with profound effects on profitability. Economists evolved concepts of economies of scale and sunk costs. Wedgwood's own factory started to differentiate markets. Based on his cost accounting, demand became a primary factor for production and pricing. The market could be divided between high-price, high-quality, and high-cost products for elite customers, while a mass market was developed with low-cost and low-price pottery. Technology and mechanization were given roles in economic scaling. Wedgwood's cost accounting innovations allowed him to survive economic downturns where competitors could not.

The Birth of Modern Auditing

At the start of the nineteenth century, eleven Londoners listed their occupation as the archaic "Accomptants." As industry, mass transportation and capital markets expanded so did the need for accountants. Business regulation increased, and industry was often taxed heavily, promoting the need for professionals. The Bankruptcy Act of 1831 allowed accountants to be appointed "Official Assignees," the first government recognition of the new profession. A primary role became the preparation of accounts and the balance sheet of public companies. Bankrupt firms were especially likely to use their services, which increasingly served an audit function.

The British Companies Act of 1844 established the incorporation of business by a formal registration process. It required annual appointment of auditors to examine the accounts and balance sheet of all public companies (the role of accountants under the British Companies Act would change substantially over the century). The Companies Act of 1862 required banks to be audited and established the practice of limited cash dividends to be paid only out of profits. By 1900, the audit was the central practice of accountants. The earliest of the *Big Six* accounting firms were started in mid-nineteenth century London. William Deloitte opened a London firm in 1845. Samuel Price and Edwin Waterhouse formed their partnership in 1849. William Cooper started his firm in 1854, to be joined by his brothers in 1861. William Peat started in 1867. These men were active in establishing the Institute of Accounting in the 1870s, and a royal charter was granted in 1880. With the Institute and professional requirements to become Chartered Accountants, the profession of accountants was firmly established.

Many of the current methods in cost accounting were developed after 1880. The *Scientific Management* analysis of mass production was a major factor. Engineers using job analysis as well as time and motion studies determined "scientific" standards of material and labor to produce each unit of output. Complex machines required complex engineering and efficient use of workers to perform specialized and repetitive tasks. Standard costs became a significant efficiency measure. Frederick Taylor analyzed the best ways to use labor and machines, and standards were determined to minimize waste. The focus was on cost cutting rather than product quality. Actual costs could be compared to standard costs to measure performance, and the variances between actual and standard costs analyzed to determine potential corrective action. Measuring and allocating overhead costs also were major concerns of *Scientific Management*.

Prior to the 1950s, management used cost accounting information primarily for planning purposes; while operating control normally was based on non-accounting information. For example, Du Pont used ROI for planning, but control was based on factors such as timeliness of delivery to customers and product quality. Multidivisional business organizations became more pronounced, and businesses turned to decoupling—different production processes took place at different sites, perhaps thousands of miles away.

Public Accounting

Until the nineteenth century, firms tended to be small and raised money from partnerships, short-term bank loans, or profits. New industries from the early nineteenth century including canals, railroads, and utilities needed large amounts of capital from private sources. The English and American organized exchanges which provided the mechanisms for the needed cash. Parliament regulated business and capital markets through British Companies Acts. American regulations were based on state laws, which were not particularly effective, yet by the turn of the twentieth century, America overtook Britain as the leading industrial power in the world. Financiers provided the capital to establish large corporations and combinations and, as demonstrated by J. P. Morgan, maintained substantial power over industries. Insiders benefited from price fixing, stock manipulation, and various schemes of questionable legality. Accountants usually aided managers and speculators. Mergers, cutthroat competitions, railroad rebates, and bribery were some of the techniques used by businesses. Beginning with Standard Oil, the trust was used to acquire businesses across state lines. By 1890, 300 trusts controlled 5000 companies. By 1900, the largest dozen trusts had capital of over $1 billion. The investment bankers became directors (78 companies at J. P. Morgan).

Government regulation was demanded by the public, often subject to monopoly pricing and various predatory practices alone. Federal regulations began with the Interstate Commerce Commission (ICC) Act of 1887 to regulated railroads. Federal antitrust began with the Sherman Act of 1890. Following the panic of 1907, the USA experienced a decade of reform in legislation. The Clayton Act of 1913 prohibited interlocking directorships. The Federal Reserve was established the next year, as was the Federal Trade Commission (FTC).

