4. Frederick R. Macaulay, Frank M. Redington and the Emergence of Modern Fixed Income Analysis

Geoffrey Poitras

The roots of fixed income analysis stretch back to antiquity, e.g., Poitras (2000); Homer and Sylla (1991). Some of the earliest examples of written language – Sumerian cuneiform tablets – involved contracts for fixed income transactions (Einzig 1970). From the Dark Ages to the Enlightenment, debates over restrictions on the payment of interest were central to the social and economic evolution of Western civilization. Intellectual progress associated with analysis of fixed income transactions includes the solution of higher order algebraic equations in the 14th and 15th centuries and the introduction of decimal fractions by Simon Stevin in the 16th century for use in compound interest tables. Modern principles of life insurance and actuarial science can be traced to the use of discounted expected value to price life annuities by Jan de Witt in the 17th century and the development of insurance mathematics by Abraham de Moivre and Thomas Simpson in the 18th century. With this lineage, identification of 20th century developments in fixed income analysis is an essential element for a book on the pioneers of financial economics. While the second half of the century features developments in fixed income derivatives and innovative security designs, this chapter focuses on earlier seminal contributions associated with measuring the adjusted term to maturity and immunizing fixed income portfolios against interest rate changes. The individuals

associated with the introduction of these contributions are the American economist Frederick Robertson Macaulay (1882-1970) and the English actuary Frank Mitchell Redington (1906-1984).

1. Fixed Income Market Overview

In modern financial markets, the expression 'fixed income' security appears to be a misnomer, e.g., Tuckman (1995, p.viii). A wide variety of securities in this class have cash flows that vary over time, depending on factors such as the level of interest rates and other contingencies that can include mortgage prepayments or common stock prices, e.g., Poitras (2005, ch.4). While the types of fixed income securities available for purchase have changed over time and a wider variety of security designs are now available, essential characteristics of securities in this class still remain. In the 18th century, for example, long term government fixed income issues were dominated by life annuities, term annuities and perpetuities, e.g., Dickson (1967); Goetzmann and Rouwenhorst (2005). In addition to the cash flow variability associated with the contingency embedded in a life annuity, refunding operations and other types of debt restructuring produced variability in the cash flows for perpetuities and term annuities. Recognizing that interest rate levels were relatively less volatile at that time, investors seeking cash flows that varied with interest rates could rollover a number of short term fixed income securities, such as government issued 'exchequer bills' or private sector demand loans.

A number of definitions for a fixed income security are possible. The most elementary definition includes all securities that offer a regular fixed payment. This includes: preferred stock; money market securities; various types bonds – including convertible, callable, and straight bonds; annuities – including perpetuities, life annuities, personal loans and mortgages; whole life and defined benefit pension plans; and, derivative trading strategies with fixed income payoffs, such as covered option

writing strategies. Fixed income analysis involves the pricing and management of fixed income securities and portfolios of these securities, including fixed income derivatives. In addition to being a fundamental part of financial economics, fixed income analysis is also central to actuarial science and elements of the subject are important in accounting, theoretical macro and micro-economics, and public policy analysis. Important historical contributions have come from a wide range of subject areas, providing a diverse intellectual foundation for fixed income analysis.

Compared to fixed income markets in the early 20th century, present day markets are characterized by a wider range of security designs and issuers, substantially higher trading volumes and market access, vastly increased quality and quantity of market information and significantly higher interest rate volatility. Yet, as illustrated by Graham and Dodd (1934, p.618-31), the variety of fixed income security designs in the early part of the century went substantially beyond the traditional"straight" bond, that offers a fixed sequence of coupon cash flows paid at regular intervals over a stated term to maturity and a return of principal on the maturity date. Some security designs would be novel even in the present day, e.g., bonds with coupon payments subordinated to preferred stock dividends. In the US, prior to the Securities Act of 1933, the legal protection for fixed income securities was provided primarily by the bond indenture contract. Bond investment was sufficiently risky that various states enacted legislation to prohibit state chartered financial institutions from purchasing bonds issued by certain classes of issuers. For example, New York state prohibited purchase of bonds issued by: foreign governments and corporations; street railway and water companies; all industrial companies; and bonds of financial companies (Graham and Dodd 1934, p.91-9).

Though legal protections and the quality of financial reporting by issuers prior to the Securities Act of 1933 paled by comparison with modern standards, bond investors did have access to various

helpful information outlets. In 1889, traditional print sources of US security market information – most notably *The Commercial and Financial Chronicle* and the various *Poor's Manuals* – was supplemented by the first appearance of the *Wall Street Journal*. During the 1890's financial reporting was strengthened by the New York Stock Exchange (NYSE) introducing a requirement that listed firms publish annual reports. In 1900, John Moody & Company was founded and commenced the publication of *Moody's Manual of Industrial and Miscellaneous Securities*, the first of a long line of such authoritative publications. After an initial false start, in 1909 Moody's became the first firm publishing letter grade credit ratings for publicly traded securities – extending a practice that was used in the credit-reporting arena. In 1906, the Standard Statistics Bureau was formed to provide "previously unavailable financial information on U.S. companies". The use of letter grade ratings for corporate bonds by Standard Statistics was introduced in 1916.[1]

By the time that Graham and Dodd (1934) appeared, the bond investor had access to a considerable array of authoritative information sources, so many that Graham and Dodd (1934, p.41) found it "impossible to discuss or even list all the sources of information which the analyst may find it profitable to consult". The availability of sufficient data provided a precondition for more detailed statistical and theoretical analysis "relating to bond yields, interest rates, stock prices, commodity prices, bank clearings and pig iron production" (Macaulay 1938, p.xii). It was this task that initially motivated Frederick Macaulay to undertake his monumental National Bureau of Economic Research (NBER) study (Macaulay 1938) containing the contribution that earned the eponym: Macaulay duration. Modern references to Macaulay invariably fail to recognize that the duration concept was introduced in the preliminary discussion of factors influencing bond yields and played no significant role in the empirical results that formed the core of the presentation. Similarly, the relationship of

Macaulay (1938) to the broader institutionalist approach to economics, pioneered by Wesley Clair Mitchell (1874-1948) and other members of the NBER staff, is also unrecognized.

2. Macaulay, the NBER and Institutionalism

Following closely on the heels of the manifesto of institutional economics – Hamilton (1919) – the establishment of the National Bureau of Economic Research (NBER) in 1920 was an important milestone in the emergence of institutionalism as, arguably, the dominant school in American economics in the inter-war period. While institutionalism as an intellectual force was not able to recover from the post-WW II 'measurement without theory' criticism leveled by Koopmans (1947) and others, this school of economic thought made contributions to the conduct of economic policy and government practice that survive to present. Following Rutherford (2001), the institutionalist agenda emerged in the immediate aftermath of WWI and was propelled by a desire to support an enhanced role for government in the economy to achieve much needed social and economic reform. This created a demand for improved economic data and policy analysis that were the touchstones of institutionalism. Proposing a "modern" and "scientific" empirical approach analogous to that used in the natural sciences, institutionalism aimed to replace the theoretically driven neoclassical approach to economics that dominated economics prior to WWI, e.g., Yonay (1994).

