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Black, Merton and Scholes: Their work and its consequences

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The Nobel Prize in Economics for 1997 was awarded to Robert C. Merton and Myron Scholes. If their partner, Fischer Black, had been alive today, he would have shared the prize. In this article, we take stock of markets for financial derivatives, and the work of Black, Merton and Scholes.

1 Financial Derivatives

If we look back at the world in the mid–sixties, price risk in financial markets was fairly limited. This was an era when state interventions were much more prevalent, the world over, and many kinds of risk were apparently absent owing to price controls. For example, "interest rate risk" did not appear to be present in India owing to direct state control over interest rates.

Ever since the early seventies, governments all over the world have steadily retreated from overt price controls. This has been motivated by an increasing realisation that these stabilisation programs involve enormous costs, upon governments in particular and upon the economy in general through distortions in resource allocation.

The evolution of the four major financial markets of the economy – equity, debt, foreign exchange, and commodities – has proceeded differently. In the case of equity, direct government interventions have been absent in almost all countries. In the case of foreign exchange, the first phase of elimination of price controls took place in OECD countries in the early seventies, though market interventions continued. From the early nineties onwards, there has been a sense that government intervention in many currencies is infeasible even when it is thought desirable. In the area of interest rates, there has been a significant shift in monetary policy away from targeting nominal interest rates. In the area of commodities, the breakdown of cartels like OPEC, and the steady reduction of controls upon agricultural commodities, has led to an increasing emphasis upon markets in determining commodity prices.

The deregulation of these four financial markets has had many consequences for productivity and economic growth. It has also generated an upsurge of price volatility. The term "risk" is often interpreted, in common parlance, as the probability of encountering losses. In the language of modern economics, however, risk is defined as volatility, where unexpected changes (whether in the positive or negative direction) are viewed symmetrically. Volatility in major financial markets of the world rose sharply in the early seventies.

For a simple example, we can think of a commodity like cement in India, where price controls once existed. Under a regime of price controls, the price apparently stayed constant for many months at a time. However, the "true" price of cement did fluctuate. The inflexibility of a controlled price generated risk for consumer (of shortages) and producers (of gluts). A builder might apparently face no risk through a clearly defined price, but the risk of actually obtaining cement might be quite considerable if shortages exist. The opposite risks were faced by a cement manufacturer. In an environment without price controls, it is the publicly visible *price* which fluctuates, and trading in cement is always possible at the market price. The market–clearing price sends out meaningful signals to influence the behaviour of consumers and producers, and the risk is explicitly visible as the volatility of cement prices.

Economic agents are uncomfortable when exposed to risk. Risk can inhibit the use of efficient production processes, and hence productivity, in the economy. Hence the management of risk has become important. There are three major 'technologies' through which economic agents can reduce the risk that they are exposed to: diversification, insurance and hedging.

Diversification is obtained when economic agents spread their exposure over many imperfectly correlated risks,

Insurance is obtained by paying a fixed cost (the insurance premium) and eliminating certain kinds of risk,

Hedging is obtained by an economic agent who offsets his natural economic exposure by the opposite position on a financial market.

These three technologies might be illustrated by analysing the risk faced by a garment exporter based in India who sells shirts to a company in the US. The firm regularly sells dollars on the market, and is exposed to the fluctuations of the dollar–rupee exchange rate.

1. The firm could diversify itself by contracting with buyers in countries other than the US, and thus reduce its exposure to fluctuations of the dollar–rupee exchange rate,
2. The firm could buy "insurance", i.e. a financial contract which would pay the firm if the price of dollars drops.
3. The firm could hedge itself by selling off the dollars that it expects to obtain at a future date at a price known today.

From the firm perspective, the elimination of financial risk using financial instruments is desirable, insofar as it does not alter the actual functioning of the firm. In this sense, the diversification alternative, which requires that the firm must discover importers in other countries and contract with them, is relatively unattractive. This alternative also fails to protect the firm from a secular movement in the *rupee*, which would influence the exchange rate faced against all currencies. For many firms, diversification is contrary to the development of sharply focussed and specialised skills of a high order. In this sense, the other two technologies of risk reduction are often preferable.