Disclosure of financial information was voluntary. During the nineteenth and early twentieth century, the balance sheet was paramount. The income statement was neglected because it was open to abuse (no accounting standard regulations existed), and the concept of earnings power had to wait to the post-World War I period. At the turn of the century, the stock exchanges were dominated by the railroad industry (60% of NYSE firms at 1900, for example). They were considered safe investments because they paid fairly consistent dividends—ignoring bankruptcies that did occur in this industry. Industrial firms did catch on in the 1920s (44% of NYSE firms in 1920), and the income statement became more important as industrials tended to pay dividends based on earnings. Unfortunately, the Roaring Twenties also was a time of rampant speculation, with securities bought on credit and with little regard to underlying earnings power. Until 1910, the NYSE had an “unlisted department” for firms that disclosed no financial information. Although 90% of NYSE firms had audits in some form by 1926, audited financial statements were not required until 1933—when stock prices stood at 10% of 1929 highs. Insider trading was common and not illegal; “preferred list” sales of new securities at discounted prices were made before the issues went public; syndicated stock pools manipulated stock prices.

The U.S. economy, which hinged on farming, had been in trouble since the early 1920s. Waves of immigrant farmers plowed increasingly marginal land, creating dustbowls, and impoverishing local banks that lent to them. But since there were no national records, knowledge about the problem was scarce. When the stock market crashed, the regulators panicked. The Federal Reserve cut back the money supply, turning a recession and stock panic into a major depression. From 1929 until 1932, 11,000 banks failed, gross national product fell about 10% a year, steel production dwindled to 12% of capacity, and the unemployment rate hit 25%. The Hawley–Smoot Tariff Act dramatically increased tariffs, with effect being to limit world trade—which effectively made this a global depression. Franklin D. Roosevelt was President Hoover’s opponent in 1932, promising a New Deal. He won in a landslide and delivered. During the first 100 days, a remarkable amount of legislation was passed (some of it a holdover from the Hoover administration). The Glass–Steagall Act separated commercial from investment banking and created the Federal Deposit Insurance Corporation to insure bank deposits; the Social Security Act established retirement and disability pensions funded with payroll taxes.

New Deal legislation led to federal responsibility for protecting investors from malpractice in the investment markets with the Securities Act of 1933. The Act was modeled on state regulations, British Companies Acts, and earlier Congressional legislation. The Securities and Exchange Commission (SEC) Act of 1934 created the SEC to administer the legislation. The Securities Acts required companies to present registration statements with new public offerings of stocks, bonds, and other securities, to make “full and fair” disclosure of financial information. Information relevant to the “prudent investor” was to be disclosed in the registration statement. Antifraud and liability regulations increased the legal responsibilities of accountants, who became liable to the public as well as the management of the firms audited. Modern financial reporting and the development of generally accepted accounting principles (GAAP) started with this federal legislation. The SEC has the authority to regulate accounting. This was delegated to the private sector and the American Institute of Accountants (AIA—later the American Institute of Certified Public Accountants or AICPA). It gave the Committee on Accounting Procedure (CAP) the responsibility to issue accounting standards in 1938. The CAP’s standards were called Accounting Research Bulletins (ARBs) and from 1938–1959, 51 ARBs were issued. Few ARBs are still in effect, but the basic structure of financial accounting has not changed much from these initial standards. Both the accounting profession and the financial community cited the CAP and this was replaced by the Accounting Principles Board (APB) in 1959. This was another AICPA committee and had many of the same problems. The APB would issue 31 Opinions until they were superseded in 1973.

Emerging Technologies and Intangible Assets

Information technology plays a pivotal role in financial control and audit today. Most, if not all financial data is now digitally recorded, and dispersed among servers, clouds, and networks of computers, over which the audited firm has no control. Additionally, firm data particularly in finance, IT, insurance, and medicine now comprise most of the audited value of the firm. Financial audits are critical mechanisms ensuring the integrity of information systems and the reporting of organizational finances. They help avoid the abuses that led to passage of legislation such as the Foreign Corrupt Practices Act, and the Sarbanes–Oxley Act. They help provide assurance that International Accounting Standards are consistently applied in calculating firm value, while controlling asset market bubbles. Expanding audit challenges have fueled a growth market in auditing throughout the past decade. Both undergraduate and graduate accounting enrollments are at their highest level in the past 40 years, with accounting students making up 40% of business school enrollments (Fig. 1).