While Thorstein Veblen (1857-1929) is often recognized as the "intellectual inspiration for institutionalism" (Rutherford 2001, p.174) and John R. Commons (1862-1945) is credited with playing a key role after 1924, it is Wesley Mitchell that served as a founding father of the movement, as a guiding light during its development and as the originator of the most significant intellectual contribution of the movement, the empirical measurement of business cycles.[2] Mitchell received his college education and, in 1899, a doctorate from the University of Chicago. During this time he

studied with and was deeply influenced by Veblen, J. Laurence Laughlin (1850-1933), the monetary economist, and John Dewey (1859-1952), the influential philosopher, psychologist and educational reformer. After a brief term at the Bureau of the Census and two years teaching at Chicago, in 1903 Mitchell followed one of his former teachers, Adolph Miller, to the University of California at Berkeley where, apart from a few brief excursions, he stayed until 1912. During this time Mitchell produced *Business Cycles* (Mitchell 1913) a book which Arthur Burns (1952,p.22) describes as "one of the masterpieces in the world's economic literature". Together with *Business Cycles: The Problem and Its Setting* (1927) and *Measuring Business Cycles* (1946, with Arthur Burns), these three books are Mitchell's definitive work on the subject that still epitomizes his career, e.g., Klein (1983).

Mitchell joined the faculty of Columbia University in 1913. Except for a brief period of government service at the end of WWI and three years as a lecturer at the New School for Social Research (1919-1921), Mitchell was a member of the faculty at Columbia until his retirement in 1944. It was during the New School period that Mitchell was instrumental in organizing the NBER, where he served as Director of Research until he resigned in 1945. From the founding of the NBER, "the National Bureau was the focus of his intellectual interest, the emotional center of his own work, and the work responsibility that lay closest to his inner life" (Burns 1952, p.102). The NBER was established with grants totaling $24,000 with which Mitchell was able to hire a small research staff to undertake the first major study on the size, growth, fluctuation and distribution of national income. The initial research staff for the national income study had three members: Willford King, Oswald Knauth and Frederick Macaulay. Though the published results of this study (Mitchell 1921-2) appeared within three years, there were a number of follow-on business cycle projects generated by

this initial effort. Among these special studies that got underway in the early 1920's was one on the cyclical fluctuations in interest rates undertaken by Macaulay (Fabricant 1984).

Unlike Mitchell who has been the subject of numerous detailed biographical studies, information on the life and times of Frederick Robertson Macaulay is scarce. He was born in Montreal in 1882, making him a Canadian by birth, not Scottish or British as reported in some sources, e.g., Spears (2001); Society of Actuaries website (www.soa.org/duration.pdf). His father was T.B. Macaulay, who served for many years as the chief actuary at Sun Life of Canada (Shiu 1990). In 1910, F.R. Macaulay graduated from the University of Colorado (CU) with an MA in Commerce (Banking) and a thesis titled, *Money, credit and the price of securities*. While Colorado may seem an unusual educational destination for someone with the career path that was to follow, it is significant that, in 1906, CU founded a College of Commerce aimed at students wanting to combine higher education with preparation for the business world. As such, CU was one of the first institutions in the US, along with Harvard and Northwestern, to establish such a program. With his Master's degree Macaulay was able to obtain university positions in economics at the University of Washington from 1915-16 and as an assistant professor of economic theory and statistics at the University of California (UC) from 1916-20. Though Mitchell had left for a position at Columbia prior to Macaulay's arrival at UC, his complementary research agenda and the academic network led Macaulay to pursue a PhD under Mitchell at Columbia. Based on his published contribution to Mitchell (1921-2), in 1924 Columbia granted Macaulay a PhD in Economics.[3]

Upon arriving at Columbia, Macaulay was able to secure a position on the research staff of the NBER, a position that he held until the completion in 1938 of his special study on the cyclical behavior of interest rates. Because none of the staff of the NBER was paid more than a modest

stipend, with senior staff being employed on a part-time basis, it was expected that the bulk of staff income would come from university teaching positions (Fabricant 1984, p.31). To this end, from 1921-26, Macaulay lectured at the New School for Social Research. His area of expertise combined with a growing network of contacts in the financial markets led Macaulay progressively into the business of financial consulting. In 1934, Macaulay joined with the father of Peter L. Bernstein (founding editor of the *Journal of Portfolio Management*) to form Bernstein-Macaulay Inc., a New York investment counsel firm.[4] Macaulay served as vice-president of this firm until his retirement in 1961. Despite his duties in the investment counsel business, Macaulay was able to pursue some research activities. After leaving the NBER in 1938, he took up the position of research director with the Twentieth Century Fund for a study commissioned by the New York Stock Exchange on short selling. The final results of this study, Macaulay and Durand (1951), is Macaulay's last published research contribution.[5] In March 1970, Frederick R. Macaulay died at age 88 at his home in Great Neck, Long Island.

Though Macaulay (1938) is remembered for introducing the duration concept, this contribution was only incidental to this monumental study that was primarily concerned with measuring the time series behavior of interest rates. Working with a difficult-to-assemble sample of 150 railway bond prices covering the period 1856-1936, Macaulay was confronted with the statistical problems of constructing a continuous series of yields from the not-continuously-observed prices of bonds with varying maturities and seasoning, subject to variations in "economic drift". Once the yield series was determined, Macaulay was then confronted with the problem of determining interest rate cycles that were isolated from the impact of changing price levels and economic activity. The problem of constructing the initial yield series was so complex that, along the way, Macaulay produced a

separate publication, Macaulay (1931), dealing with the theoretical issues surrounding the smoothing of time series. That the Macaulay (1938) study took so long to complete is a testament to the patience and diligence of both Macaulay and Mitchell. Ignoring the Macaulay duration insight, the end product still ranks as a classic in both empirical and theoretical fixed income analysis.

3. Macaulay's Duration: Measurement without Theory?

Weil (1973) draws together various sources on duration dating from the introduction of the Macaulay duration measure in Macaulay (1938) up to Fisher and Weil (1971) when the duration concept fully emerged within the mainstream literature of modern financial economics.[6] The measure can be expressed in compact form as:

$$D = \frac{\left[\sum_{t=1}^{T} \frac{t\ CF_t}{(1+y)^t}\right]}{\sum_{t=1}^{T} \frac{CF_t}{(1+y)^t}}$$

where D is the Macaulay duration, CF_t is the cash flow at time t, y is the yield to maturity (or discount rate) and T is the term to maturity. Macaulay stated this formula for a straight bond where CF_t is the fixed coupon payment (C) for all periods up to T when CF_T equals the coupon payment plus return of principal ($C + M$). Macaulay (1938, p.48) referred to this measure as the "'duration' of a bond" and gave a closed form expression for the solution of the sum. The duration concept was explicitly introduced to measure the adjusted term to maturity of a bond. For example, Macaulay (1938, p.45) states: "If two bonds have the same maturity and the same yield but one has a higher coupon rate than the other, the one having the higher coupon rate represents an essentially shorter term loan than the other".