The "insurance" described above is not sold by any "insurance company" in the world. The financial contract, however, is appropriately viewed as a kind of insurance, where a fixed payment is exchanged for the elimination of certain kinds of risks. This is achieved using *options*, which are the main subject of this article.

The third alternative is obtained on *forward markets*, where agents strike up contracts to trade at a future date at a stated price. The modern, institutionalised version of the forward market is called a *futures market*.

In the case of either insurance or hedging, a natural question that arises is: who would the counterparty be? What economic agents would be willing to sell insurance (options) to the garment exporter, or buy dollars at a future date from the garment exporter? The most natural candidate for the counterparty is an *importer*, who is exposed to the opposite risk of the exporter. The importer needs to buy dollars at a future date, and can become a counterparty to the exporter who wishes to sell dollars. The importer can safely sell insurance, exchanging a fee under normal circumstances for a payout at times when the importer has profited tremendously (i.e. when the rupee has appreciated sharply).

This reasoning illustrates the role for options and futures in the modern economy: these markets provide means through which economic agents can control the risks that they are exposed to. It should be emphasised that through these methods, risk is not destroyed, it is only transferred from one economic agent to another. The buyer of an option reduces his risk, but that risk is transferred to the seller of the option. The inverse nature of the risks faced by importers and exporters is a natural situation where the agents can enter into contracts which are mutually beneficial. The institution of modern derivatives exchanges reduces the search costs of economic agents who wish to discover and enter into such mutually beneficial contractual relationships.

The financial markets which enable this repackaging and transfer of risk are called *financial derivatives markets*. Financial derivatives are the modern functional replacement for the 'price stabilisation programs' which governments once used. However, financial derivatives do not eliminate risk or price volatility in the economy; instead, they give individual economic agents the means through which their risk can be transferred to others. When thousands of firms and individuals in the entire economy use derivatives, we obtain a very different *distribution of risk* in the economy as compared with what is found without derivatives. Since economic agents voluntarily enter into these contracts, they have to be better off as a consequence of the contracting. Thus the use of derivatives markets can only be welfare–enhancing.

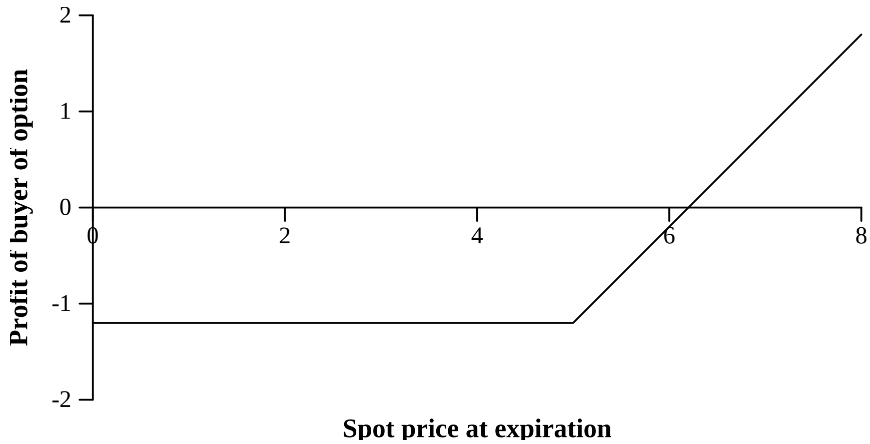

Figure 1: Payoff diagram for owner of option

2 Options

Our main focus in this article reflects the work of Black, Merton, and Scholes: it is on *options*. Amongst derivatives, futures are relatively simple instruments, and the analysis of futures contracts was well understood many decades ago. In contrast, options are analytically complex.

An example of an option contract is as follows. A person A buys an option from B whereby A has the right to buy a widget from B on 31 Dec 1997 at a price of Rs.5. Here, A has the right *but not the obligation*. If A chooses to buy, then B has to go through with the terms of the contract. However, A has the choice of not buying if he so desires.[1]

If, on 31 Dec 1997, the widget trades at above Rs.5 then it is optimal for A to exercise his option. If the market trades widgets at below Rs.5, then it is optimal for A to ignore his option. This is expressed in Figure 1, which shows the *payoff diagram* to the buyer of the option. This is an option with a price of Rs.1.2, so that the option holder has lost Rs.1.2 regardless of exercise. The option has an exercise price of Rs.5, so that it is exercised if the spot price is above Rs.5. If the spot price is above Rs.5 but below Rs.6.2, the option holder has still made a loss, because the price of the option has not been recouped by exercise. When the spot price crosses Rs.6.2, the owner of the option profits. The profits to the owner of the option can potentially be infinitely large, insofar