Graduate degrees are increasingly important to the profession, around 40% of accounting graduates hired by public accounting firms have graduate degrees. The second largest group and hired into public accounting had degrees in information technology and computer science. The most prestigious of the accounting firms, the largest accounting firms, the *Big Four*, have increased their intake substantially (Table 1).

The financial information sector of the USA and world economies are major contributors to jobs' growth and wealth. In 2018, it represented around 15% of the US economy (about 2 trillion dollars) and around 10% of the global economy (around 7 trillion dollars). In addition to accounting firms, large banks, rating agencies, funds, private investment, and many other fields require accounting expertise to function competitively in current markets. Increasingly that means expertise in information technologies as well.

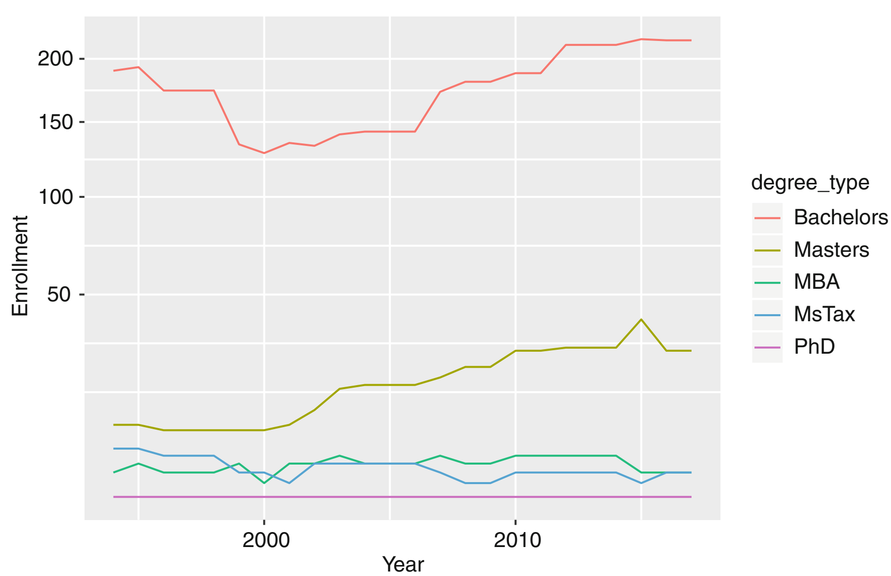

Fig. 1 Enrollments in audit degree programs, USA

Table 1 The 'Big Four' accounting firms (y/e 2018)

Firm	Revenues	Employees	Rev. per. emp	Headquarters
Deloitte	$43.2 bn	286,200	$150,943	United Kingdom
PwC	$41.3 bn	250,930	$164,588	United Kingdom
EY	$34.8 bn	260,000	$133,846	United Kingdom
KPMG	$29.0 bn	207,050	$139,870	Netherlands

Auditors have been grappling for many decades with calls to increase the scope of their audits to non-traditional measures of corporate performance financial forecasts, brand valuations, valuations of intangible assets, social accountability, and so forth. For the most part, they have rebuffed any efforts to expand auditing because of concerns over objectivity and the ability to provide sufficient reliability of their opinions (Aboody and Lev 1998; Lev 2001, 2004).

The stock market valuation of the Fortune 500 companies (which include many traditional industries such as oil and autos) has grown increasingly higher than the accountants book valuations over the past three decades. This is reflected in the growth of intangible assets, which may be loosely defined as valuable things the firm owns, like patents, skills, and so forth, that are not explicitly assessed in an audit, nor presented on the financial reports.

Tobin's q is the ratio between a physical asset's market value and its replacement value. It was first introduced by Kaldor (1966) and popularized by Nobel Laureate James Tobin. Values are supplied in the Federal Reserve Z.1 Financial Accounts of the United States, which is released quarterly. The average (arithmetic mean) q-Ratio is about 0.70. The chart below shows the q-Ratio relative to its arithmetic mean of 1 (i.e., divided the ratio data points by the average). This gives a more intuitive sense to the numbers. For example, the all-time q-Ratio high at the peak of the Tech Bubble was 1.61—which suggests that the market price was 136% above the historic average of replacement cost. The all-time lows in 1921, 1932 and 1982 were around 0.30, which is approximately 55% below replacement cost. The latest data point is 55% above the mean and now in the vicinity of the range of the historic peaks that preceded the Tech Bubble (Fig. 2).