One of the intriguing aspects of the duration concept is that it has a range of applications, not just as a weighted average or adjusted term to maturity. The intellectual development of these various applications contributes to the intrigue of the concept.[7] While Macaulay, the institutionalist, introduced duration to empirically measure the length of a bond's sequence of cash flows, the 'revivalist' neo-classical economist John Hicks (1904-1989) developed the duration concept to theoretically measure the elasticity of the "capital value of a stream of payments" with respect to a change in the discount factor $\beta = (1 / (1 + y))$.[8] Unlike Macaulay (1938) where the cash flows of a straight bond are used to define the cash flows ($CF = C$ or $C + M$), Hicks permits the individual terms in the stream of cash flows (CF_t) to vary across time periods (see Appendix). Instead of referring to the 'duration' of the cash flows, Hicks uses the terminology "average period". Like Macaulay, Hicks provides a solution for the average period of a fixed payment perpetual cash flow. While Hicks (1939) was widely read at the time, due both the academic stature of the author and the importance of the content to neoclassical theory, the 'capital value' context of the Hicksian duration measure was sufficiently obscure to financial applications that, in demonstrating the elasticity property of Macaulay duration, Fisher (1966) did not reference the contribution by Hicks (1939).[9]

In addition to Hicks and Macaulay, a number of sources also recognize Paul Samuelson (1915-) as one of the 'discoverers' of the duration concept, e.g., Weil (1973), Bierwag (1987).[10] While the claims of Hicks (1939) and Macaulay (1938) to the discovery of duration have difficult-to-ignore credibility, the source of Samuelson's priority – Samuelson (1945) – is more problematic. The essential problem does not relate to the voracity of Weil (1973, p.590) where it is reported that Samuelson was "unaware of Macaulay's work", or to the appearance of an incorrect statement in Samuelson (1945) of a relatively simple derivative. Rather, the problem is whether the substance

of the contribution is sufficient to warrant priority recognition. As outlined by Weil (1973) the claim to priority is that Samuelson (1945) examines the impact of interest rate changes on financial institutions with interest bearing assets and liabilities – insurance companies, banks, even universities. A measure of "weighted average time period of inpayments and outpayments" is derived and used to reach the conclusion that: "increased interest rates will help any organization whose [weighted] average time period of disbursements is greater than the average time period of receipts" (Samuelson 1945, p.19).

Samuelson (1945, p.19) provides the following derivation of the theoretical result needed for his main conclusion:

> "Let N_t = inpayment t years after the present, C_t = corresponding outpayments, V = present value, i = interest rate per annum averaged over time. Then:
>
> $$V = \sum \frac{N_t}{(1+i)^t} - \sum \frac{C_t}{(1+i)^t}$$
>
> $$and \quad \frac{dV}{di} = -\frac{\ln(1+i)}{(1+i)^2}\left\{\sum \frac{t\,N_t}{(1+i)^{t-1}} - \sum \frac{t\,C_t}{(1+i)^{t-1}}\right\}$$
>
> By rearranging terms we find that $(dV/di) > 0, = 0, < 0$ depending upon whether $\bar{N} > \bar{C}$, $\bar{N} = \bar{C}$, $\bar{N} < \bar{C}$, where $\bar{N}, \bar{C}$ are respectively weighted average time periods of inpayments and outpayments, whose weights are proportional to discounted dollar amounts."

As noted by Weil (1973, p.590) the stated derivative is incorrect because the $ln(1 + i)$ term does not belong. In addition, the solution does not standardize by the initial value of V, as in Hicks (1939) and Macaulay (1938), preventing a direct connection to an elasticity measure that is expressed in units of time. What Samuelson (1945) does partially anticipate is the solution given by Redington

(1952) to the immunization problem. However, Samuelson (1945) does not identify the application of this result to fixed income portfolio management -- an insight that involves a considerably more sophisticated model and deeper insight. As such, Samuelson (1945) suffers in comparison to the depth and completeness of analysis given by Redington (1952). While Samuelson (1945) does provide a helpful insight to an important problem in fixed income analysis, does Samuelson warrant priority credit for 'discovering' the duration concept?

The problem of determining priority in scientific discovery has been an ongoing puzzle for centuries. In the modern era, intellectual historians and sociologists of science have proposed a number of fascinating theories and interpretations of scientific discoveries and intellectual movements, e.g., Kuhn (1962), R.K. Merton (1973), S. Stigler (1999), Frickel and Gross (2005). The emergence of modern financial economics, in general, and the concept of duration, in particular, are viable case studies for these theories. Given that a number of chapters in Parts II and III of this book examine the application of specific theories of intellectual movements to modern financial economics, this chapter will consider the applicability of the duration concept for two theories of scientific discovery: R.K. Merton's 'theory of multiples' and S. Stigler's 'Law of Eponym'. The theory of multiples maintains that "all scientific discoveries are in principle multiples" (Merton 1973, p.356). The 'Law of Eponymy' states that "no scientific discovery is named after its original discoverer" (Stigler 1999, p.277). While it may appear that the 'Law' is a stronger version of the 'theory', this is incorrect because it is possible for an eponym to be awarded to an individual that was not one of the multiple discoverers. 'Giffen's paradox' is such an eponym from economics and the 'Gaussian distribution' is an example from statistics.

Following Mirowski (1995), Merton's theory of multiples was developed in reaction to earlier

studies by "radical" sociologists and anthropologists that proposed the concept of scientific 'discovery' was a cultural phenomenon. Where the theory of multiples implies that hereditary characteristics, individual capabilities and the idealistic norms of the scientific community are the driving forces of discovery, the cultural approach examines: "what counts as a fact or discovery, what inferences are made from facts, what is regarded as rational or proper conduct, how objectivity is recognized, and how the credibility of claims is assessed" (Shapin 1995, p.300). The cultural approach views 'scientists' as acting within narrowly defined fields, populated by networks of actors jostling for "intellectual attention space" (Collins 1998) in order to achieve the prestige, status and income that comes with priority recognition from the "authoritative socializing institutions" defining what constitutes productive research effort. Crucially, the selection of dominating paradigms can have more to do with the cultural objectives of the scientific networks than with the pursuit of idealistic scientific norms or practical usefulness.

Without seeking to provide a resolution to the 'genetics vs. culture' debate, there are some cursory observations that can be made about the multiple discoveries of the duration concept. The struggle for intellectual attention space in economics during the inter-war period was dominated by two schools of thought: the institutionalists and the neoclassicals. The competing paradigms of these schools differed substantively "over the relative importance of theory versus empirical research" Yonay (1995, p.46). In stressing the importance of empirical research, the institutionalists maintained that theory was limited by factors such as the irrational element in behavior, the constraints imposed by institutions and by the evolution of the economy over time. It was the scientific analysis of quantitative data that would permit the identification of inexorable laws of economic activity, such as the business cycles. The discovery of these laws would facilitate the

implementation of activist economic policies, such as those embodied in various New Deal initiatives, designed to further social and economic progress. Being a member of the NBER research staff, Macaulay was a soldier in the institutionalist army of Mitchell, J.M. Clark and J.R. Commons.