[1]There is a taxonomy in options which merits mention: options can be "american" or "european", and they can be "call options" or "put options". An option which gives the holder the right to buy something is called a *call option*. An option which gives the holder the right to sell something is called a *put option*. An option which can be exercised only on the expiration date is called a *european option*. An option which can be exercised anytime upto the expiration date is called a *american option*. The discussion in this article has centred upon european call options; american options and put options have been ignored. The essential ideas of their analysis are identical to those described here.

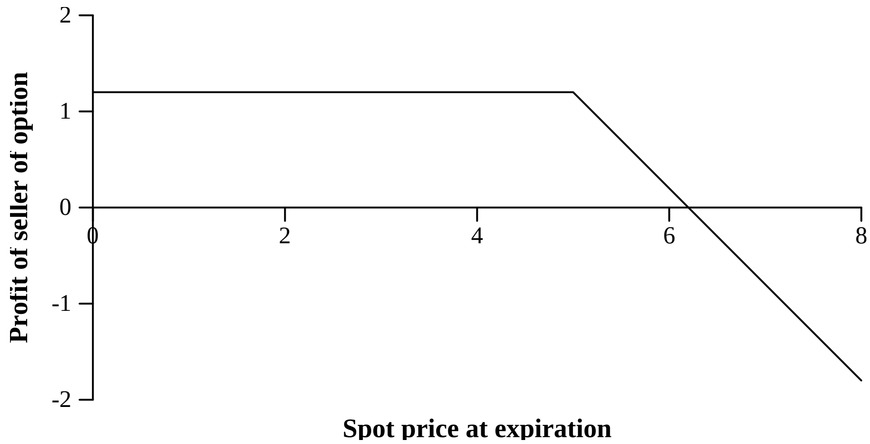

Figure 2: Payoff diagram for seller of option

as the spot price at expiration can become very large.

The standard notation of the options literature uses the terms X for the exercise price of the option, T is the time to expiration, S_T is the spot price on the expiration date, and C is the price of the option.

From the viewpoint of the buyer of the option, once the price of the option is paid, an option has only upside potential – it can yield profits, but there can be no loss. Conversely, the seller of the option obtains the price of the option immediately, and then runs the risk of losses upon option exercise. The payoff diagram of the seller of the option is in Figure 2.

Many contractual arrangements are binding on both parties. Option contracts are unique insofar as one side (the buyer) has a non–binding option of going through with a defined transaction, while the other party has no such flexibility. This flexibility is valuable; the owner of the option is richer by an "option value".

This example has been couched in purely financial terms. However, a wealth of option–like contracts are present in the world:

- Insurance contracts are remarkably like options. The buyer of health insurance pays a insurance premium (the option price) and then faces no downside risk.[2]
- Firms often obtain rights to a technology as an "option" whereby they can commercialise the technology if desired, but they do not have to.
- Many foreign companies which have entered India as of date can be viewed as small operations designed to give the parent company the option of rapidly enlarging its interest in India, if India's economy works out correctly.

[2]While insurance and options are functionally similar, insurance differs from exchange–traded options in many essential ways. Insurance is typically sold by a small set of firms, with high entry barriers, whereas anyone can sell options on the options market. Insurance companies typically focus on stable and predictable kinds of risk, such as life and health, while options markets generally deal with price risk.

- When a firm builds a factory, it has the right (but not the obligation) of producing goods. If input and output prices shape up wrong, the firm can idle the factory. If input and output prices shape up correctly, the firm can run the factory for one, two or three shifts.[3]
- When an employee has the right to resign from a job, but the firm does not have the right to dismiss him, the contract between the firm and the employee bundles an option. The equilibrium on the labour market will hence involve lower wages to compensate firms for the option that they have written.
- When a toll road is built, individuals have the right (but not the obligation) of using it. In this sense, infrastructure enriches citizens by giving them free options.
- Asset liquidity on secondary markets can be viewed as an option. Without secondary markets, investments in a company are irreversible. Secondary markets which impose low transactions costs give investors the option of exiting from an investment if desired.[4]

These examples illustrate the widespread use of option–like relationships in the modern economy. In this sense, understanding options is directly useful insofar as option contracts are traded on financial markets, but the applications of option pricing theory go well beyond this.