Since the 1980s, accounting has evolved to focus less on physical things and more on intangibles and information. Information is increasingly the asset of value in firms, and IT provides the tools to manage, process, and deliver information products and services. In 1980, most of firm value was comprised of physical goods accounted for in the financial statements; by 2018, 40–80% of firms value was in unmeasured *intangible* assets. Much of this *intangible* value is held in databases, intellectual property, proprietary processes, and individual expertise.

Historically, book value was relatively accurate in assessing the value of a firm—up until the 1970s. The 1970s introduced "financial engineering" as exemplified by the conglomerate fad initiated by firms like LTV and Textron. Firms became harder to value from both an investment and an accounting perspective. The 1970s was also a period when Treasury rates approached 15%, and firms were feeling new competition from Asia. This pushed many firms into a negative equity position, which was only remedied by the availability of easy money in the 1980s. Since then, the growth of stock market valuations have steadily outpaced book value, at least partly reflecting the growth of intangible "knowledge" assets that are of value to investors but poorly tracked in accounting systems.

Information technology now plays a pivotal role in financial control and audit: most, if not all financial data is now digitally recorded and dispersed among servers, clouds, and networks of computers over which the audited firm has no control. Intellectual property, accounting, finance, IT, and risk data now comprise most of the value of the firm. Financial audits are critical mechanisms ensuring the integrity of information systems and accurate reporting. Over the past 30 years, the information intensive parts of the economy have been consistently more profitable than industries requiring heavy investment

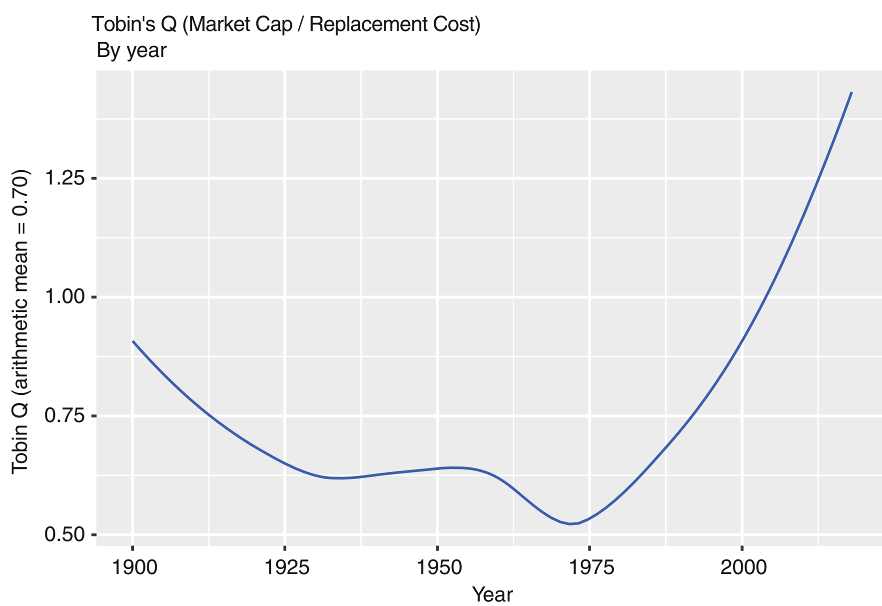

Fig. 2 Tobin's q (market cap/replacement cost)