In contrast to the inductive approach of the institutionalists, the neoclassicals maintained that deductive reasoning based on models employing rational maximizing individuals were the best approach to studying the economy. Leading American neoclassicals, such as Frank Knight, "did not believe in the ability of empirical research to find generalizations useful for prediction" (Yonay 1995, p.51). Because deductive models of rational maximizing individuals, by construction, abstract from the irrational actions of individuals and the restrictions imposed by institutions, the less precise connection to 'real time' economics generated a less ambitious policy agenda. In the case of Hicks, this picture is further clouded by the schism between British and American neoclassical schools and the role of Hicks in the post-WWII rise of mathematics as the medium to formulate and present neoclassical results. Given the domination of modern financial economics by American scholars, there was a natural tendency to emphasize, study and promote the contributions of leading figures in US academia associated with this school of thought, if only to perpetuate and reinforce the prestige of the network sustaining the 'modern Finance' school.

The duration concept has three primary uses and, as a consequence, three potential claims to discovery: as a weighted average term to maturity in Macaulay (1938); as an elasticity in Hicks (1939); and, as a tool in fixed income portfolio management in Redington (1952). The application proposed by Samuelson (1945) can be viewed as an extension of Hicks (1939) and an anticipation of Redington (1952). Durand (1957) accurately identifies the applicability of Macaulay (1938) to individual securities. Durand also gives considerable attention to the use of duration in fixed income

portfolio management, referencing Redington (1952) and a list of other contributions from actuarial journals. Samuelson (1945) is also noted – not surprising given Durand's position as a professor at MIT. Hicks (1939) is not identified. In deriving the result that duration is an elasticity measure (using the bond price), Fisher (1966) recognizes Macaulay (1938) but no reference is given to Hicks (1939). As such, there is a basis – at least as strong as that of Samuelson – for also including Fisher in the list of discoverers of duration. An early introduction of the eponym "Macaulay's duration" appears in Fisher and Weil (1971, p.416). An accurate accounting of the various contributions on duration does not appear until Weil (1973), thirty five years after Macaulay's initial contribution.

A recent proponent of Merton's theory of multiple discoveries, Niehans (1995, p.18) attributes multiple discoveries in economics to "the imperfection of scientific communication", claiming that "the influence of the political, ideological and economic environment ... to be relatively weak". Yet, from the perspective of the cultural approach, the long time lag within financial economics in applying and extending the duration concept, the widespread ignorance of the duration-as-elasticity contribution made by Hicks (1939), and the lack of attention to fixed income analysis, in general, are significant developments requiring explanation. Observing that Macaulay (1938) was a major NBER research study and that Hicks (1939) was one of the most important economic theory texts in the 20th century, it is difficult to sustain the view that 'imperfect communication' was a substantive factor in the multiple discoveries. Similarly, Niehans claims that in economics: "multiple discoveries are most likely to occur if scientists, equipped with similar analytical tools, are confronted with the same flaws of existing theory". In the case of duration, the multiple discoveries are due less to flaws in existing theory than with identifying the multiple applications associated with the same concept.

In addition to posing difficulties for sympathetic interpretations of Merton's theory of multiples, Macaulay duration also poses difficulties for Stigler's Law of Eponymy. While Macaulay (1938, p.47, n.21) recognizes a notion related to duration in the actuarial textbooks – the concept of equated time – that involves an abstract solution to a theoretical problem distinct from the practical problem of measuring the length of the sequence of cash flows from a fixed income security. The eponym appears to fall within the accepted usages set out by Stigler: "The Law is not intended to apply to usages that do not survive the academic generation in which the discovery is made". Macaulay had died by the time of the appearance in print of the sources where the eponym entered common usage, Fisher and Weil (1971) and Weil (1973). The eponym is still widely used. The eponym is also accepted impartially "by the community at a distance". Similarly, Macaulay is the only "antagonist" named in the eponym. All that remains is to refute the claim that "lengthy research may be necessary" to demonstrate that the eponym does actually support the Law. However, this claim poses a challenge to proponents of the Law to demonstrate the Law's validity rather than being a confirmation of the Law itself.

4. Discovery, Priority and the Emergence of Modern Fixed Income Analysis

The emergence of modern financial economics in the 1950's is a textbook example of Kuhn's paradigm transforming revolution. The subject of 'Finance' – often referred to as "old finance", e.g., Merton (1987), Haugen (1999), Poitras (2005, p.119-131) – was displaced on the intellectual landscape by modern financial economics during the 1960's. According to R.C. Merton (1987, p.150), old finance was: "an essentially loose connection of beliefs based on accounting practices, rules of thumb and anecdotes". In contrast, modern financial economics features "rigorous mathematical theories and carefully documented empirical studies". While this 'progress of science'

explanation seems to provides ample justification for the revolutionary paradigm change, the voracity of the claim is debatable. The rise of modern financial economics was part of a broader revolution within economics based on the paradigm of a mechanistic world populated by rational utility maximizing individuals. This permitted the application of rigorous mathematical theories that abstracted from 'real time' financial and economic activities in order to derive logical relationships. The inductive approach and empirical methodology of old finance had similarities to institutionalism with certain leading figures, such as David Durand (1913-1996) and Macaulay, having strong roots in that school.[11]

As R.C. Merton observes, the roots of the old finance school had various strands. Lacking a cohesive theoretical focus, the subject was more 'vernacular' – practitioner oriented – than 'academic' – compared with modern financial economics.[12] However, the characterization of old finance as a collection of beliefs, rules of thumb and anecdotes belongs more to the realm of G. Stigler's "hucksterism" than legitimate and informed comment (Stigler 1965, p.4). While Merton accurately identifies one strand of old finance as involving accounting, another historically more important strand which went unrecognized by Merton involves actuarial science.[13] This strand connects directly to fixed income analysis, a subject that received little direct attention in the core theories of modern financial economics: the capital asset pricing model, Markowitz mean-variance portfoliio optimization and the efficient markets hypothesis. From the beginning of the subject in the 18th century, the techniques employed in actuarial science have been both mathematically rigorous and supported by careful empirical studies. In addition, unlike modern financial economics, actuarial science has a necessary connection with 'real world' applications in insurance and pension planning.