3 Pricing Options

The central puzzle about options concerns pricing. What is an option worth? Given the characteristics that define an option, how is its fair value determined? The characteristics may be enumerated as :

1. The identity of the underlying asset,
2. The exercise price X,
3. The date of exercise, T,
4. The present spot price of the underlying asset, S.

Options trading has been done for many centuries by traders using their instincts to guide the choice of prices. At the dawn of modern financial economics, researchers faced the challenge of finding a scientific theory which would yield an explicit solution to the question of how options can be priced.

The identity of the underlying asset impinges upon option pricing via the *volatility* of returns on the asset. Options on more volatile assets are more valuable – e.g. the insurance premium would be higher if there was more uncertainty about an outcome. When the volatility of an asset goes up, options on that asset become *more* valuable.

[3] [DP94] analyses the economics of investment from an option pricing perspective.

[4] In jargon, the person who places limit orders is an option writer, and earns impact cost. The person who places market orders is exercising the option, and pays impact cost.

4 A Bird's Eye View of Pricing Procedures

There are two major 'technologies' which are used in financial economics for pricing financial instruments: *arbitrage–based pricing* and *risk–based pricing*.

4.1 Pricing based on risk

At the simplest, let G_{bt} be the price of gold in Bombay on date t. What is the fair value of G_{bt}? The equilibrium price of gold will reflect the future risk and return that owners of gold face. It will also depend upon the *risk aversion* of individuals in the economy: in an economy where people are timid and dislike bearing risk, the "price" of risk will be high, and risky instruments will command low prices.

Any theory which explains G_{bt} must involve these parameters – future risk and return, and the risk tolerance in the economy. This is an example of "risk–based pricing".

4.2 Pricing based on arbitrage

In contrast, suppose we can take G_{bt} as given, and ask questions about G_{pt}, the price of gold in Poona at time t. The analysis of G_{pt} does not require any analysis of risk, return and risk tolerance. It only depends upon *arbitrage*, which is the process of obtaining riskless profits: if gold is cheaper in Poona, then economic agents will buy gold in Poona and transport it to Bombay, and vice versa. When such arbitrage takes place, it equalises differences, i.e. if gold is cheaper in Poona, then arbitrageurs serve to drive up the price of gold in Poona and reduce the price of gold in Bombay, thus restoring the equilibrium. This gives us a clear method to price gold in Poona: G_{pt} must be very close to G_{bt}. This is called "arbitrage–based pricing".

The application of arbitrage–based pricing has several interesting facets:

1. We think that the economy is richly populated with myriad intelligent economic agents, all of whom seek profits, who would *rapidly* exploit arbitrage opportunities when they surface. Hence, we would not normally see G_{bt} and G_{pt} having values which violate this "principle of no–arbitrage". By this rationale, pricing theory based on arbitrage would be true most of the time, except for the few seconds (or milliseconds) that would elapse between the surfacing of an arbitrage opportunity and its exploitation by some profit–seeker in the economy.
2. Strictly speaking, the *cost of transportation* between Poona and Bombay is non–zero, hence we need not have $G_{bt} = G_{pt}$. If the error in prices is sufficiently small, then the costs incurred in transportation might be large enough to wipe out the profits, thus rendering the arbitrage infeasible. Hence, there would be a "no–arbitrage band" surrounding G_{bt}; if G_{pt} took any value inside this band, then arbitrage would not be feasible even though $G_{pt} \neq G_{bt}$. We predict that G_{pt} would lie somewhere between $G_{bt} - \delta$ and $G_{bt} + \delta$ where δ reflects the cost of transporting gold.

As this example suggests, pricing theories based on arbitrage are powerful and convincing. They do not require an analysis of the complex issues of risk, return and the risk tolerance of agents. Arbitrage based pricing only relies on three simple foundations:

1. The assumption that economic agents are intelligent in detecting arbitrage opportunities,
2. The assumption that economic agents are profit seeking and would attempt to exploit them,
3. The fact that transactions costs are a hurdle faced in doing arbitrage. To the extent that transactions costs could be accurately measured, we would get good estimates of the δ, i.e. the size of mispricings which cannot be exploited by arbitrageurs.