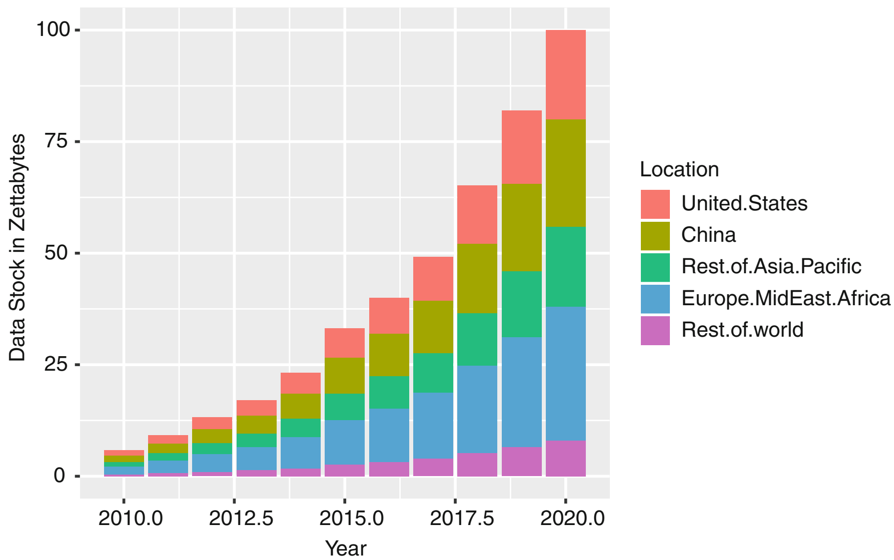

Fig. 3 Global stock of data assets (source: IDC)

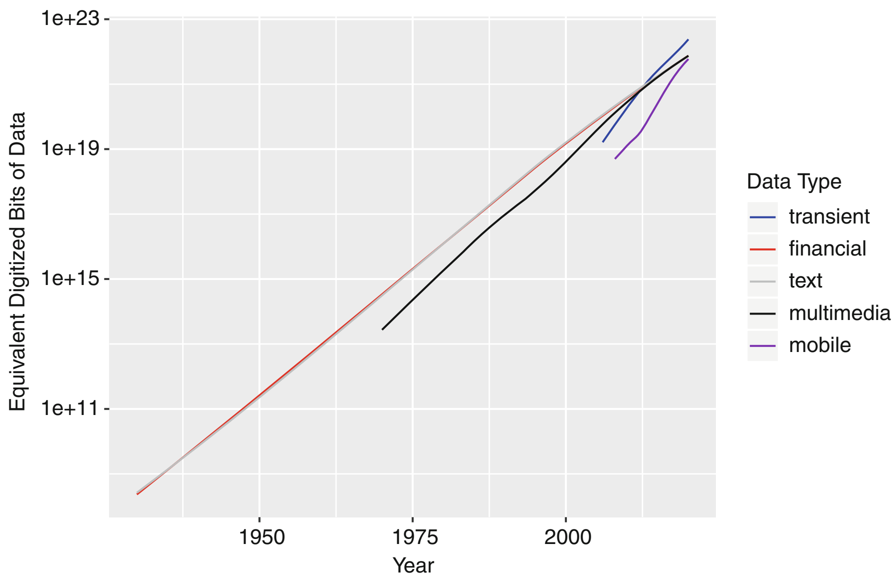

Fig. 4 Growth of data (source: EMC digital universe project)

in machinery and other fixed assets. Conclusion: return on investment is strongly correlated with investment in intangible assets.

The value of all the data in America is between \$1.5 and \$2 trillion, or around 5% of America's stock of private physical capital. The amount of data in the world has been growing exponentially for decades. The first human genome (three gigabytes of data, which nearly fills a DVD) was sequenced in 2003; by 2020 more than 25 million people had had their genomes sequenced. The latest autonomous vehicles produce up to 30 TB for every 8 hours of driving. IDC estimates that the world will generate over 90 ZB per year in 2020 (1 ZB = 1 trillion billion bytes), more than all data produced since the advent of computers (Figs. 3 and 4).

Data is approximately doubling every 2 years, in 2020, with about 20 trillion bytes of data for every person on earth. Spending on IT hardware, software, services, telecommunications, and staff, that could be considered the "infrastructure" of Big Data, is growing around 40% annually in the USA and China, and approaching that in the rest of the world. There has been a rapid migration of data from local islands of technology such as corporate servers, mainframes, personal computers, and portable devices toward data investment in targeted areas like storage management, security, and cloud computing. Data management often centers around the partitioning of data residence between "edge" computers and "cloud" servers.

The mode in which data is presented has changed dramatically over the past century. Most digitized data was in columnar spreadsheet format up through the 1980s. Increased bandwidth, storage, and processing power has allowed richer formats to dominate over the past two decades. Much of the information needed for effective auditing is now encapsulated in these more complex modalities.