The old finance school was a diverse and loosely knit collection of ideas and individuals. Certain leading texts of the old finance, such as Graham and Dodd (1934) and Dewing (1953), dealt with practical issues confronting 'real time' security analysts. In using an academic approach relevant to issues of vernacular security analysis, these texts were prototypical examples of the old finance school. Because of the focus on analyzing characteristics of individual securities, it was not possible to also identify inexorable laws common to all "capital assets". Rather, to achieve the objective of identifying securities providing superior investment returns, these texts do provide 'rules of thumb' and 'anecdotes' to employ in, say, the analysis of the accounting statements of publicly traded firms. It was these notions that Merton (1987) is identifying with old finance. However, this blanket identification ignores other members of the old finance school, such as Macaulay and Durand, that made substantive empirical and, to a lesser extent, theoretical contributions. These members of old finance made explicit references to actuarial studies, e.g., Durand (1957), establishing a connection to a mathematically rigorous and empirically rich historical tradition that dealt with the calculation of present value and discounted expected value, concepts central to financial calculations.[14]

Based on the studies contained in Hawawini (1982), the revolution started by Markowitz (1952) and Modigliani and Miller (1958) had succeeded in conquering the old finance by the end of the 1960's without making a substantive contribution to fixed income analysis.. When attention started turning to fixed income analysis during the 1970's and the connection to actuarial science could have been 'reestablished', the intellectual attention space of modern financial economics was overwhelmed with the Black-Scholes option pricing model. Progress on theoretical fixed income analysis since the early 1970's has been driven by the meteoric rise of financial engineering and risk management in both the academic and vernacular realms. In this rise, fixed income securities have

been featured. Risk management methodologies for fixed income situations, such as value at risk, have become prominent. Fixed income securities are the underlying commodity for a range of derivatives contracts used in risk management activities. As such, the resurgence in fixed income securities analysis has featured contributions oriented to empirical and theoretical aspects of these applications.[15] Much of the empirical research has been aimed at fitting the time series behavior of variables such as the term structure, credit spreads and default probabilities, and specific maturity interest rates.

5. F.M. Redington and the Immunization Concept

Over half a century has passed since Frank M. Redington proposed the classical immunization rules for protecting the surplus of a fixed income portfolio from changes in interest rate levels (Redington 1952). While Redington made a significant number of contributions to actuarial science (Chamberlain 1986), in areas ranging from pension planning to mortality statistics, it is the contribution to immunization theory that still resonates. In summarizing Redington (1952), Chamberlain (1986, p.67) observes:

> the bolt from the blue was in the early part of the paper – immunization theory, appearing from nowhere, astonishing those present as the nearest thing to a religious revelation that could be officially experienced in one's role as a business man and actuary.

This sentiment resonates into the present where immunization theory is a required component of actuarial certification examinations and the concept is still influential in actuarial research, e.g., Shiu (1990), De Felice (1995). Despite the fundamental connection of immunization theory with the subject matter of financial economics, the result was largely ignored outside the actuarial community until Fisher and Weil (1971) revived interest in the underlying portfolio management problem. The

debate that followed the appearance of Redington (1952) was conducted almost exclusively within the realm of actuarial science. Helpful early expositions, such as Wallas (1960), appear only in actuarial sources.

Unlike Macaulay, detailed biographical information is available about Redington, e.g., Skerman in Chamberlain (1986, p.xix-xxiii). The story is not difficult to tell. Frank Mitchell Redington was born in Leeds, England in 1906, the son of a junior shop assistant. After a successful undergraduate at Cambridge, in 1928 Redington joined the Prudential life insurance company, at a time "when Universities supplied only a minority of the Company's trainees" and university graduates "were not given equal treatment, but competed on equal terms with entrants from Schools" (Skermag, p.xix). Outside of administrative posts within the actuarial profession, such as serving as Chairman of the Life Offices' Association (1956-7), and time spent on government service, for the rest of his working life Redington was employed by the Prudential. He joined the management council in 1945 as an Assistant Actuary and became chief actuary in 1951, a position he held until his retirement in 1968. Upon his retirement, he was awarded the Gold Medal of the Institute of Actuaries. He never held a teaching position at an academic institution and did not obtain a doctorate. His research contributions appear only in actuarial publications. Redington (1952) is his only publication to receive substantial attention outside the actuarial community.

The methodology of using of series solutions to solve valuation problems in actuarial science has a history stretching back to de Moivre's solution for the price of a life annuity. In this tradition, Redington (1952) uses a Taylor series expansion of the value function for a 'zero surplus' fund to solve for the classical immunization conditions. The modern formulation of these conditions is to set the duration of assets equal to the duration of liabilities and to have the convexity of assets greater

than the convexity of liabilities. If these two conditions are satisfied, then the fund surplus will be 'immunized' against instantaneous shifts – either up or down – in the level of interest rates. Due to the structure of the argument using a zero surplus fund as the dependent variable in the Taylor series, Redington (1952) does not state the immunization in terms of durations and convexities but, rather, 'mean term' and 'spread about the mean value' are used. Redington (1952, p.290) derives the classical immunization rules by specifying the "present value of the liability outgo" (V_L) and the "present value of the asset-proceeds" (V_A), both discounted at the same rate of interest. A zero surplus fund is created by assuming these two present values are equal with "any excess being 'free' funds to be separately invested". This means that Redington was not assuming a zero surplus fund, *per se*, but was modelling the immunization problem by creating a segmented problem with the surplus considered separately.

Redington (1952) evaluates the impact of a change in the interest rate on the initial surplus $(V_A - V_L)$ using a Taylor series expansion (Poitras 2005, sec. 5.2). Using the ϵ form of the expansion, Redington states the expansion for the surplus function, $(V_A' - V_L')$, as:

$$V_A' - V_L' = (V_A - V_L) + \epsilon \frac{d(V_A - V_L)}{dy} + \frac{\epsilon^2}{2!} \frac{d^2(V_A - V_L)}{dy^2} + \ldots$$

Redington then observes that the first term will be zero by assumption and: "In practice the first derivative is the most important for small changes of the rate of interest and I shall define a fund as immunized if the assets are invested so that $[d(V_A - V_L)/dy]$ is zero." Evaluating the first derivative, Redington states the "mean term" immunization conditions as:

$$\sum_{t=1}^{T} t \frac{A_t}{(1+y)^t} = \sum_{t=1}^{T} t \frac{L_t}{(1+y)^t}$$

where A_t and L_t are the asset and liability cash flows observed at time t. Observing $(V_A = V_L)$ at $t=0$, it is possible to transform this result into the classical immunization condtion: 'equate the duration of assets and liabilities'. However, this step does not appear in Redington (1952), leaving the connection to Macaulay duration undeveloped and unrecognized.

Redington deals with the convexity term by observing that if $[d^2(V_A - V_L)/dy^2] > 0$ then any change in interest "will result in a profit to the fund so long as the change is not so large that the higher terms in the expansion begin to take effect." Redington felt that higher convexity for assets relative to liabilities was "desirable" but used illustrations that showed "the point is not of great importance". Redington then states the theoretical conditions for "a satisfactory immunization policy" by specifying that the first derivative term in the Taylor series be zero, i.e., equate the duration of assets and liabilities, and that the second derivative term be positive, i.e., the convexity of assets be greater than the convexity of the liabilities. Given this result, the bulk of Redington (1952) is concerned with developing the implications of these immunization rules. For example, Redington (1952, p.291) recognizes that the perpetuity represents a limit to the possible asset duration, i.e., the possibility of a duration gap is identified. There are so many insights contained in Redington (1952) that the contribution can still be considered required reading for those seeking to understand the application of immunization theory.

The (non-multiple) priority of Redington in discovering fixed income portfolio immunization is supported by Redington's claim: "The immunization theory contained in the paper is, I believe, original" (Redington 1952, p.101). Observing that Redington (1952) contains no references in the

main body of the text, in the conclusion section Redington does identify a number of papers and individuals – two being colleagues at the Prudential – that were influential in developing and clarifying his concept of immunization. Closer examination of these sources provides little that would undermine the claim to originality. Recognizing that Redington was deeply immersed in actuarial studies, Hawawini (1982) extends the search for precursors to previously published articles in actuarial science. This search uncovered Lidstone (1893) which derives the elasticity for any general annuity price with respect to a change in the interest rate – a result that anticipates Hicks (1939) . Lidstone also identifies the contribution of King (1890) which states the Taylor series expansion for the value of a life annuity and connects the first coefficient in the series with interest sensitivity. Both sources cite *The Institute of Actuaries Textbook* for the solution to the derivative of the annuity certain price with respect to a change in the interest rate. The solution involves an "increasing annuity" that starts with a payment of one and increases by 1 per annum.

Being a dedicated actuary, it can safely be assumed that Redington was aware of results such as Lidstone (1893). However, such results dealt with the interest sensitivity of the present value of individual security cash flows and have more implications for the priority claim of Hicks (1939). The formulation of the immunization problem in terms of the difference between assets and liabilities has echoes in Samuelson (1945), but Redington does so much more: the explicit introduction of surplus; the use of Taylor series expansions to analyze the solution; the recognition of the convexity condition to ensure immunization; and the introduction of the "immunization" terminology. Having provided a general solution, Redington (1952, p.294) details "practical complications" arising in implementing the conditions.

(a) There is difficulty in relating varied yields on assets to some particular rate of interest for

valuing liabilities. Yields are not uniform for all terms of assets, and the differentials are not stable in time. Nor are the differentials between classes of assets stable.

(b) The theory is considerably disturbed by the wide range of redemption dates contained in may Government securities. Options, whether in the assets or the liabilities, can be serious danger points.

(c) The theory would be difficult to interpret in practice because of the existence of such assets as equity shares, properties, mortgages on an open basis, and so on. Either the income, or the term, or both, of many assets are indeterminate.

(d) Offices would be reluctant, and properly so, to invest heavily in long-term securities in a period of very low interest rates.

(e) Investment policy must be flexible to take advantage of special opportunities.

(f) Offices have considerable surplus funds, which can be regarded as falling outside of immunization theory.

This listing of qualifications to the classical immunization results provides a prescient road map to future research on immunization theory, in particular, and fixed income analysis, in general.

6. Conclusions

This chapter examined the intellectual history of two fundamental concepts in modern fixed income analysis: Macaulay duration and immunization theory. Compared to the modern portfolio theory and efficient markets models which monopolized the attention space of financial economics during the 1960's, the diffusion of these ideas into the received wisdom of financial economics has been strikingly slow. Macaulay was dead and Redington was retired before the contributions were recognized within mainstream financial economics. In striking contrast to the lack of recognition

by financial economists, Redington (1952) received almost immediate and reverential recognition within the actuarial science community. Macaulay (1938) received similar treatment. As a member of the NBER research staff, Macaulay was strongly affiliated with the institutionalist school of economics and Macaulay (1938) was widely recognized as a major contribution to the inductive business cycle research fostered by W.C. Mitchell. The demise of the institutionalist agenda as a force within economics during 1950's diverted attention from the significance of the duration concept introduced in Macaulay (1938). Though there were subsequent contributions, such as Durand (1957), that recognized and developed the duration and immunization concepts, in evaluating the progress of prior work on duration Ingersoll et al. (1978) conclude: "we have made but one small step in risk reduction along the road to immunization".

The diffusion of the duration and immunization concepts into modern financial economics provides an interesting case study in the sociology of scientific knowledge. It would be difficult to identify two more unlikely claimants to priority for a scientific discovery. Neither achieved any significant academic stature during their working lifetimes. Redington was a career actuary at the Prudential. After an early career in academia, for the last thirty years of his professional life Macaulay worked primarily as a financial consultant. Prestige, status and income-seeking academic scientists working in the narrowly defined field of modern financial economics, populated by a network of actors jostling for intellectual attention space, were reticent to recognize and explore the scientific discoveries of such individuals. Neither the practical usefulness of the concepts or the idealistic pursuit of scientific knowledge prevented decades from passing before adequate recognition was given to the discoveries. As a consequence, the subject of modern financial economics has suffered from a lack of attention to fixed income analysis and the important

intellectual and historical connection to actuarial science has been ignored.

Appendix:

Derivation of Duration as an Elasticity

Recognition that Macaulay duration can be interpreted as a point elasticity measure of bond price change with respect to a change in interest rates was sufficiently 'new' that Hopewell and Kaufman (1973) provide the derivation of the elasticity representation in full. More precisely, elementary economics teaches that using the unadjusted derivative to measure the sensitivity of a variable *Y*, say quantity demanded, with respect to the change in another variable *X*, say the price of the commodity or income of the consumer, is ineffective because the measurement unit dependent starting levels of *X* and *Y* will impact the result. Instead, the elasticity measure uses the changes in the derivative scaled by the initial level of *X* and *Y*. Where appropriate, a minus sign is added to ensure that the elasticity is a positive number, i.e., for $\eta_{X,Y}$, the elasticity of *Y* with respect to *X*, the formula is: $\eta_{X,Y} = -\left\{ \frac{X}{Y} \frac{dY}{dX} \right\}$. To apply this to the duration measure for the bond price change with respect to a change in the interest rate, observe that $d(1 + y) = dy$:

$$\frac{dP_B}{d(1+y)} = -\left\{ \sum_{t=1}^{T} \frac{t\,C}{(1+y)^{t+1}} + \frac{T\,M}{(1+y)^{T+1}} \right\}$$

$$\rightarrow \quad -\frac{1+y}{P_B} \frac{dP_B}{d(1+y)} = \frac{\sum_{t=1}^{T} \frac{t\,C}{(1+y)^{t}} + \frac{T\,M}{(1+y)^{T}}}{P_B} = D^* = \textit{Macaulay Duration}$$

Hicks (1939) evaluates $\frac{\beta}{K} \frac{dK}{d\beta}$ as the result for the elasticity of the capital value (K) with respect to the change in the discount factor $\beta = (1 / (1 + y))$ where K is specified as:

$$K = \sum_{t=1}^{T} \beta^t \, CF_t = \sum_{t=1}^{T} \frac{CF_t}{(1 + y)^t}$$

By allowing for period to period cash flow variability, this approach to defining the duration formula is more general than Macaulay (1938). The resulting elasticity is also'tidier' in avoiding the requirement of having to insert a minus sign to ensure that elasticity is a positive number.