Much of the growth in data has been driven by user creation through social networks and multimedia (videos, pictures, music). There is also a rapid growth in transient data. Phone calls that are not recorded, digital TV images that are consumed but not saved, packets temporarily stored in routers, digital surveillance images purged from memory when new images come in, and so forth.

Financial Accounting

Accountancy is the process of communicating financial information about a business entity to users such as shareholders and managers. The communication is generally in the form of financial statements that show, in money terms, the economic resources under the control of management; the art lies in selecting the information that is relevant to the user and is reliable. The principles of accountancy are applied to business entities in three divisions of practical art, named accounting, bookkeeping, and auditing. Accounting is defined by the American Institute of Certified Public Accountants (AICPA) as "the art of recording, classifying, and summarizing in a significant manner and in terms of money, transactions and events which are, in part at least, of financial character, and interpreting the results thereof." Today, accounting is called "the language of business" because it is the vehicle for reporting financial information about a business entity to many different groups of people. Accounting that concentrates on reporting to people inside the business entity is called management accounting and is used to provide information to employees, managers, owner-managers, and auditors. Management accounting is concerned primarily with providing a basis for making management or operating decisions. Accounting that provides information to people outside the business entity is called financial accounting and provides information to present and potential shareholders, creditors such as banks or vendors, financial analysts, economists, and government agencies. Because these users have different needs, the presentation of financial accounts is very structured and subject to many more rules than management accounting. The body of rules that governs financial accounting in a given jurisdiction is called Generally Accepted Accounting Principles, or GAAP. Other rules include International Financial Reporting Standards, or IFRS, or US GAAP. Accounting standards have historically been set by the American Institute of Certified Public Accountants (AICPA) subject to Securities and Exchange Commission regulations. The AICPA first created the Committee on Accounting Procedure in 1939 and replaced that with the Accounting Principles Board in 1951. In 1973, the Accounting Principles Board was replaced by the Financial Accounting Standards Board (FASB) under the supervision of the Financial Accounting Foundation with the Financial Accounting Standards Advisory Council serving to advise and provide input on the accounting standards. Other organizations involved in determining United States' accounting standards include the Governmental Accounting Standards Board (GASB), formed in 1984, and the Public Company Accounting Oversight Board (PCAOB).

In 2008, the FASB issued the FASB Accounting Standards Codification, which reorganized the thousands of US GAAP pronouncements into roughly 90 accounting topics. In 2008, the Securities and Exchange Commission issued a preliminary "roadmap" that may lead the USA to abandon Generally Accepted Accounting Principles in the future and to join more than 100 countries around the world instead of using the London-based International Financial Reporting Standards. As of 2010, the convergence project was underway with the FASB meeting routinely with the IASB. The SEC expressed their aim to fully adopt International Financial Reporting Standards in the USA by 2014. With the convergence of the US GAAP and the international IFRS accounting systems, as the highest authority over International Financial Reporting Standards, the International Accounting Standards Board is becoming more important in the US.

The Products of Accounting: Financial Statements

There are four main financial statements. They are (1) balance sheets, (2) income statements, (3) cash flow statements, and (4) statements of shareholders' equity.

Balance sheets show what a company owns and what it owes at a fixed point in time. Income statements show how much money a company made and spent over a period of time. Cash flow statements show the exchange of money between a company and the outside world also over a period of time. The fourth financial statement, called a "statement of shareholders' equity," shows changes in the interests of the company's shareholders over time.

The Balance Sheet

A balance sheet provides detailed information about a company's assets, liabilities, and shareholders' equity. Assets are things that a company owns that have value. This typically means they can either be sold or used by the company to make products or provide services that can be sold. Assets include physical property, such as plants, trucks, equipment, and inventory. It also includes things that cannot be touched but nevertheless exist and have value, such as trademarks and patents. And cash itself is an asset. So are investments a company makes. Liabilities are amounts of money that a company owes to others. This can include all kinds of obligations, like money borrowed from a bank to launch a new product, rent for use of a building, money owed to suppliers for materials, payroll a company owes to its employees, environmental cleanup costs, or taxes owed to the government. Liabilities also include obligations to provide goods or services to customers in the future. Shareholders' equity is sometimes called capital or net worth. It is the money that would be left if a company sold all of its assets and paid off all of its liabilities. This leftover money belongs to the shareholders, or the owners, of the company. A company's balance sheet is set up like the basic accounting equation shown above. On the left side of the balance sheet, companies list their assets. On the right side, they list their liabilities and shareholders' equity. Sometimes balance sheets show assets at the top, followed by liabilities, with shareholders' equity at the bottom. Assets are generally listed based on how quickly they will be converted into cash. Current assets are things a company expects to convert to cash within 1 year.