References

Bierwag, G. (1987), *Duration Analysis, Managing Interest Rate Risk*, Cambridge, MA: Ballinger.

Burns, A. (ed.) (1952), *Wesley Clair Mitchell: The Economic Scientist*, New York: National Bureau of Economic Research.

Chamberlain, G. (ed.)(1986), *A Ramble Through the Actuarial Countryside*: *The Collected Papers & Speeches of Frank Mitchell Redington*, Staple Inn, UK: Institute of Actuaries Students' Society.

Collins, R. (1998), *The Sociology of Philosophies: A Global Theory of Intellectual Change*, Cambridge, MA: Belknap Press of Harvard University Press.

Crouhy, M., D. Galai and R. Mark (2001), *Risk Management*, New York: McGraw-Hill.

Culp, C. (2001), *The Risk Management Process*, New York: Wiley.

De Felice, M. (1995), "Immunization theory: an actuarial perspective on asset-liability management", in *Financial Risk in Insurance*, p. 63-85 in G. Ottaviani (ed.), Berlin: Springer-Verlag.

Dickson, P. (1967), *The Financial Revolution in England*, New York: St. Martin's Press.

Durand, D. (1957), "Growth Stocks and the Petersburg Paradox", *Journal of Finance* 12: 348-63.

_____ (1959), "The Cost of Capital, Corporation Finance and the Theory of Investment: comment", *American Economic Review* 49: 639-55.

_____ (1989), "Afterthoughts on a controversy with MM, plus new thoughts on growth and the cost of capital", *Financial Management* 18:12-18.

_____ (1992), "What price growth? A paradox revisited", *Journal of Portfolio Management* 19: 84-91.

Einzig, P. (1970), *The History of Foreign Exchange*, London: Macmillan.

Fabricant, S. (1984), "Toward a Firmer Basis of Economic Policy: The Founding of the National Bureau of Economic Research", National Bureau of Economic Research, http://www.nber.org.proxy.lib.sfu.ca/nberhistory/sfabricantrev.pdf.

Fisher, L. (1966), "An Algorithm for Finding Exact Rates of Return", *Journal of Business* 39: 111-8.

Fisher, L. and R. Weil (1971), "Coping with the Risk of Interest Rate Fluctuations: Returns to Bondholders from Naive and Optimal Strategies", *Journal of Business* 44: 408-31.

Frickel, S. and N. Gross (2005), "A General Theory of Scientific/Intellectual Movements", *American Sociological Review* 70: 204-232.

Goetzmann, W. and Rouwenhorst (2005), *The origins of value: the financial innovations that created modern capital markets*, Oxford UK: Oxford University Press.

Grove, M. (1966), "A Model of the Maturity Profile of the Balance Sheet", *Metroeconomica* 18: 40-55.

Graham, B. and D. Dodd (1934), *Security Analysis*, New York: McGraw-Hill.

Hamilton, W. (1919), "The Institutional Approach to Economic Theory", *American Economic Review* 9: 309-18.

Hawawini, G. (ed.) (1982), *Bond Duration and Immunization: Early Developments and Recent Contributions*, New York: Garland Publishing.

Hicks, J. (1939), *Value and Capital*, Oxford, UK: Clarendon Press.

Homer, S. and R. Sylla (1991), *A History of Interest Rates* (3rd ed.), London: Rutgers University Press.

Hopewell, M. and G. Kaufman (1973), "Bond Price Volatility and Term to Maturity: A Generalized Respecification", *American Economic Review*: 749-53.

Ingersoll, J., J. Skelton and R. Weil (1978), "Duration Forty Years Later", *Journal of Financial and Quantitative Analysis* (Nov.): 621-50.

King, G. (1890), "Discussion: On a Table of Coefficients Arising out of a given Mortality Table", *Journal of the Institute of Actuaries* 28: 214-6.

Klein, P. (1983), "The Neglected Institutionalism of Wesley Clair Mitchell: The Theoretical Basis for Business Cycle Indicators", *Journal of Economic Issues* 4: 867-93.

Koopmans, T. (1947), "Measurement without Theory", *Review of Economics and Statistics* 29: 161-72.

Kuhn, T. (1962), *The Structure of Scientific Revolutions*, Chicago, IL: University of Chicago Press.

Lidstone, G. (1893), "On the Approximate Calculation of the Values of Increasing Annuities and Assurances", *Journal of the Institute of Actuaries* 31: 68-72.

Macaulay, F. (1910), *Money, credit and the price of securities*, University of Colorado.

_____ (1922), *The personal distribution of income in the United States*, New York: Harcourt, Brace and company.

_____ (1931), *The smoothing of time series*, New York: National Bureau of Economic

Research.

_____ (1938), *The Movements of Interest Rates. Bond Yields and Stock Prices in the United States since 1856*, New York: National Bureau of Economic Research.

Macaulay, F. and D. Durand (1951), *Short selling on the New York Stock Exchange*, New York: Twentieth Century Fund.

Markowitz, H. (1952), "Portfolio Selection", *Journal of Finance* 7: 77-91.

Merton, R.C. (1987), "In Honor of Nobel Laureate, Franco Modigliani", *Journal of Economic Perspectives* 1: 145-55.

Merton, R.K. (1973), *The sociology of science : theoretical and empirical investigations*, edited with an introduction by Norman W. Storer, Chicago: University of Chicago Press.

Mirowski, P. (1995), "A confederacy of bunches: comment upon Niehans on 'Multiple Discoveries'", *European Journal of the History of Economic Thought* 2: 279-87.

Mitchell, W. (1913), *Business Cycles*, Berkeley, CA: University of California Press; reprinted (1970) by New York: B. Franklin.

Mitchell, W., W. King, F. Macaulay and O. Knauth (1921-2), *Income in the United States: its amount and distribution, 1909-1919*, New York: Harcourt, Brace and company.

Modigiliani F. and M. Merton (1958), "The cost of capital, corporation finance and the theory of investment", *American Economic Review* 48: 261-97.

Poitras, G. (2000), *The Early History of Financial Economics, 1478-1776,* Cheltenham, UK: Edward Elgar.

_____ (2005), *Security Analysis and Investment Strategy*, Oxford, UK: Blackwell Publishing.

Rubinstein, M. (2003-2006), "Great Moments in Financial Economics Series", *Journal of*

Investment Management: (2003, Q1), "Present Value", (2003, Q2), "Modigliani-Miller Theorem"; (2004, Q1), "Short-Sales and Stock Prices"; (2005, Q4), "The Fundamental Theorem (Part I); (2006, Q1), "The Fundamental Theorem (Part II)".

Rutherford, M. (2001), "Institutional Economics: Then and Now", *Journal of Economic Perspectives* 15: 173-94.

Shapin, S. (1995), "Here and Everywhere: Sociology of Scientific Knowledge", *Annual Review of Sociology* 21: 289-321.

Shiu, E. (1990), "On Redington's theory of immunization", *Insurance: Mathematics and Economics* 9: 171-5.

_____ (1987), "On the Fisher-Weil immunization theory", *Insurance: Mathematics and Economics* 6: 259-66.

Spears, B. (2001), "Duration Measures Risk in Loan and Investment Portfolios", *Credit Union Magazine* 67: 44-5.

Stigler, G. (1965), *Essays in the History of Economics*, Chicago: University of Chicago Press.

Stigler, S. (1999), *Statistics on the Table: The History of Statistical Concepts and Methods*, Cambridge, MA: Harvard University Press.

Szelely, G. and D. Richards (2004), "The St. Petersburg paradox and the crash of high-tech stocks in 2000", *The American Statistician* 58: 225-31.

_____ (2005), "Remain Steadfast with the St. Petersburg Paradox to Quantify Irrational Exuberance", mimeo, Penn. State University, Dept. of Statistics, June 27, 2005.

Tuckman, B. (1995), *Fixed Income Securities*, New York: Wiley.

Wallas, G. (1960), "Immunization", *Journal of the Institute of Actuaries Students' Societies* 15: 345-

57.

Weil, R. (1973), "Macaulay's Duration: An Appreciation", *Journal of Business* 46: 589-92.

Yonay, Y. (1994), "When Black Boxes Clash: Competing Ideas of What Science is in Economics 1924-39", *Social Studies of Science* 24: 39-80.

Notes

1. The modern day ratings agency – the Standard & Poor's Corporation – was created by the merger of the Standard Statistics Bureau and Poor's Publishing in 1941.

2. Burns (1952) is a collection of papers on the importance and impact that Mitchell had for so many in the economics profession during his life. In addition to containing fitting tributes to Mitchell, Burns (1952) also contains such a wealth of information on subjects such as institutionalism and business cycle theory that it belongs in the category of a classic book in the history of economic.

3. Some sources list the Ph.D. granting date as 1922. Macaulay submitted his portion of the *The personal distribution of income in the United States*, published in 1922, as his dissertation. Columbia University lists the formal date of deposit for his dissertation as 1924.

4. In 1967, in a transaction that has been described as the first major deal of Sandy Weill, later to be head of Citicorp, Bernstein-Macaulay became a subsidiary of Carter, Berlind & Weill Inc. (shortly to become Berlind, Weill, Levitt & Cogan Inc. in 1968). Weill served as chairman of this firm from 1965-1984. During his tenure, the firm was subsequently acquired and became part of Hayden, Stone Inc.. Further transactions resulted in the firm becoming, in 1979, Shearson Loeb Rhodes, the second largest brokerage house in the US after Merrill-Lynch. In 1981, this firm was sold to American Express. Peter L. Bernstein joined Bernstein-Macaulay in 1951 and assumed the position of CEO when his father died unexpectedly. He continued in this position until 1973 when he left the firm, by then part of Hayden, Stone to head Peter L. Bernstein, Inc. a financial consulting firm. The following year he founded *The Journal of Portfolio Management* one of the leading journals spanning the area between financial theory and practice.

5. The connection between David Durand and Macaulay has interesting aspects. Durand was also a Columbia PhD and member of the NBER staff after Macaulay's departure. Paul Samuelson claims that, while at the NBER, Durand "pioneered the empirical study of how long-term bonds usually require a higher yield than short. Everyone understands that today, but he was the first to document it". Durand assumed the position of Associate Professor at MIT in 1955 and professor in 1958, a position he held until his retirement in 1973. Given his strong institutionalist background, Durand used his prestigious academic situation to question the rise of

modern financial economics, e.g., Durand (1959).

6. This is not to say that Fisher and Weil (1971) was the first to consider the duration measure after Macaulay (1938). As discussed later in this section, there is a number of studies prior to Fisher and Weil (1971) that examined the duration measure.

7. Hawawini (1982) reproduces most of these early studies and provides a useful overview of the various contributions.

8. The place of John Hicks in the history of economic thought is difficult to situate. The neo-classical school of economics developed out of the marginalist revolution that can be traced to the 1871-74 period when the concept of diminishing marginal utility and the modern demand curve was introduced by Jevons, Menger and Walras, replacing the classical labor theory of value. In the 1890-1894 period, this marginalist foundation was extended to include the marginal productivity theory of distribution by J. B. Clark, Wicksteed and Wicksell. During the 1934-1947 period, a "Paretian revival" took place in the neoclassical approach when ordinal utility was introduced by John Hicks, Hotelling, Lange and Paul Samuelson. Other neoclassical contributions made by Hicks include the Hicksian compensation test and the elasticity of substitution. For this reason, Hicks is referred to as a 'revivalist' neoclassical economist. However, Hicks also made contributions in areas outside of neoclassical economics, such as in Keynesian economics, with the introduction of the IS-LM model.

9. As Weil (1973, p.590) observes, this does not mean that Hicks was completely unrecognized. Weil credits the relatively obscure Grove (1966) with having "been the first to cite both Macaulay and Hicks." However, prior to Weil (1973), mainstream sources that employed the duration measure to analyze securities, such as Durand (1957), did not recognize Hicks (1939) though a variety other sources, such as Redington (1952), were identified.

10. Bierwag et al. (1981, p.3) goes farther in observing: "It is ironic that Redington's article published in an actuarial journal not widely read by non-actuarials, has received wider recognition than Samuelson's similar and earlier article in the *American Economic Review*." This statement is an excellent example of the network reinforcement process in intellectual movement development. Samuelson (1945) is concerned with measuring the sign of the impact that interest rate changes have on financial institutions and Redington (1952) is concerned with the conditions required for immunization of the balance sheet of a specific financial institution, a life insurance company. The differences between these two contributions are more than substantive.

11. Biographical information on Durand is available in a number of sources. The March 6,1996 edition of *Tech Talk,* the official MIT newspaper, has a lengthy memorial by Enders Robinson, a close friend of Durand. Good coverage of available sources is given in Szekely and Richards (2005).

12. In the context of financial markets, the distinction between"vernacular" and"academic" analysis has been introduced by intellectual historians and sociologists of science studying the popularization of finance during the 19th century, e.g., Preda (2006). Vernacular analysis is aimed at 'real time' financial decision making and is typically anecdotal, imprecise and uses language that is intellectually accessible by the broad population. Academic analysis is aimed at the community of academics staking claim to the subject area and is theoretical, precise and involves language that is intellectually accessible mainly by academics involved in that community.

13. In a path-breaking series of papers, Rubinstein (2003-6) connects the core theoretical results of modern financial economics with contributions from the early 17th and 18th contributors to the intellectual history of actuarial science. Goetzmann and Rouwenhorst (2005) steers a similar course through the early financial history.

14. In Szekely and Richards (2004), the arguments in Durand (1957) have been revived. See also Durand (1989) and Durand (1992) for more information on how Durand viewed his various contributions.

15. Crouhy et al. (2001) and Culp (2001) are recent texts containing detailed references on these developments.