A good example is inventory. Most companies expect to sell their inventory for cash within 1 year. Noncurrent assets are things a company does not expect to convert to cash within 1 year or that would take longer than 1 year to sell. Noncurrent assets include fixed assets. Fixed assets are those assets used to operate the business but that are not available for sale, such as trucks, office furniture, and other property. Liabilities are generally listed based on their due dates. Liabilities are said to be either current or long term. Current liabilities are obligations a company expects to pay off within the year. Long-term liabilities are obligations due more than 1 year away.

Shareholders' equity is the amount owners invested in the company's stock, plus or minus the company's earnings or losses since inception. Sometimes companies distribute earnings, instead of retaining them. These distributions are called dividends. A balance sheet shows a snapshot of a company's assets, liabilities, and shareholders' equity at the end of the reporting period. It does not show the flows into and out of the accounts during the period.

The Income Statement

An income statement is a report that shows how much revenue a company earned over a specific time period (usually for a year or some portion of a year). An income statement also shows the costs and expenses associated with earning that revenue. The literal "bottom line" of the statement usually shows the company's net earnings or losses. This tells you how much the company earned or lost over the period. Income statements also report earnings per share (or "EPS"). This calculation tells you how much money shareholders would receive if the company decided to distribute all of the net earnings for the period.

Cash Flow Statements

Cash flow statements report a company's inflow and outflow of cash. This is important because a company needs to have enough cash on hand to pay its expenses and purchase assets. While an income statement can tell you whether a company made a profit, a cash flow statement can tell you whether the company generated cash. A cash flow statement shows changes over time rather than absolute dollar amounts at a point in time. It uses and reorders the information from a company's balance sheet and income statement. Cash Flow Statements may be generalized to Working Capital Statements, which replace cash in the calculations, with more general Current Assets and Current Liabilities, both of which are expected to expire within the operating cycle (typically 1 year) and thus are what would be called "near-cash." The bottom line of the cash flow statement shows the net increase or decrease in cash for the period. Cash flow statements are divided into three main parts. Each part reviews the cash flow from one of three types of activities: (1) operating activities, (2) investing activities, and (3) financing activities.

The Methodology of Accounting

Financial accounting is the vehicle through which firms can record and report important economic transactions that affect their wealth. It is a quasi-axiomatic system where fundamental "principles" are loosely applied to the recording of economic events (transactions) that affect firm wealth. These detailed transactions are summarized into accounts based on a firm-specific classification called the Chart of Accounts. The accounts are further organized and summarized for reporting in accordance with generally accepted accounting principles (GAAP).

The accounting perspective in practice today derives from Al-Khwarizmi's eighth century system of algebraic balancing and arithmetic manipulation. The system is inherently linear—prices and costs are assumed to be additive and generally are considered fixed across transactions. But in practice, many economic processes are non-linear and data may be incomplete and inaccurate. Consequently, modern accounting reports are economic approximations that are made to facilitate tractability and scalability in accounting systems. The perspective adopted by modern auditors reflects trade-offs made in accounting reports, and many standard audit procedures accommodate the inherent uncertainty of financial accounting.

Generally Accepted Accounting Principles (GAAP)

Generally Accepted Accounting Principles (GAAP) refer to the standard framework of guidelines for financial accounting used in any given jurisdiction, generally known as accounting standards. GAAP includes the standards, conventions, and rules accountants follow in recording and summarizing, and in the preparation of financial statements. Financial Accounting is information that must be assembled and reported objectively. Third-parties who must rely on such information have a right to be assured that the data is free from bias and inconsistency, whether deliberate or not. For this reason, financial accounting relies on GAAP. Principles derive from tradition, such as the concept of matching. In any report of financial statements (audit, compilation, review, etc.), the preparer/auditor must indicate to the reader whether or not the information contained within the statements complies with GAAP.

Theory

The basic accounting equation is assets = liabilities + stockholders' equity. This is the balance sheet. The foundation for the balance sheet begins with the income statement, which is revenues − expenses = net income or net loss. This is followed by the retained earnings statement, which is beginning retained earnings + net income − dividends = ending retained earnings or beginning retained earnings − net loss − dividends = ending retained earnings.

Assumptions

1. Accounting Entity: assumes that the business is separate from its owners or other businesses. Revenue and expense should be kept separate from personal expenses.
2. Going Concern: assumes that the business will be in operation indefinitely. This validates the methods of asset capitalization, depreciation, and amortization. only when liquidation is certain is this assumption not applicable.
3. Monetary Unit principle: assumes a stable currency is going to be the unit of record. The FASB accepts the nominal value of the US Dollar as the monetary unit of record unadjusted for inflation.
4. The Time-Period principle implies that the economic activities of an enterprise can be divided into artificial time periods.

Principles

1. Historical cost principle requires companies to account and report based on acquisition costs rather than fair market value for most assets and liabilities. This principle provides information that is reliable (removing opportunity to provide subjective and potentially biased market values), but not very relevant. Thus there is a trend to use fair values. Most debts and securities are now reported at market values.
2. Revenue recognition principle requires companies to record when revenue is (1) realized or realizable and (2) earned, not when cash is received. This way of accounting is called accrual basis accounting.

3. Matching principle. Expenses have to be matched with revenues as long as it is reasonable to do so. Expenses are recognized not when the work is performed, or when a product is produced, but when the work or the product actually makes its contribution to revenue. Only if no connection with revenue can be established, cost may be charged as expenses to the current period (e.g., office salaries and other administrative expenses). This principle allows greater evaluation of actual profitability and performance (shows how much was spent to earn revenue). Depreciation and Cost of Goods Sold are good examples of application of this principle.
4. Full Disclosure principle. Amount and kinds of information disclosed should be decided based on trade-off analysis as a larger amount of information costs more to prepare and use. Information disclosed should be enough to make a judgment while keeping costs reasonable. Information is presented in the main body of financial statements, in the notes or as supplementary information

Constraints

1. Objectivity principle: the company financial statements provided by the accountants should be based on objective evidence.
2. Materiality principle: the significance of an item should be considered when it is reported. An item is considered significant when it would affect the decision of a reasonable individual.
3. Consistency principle: means that the company uses the same accounting principles and methods from year to year.
4. Conservatism principle: when choosing between two solutions, the one that will be least likely to overstate assets and income should be picked.

The Accounting Process and Major Document Files

Accounting Entries and Document Files

Al Khwarizmi's algebraic method of balancing accounting entries developed into the standards for error control, nominal accounts, and real accounts that became universal in accounting. By the twelfth century, Fibonacci had codified and circulated these in Latin. This work was popularized by another Italian, Luca Pacioli, in the fifteenth century in one of the first printed and widely distributed texts on business mathematics. This is the double-entry bookkeeping method we use today, which is conceived in terms of debits and credits. Pacioli's most important contributions were

1. In deciding which account has to be debited and which account has to be credited, the processes of balancing and completion follow the accounting equation: Equity = Assets − Liabilities.
2. The accounting equation serves as an error detection tool. If at any point, the sum of debits for all accounts does not equal the corresponding sum of credits for all accounts, an error has occurred.
3. In the double-entry accounting system, each accounting entry records related pairs of financial transactions for asset, liability, income, expense, or capital accounts.
4. A document file that records economic events that result in an increase or decrease in wealth of the firm is called a Journal, and the transaction is the Journal Entry.
5. Pacioli's term for a Journal is a "Daybook"—a term that was used up to the twentieth century in accounting.

The system popularized by Pacioli has become the standard fare for introductory accounting courses around the world. For the purpose of the accounting equation approach, all the accounts are classified into the following five types: assets, liabilities, income/revenues, expenses, or capital gains/losses. If there is an increase or decrease in one account, there will be equal decrease or increase in another account.

Books of Accounts

Each financial transaction is recorded in at least two different real ledger accounts within the financial accounting system, so that the total debits equals the total credits in the general ledger, i.e., the accounts balance. The transaction is recorded as a "debit entry" (Dr.) in one account, and a "credit entry" (Cr.) in a second account. The debit entry will be recorded on the debit side (left-hand side) of a general ledger, and the credit entry will be recorded on the credit side (right-hand side) of a