The example that we have used, i.e. the price of gold in Bombay vs. Poona, appears trite; it seems extremely obvious that gold should be priced the same between these two cities. Arbitrage arguments have, however, been applied to problems of considerably more complexity than this one. For example, all pricing on futures markets is based on no–arbitrage principles: arbitrage binds the spot price and the futures price together. The main appeal of arbitrage–based pricing is the fact that in situations when it is applicable, it is a powerful argument which is highly successful empirically.

4.3 The law of one price

The "law of one price" is a close consequence to the no–arbitrage principle. It asserts that if two financial instruments x and y behave identically, then they must have the same price. If this were not the case, then rational agents would continuously sell the costlier and buy the cheaper, till the prices became equal.

The law of one price is like the no–arbitrage principle in seeming obvious. However, it has powerful ramifications when carried to its logical conclusion. For example, we will use it in Section 5.1 to derive a result which is quite powerful and interesting.

4.4 History of arbitrage– and risk–based pricing

Remarkably enough, one of the earliest pieces of research in financial economics was also the first use of the arbitrage–pricing argument. This was the work of Modigliani and Miller in 1958 which asserted the irrelevance of debt vs. equity in the cost of capital of a firm [MM58] for which Merton Miller won the 1989 Nobel Prize (Franco Modigliani was awarded the Nobel Prize much earlier, for his work in the analysis of consumption).

In the 1960s, the major achievement of finance was the "capital asset pricing model (CAPM)", an analysis of the relationship between risk and return. The CAPM aims to calculate the rate of return which a portfolio on the equity market must yield at equilibrium, given its level of risk. The CAPM is the most prominent example of a risk–based pricing theory. William Sharpe won the 1989 Nobel Prize for this work.

5 Option Pricing

The first modern attempt at analysing options dates back to the year 1900, when the young French mathematician Louis Bachelier wrote a dissertation at Sorbonne titled *The Theory of Speculation.* Bachelier was the first person to think about financial prices using the modern tools of probability theory. The approach that he took, and many of the results that he obtained, were far ahead of their time. As a consequence, they were to lie dormant for sixty years.

In the sixties, MIT was a hotbed of interest ond curiosity about options. A host of researchers, including Paul Samuelson, worked on the question of pricing options. From a modern perspective, we can classify many of the early attempts at pricing options as being risk–based models: these were option pricing formulas which required the knowledge of expected future returns on the underlying asset. The practical usefulness of these theories was limited, because forecasting the expected future returns on the underlying asset is difficult.

A major advance in option pricing was accomplished by Hans Stoll in 1969, when he used the no–arbitrage argument to link up the price of a call option and a put option. This principle is called “put–call parity”.

5.1 Put–Call Parity: A Canonical Arbitrage Argument

Put–call parity is a classic application of arbitrage–based pricing: it does not instruct us on how to price either put or call options, but it offers us an iron law *linking the two prices.* Hence, if call options can be somehow priced, then the price of the put option is immediately known.

Since put–call parity is a canonical arbitrage argument, we will spell it out in detail here. Suppose a person has one share of Reliance and buys a put option at Rs.300 which can be exercised T years in the future. In this case, the person faces no future *downside risk* below Rs.300, since the put option gives him the right to sell Reliance at Rs.300. Suppose, in addition, the person *sells* a call option on Reliance at Rs.300. In this case, if the price goes above Rs.300, the call holder will exercise the call option and take away the share at Rs.300. The sale of the call eliminates *upside risk* above Rs.300.

Hence, the following portfolio – one share, plus a put option at Rs.300, minus a call option at Rs.300 – risklessly obtains Rs.300 on date T.

This payoff is identical to a simple bond which yields Rs.300 on date T. Suppose the interest rate in the economy is r, then this bond has the present price $300 \cdot (1 + r)^{-T}$.

This is a situation to which the law of one price applies: we have two portfolios which yield the identical payoff:

1. $300 \cdot (1+r)^{-T}$ invested in a simple bond, which turns into Rs.300 on date T for sure, and
2. A portfolio formed of $S + P - C$, which turns into Rs.300 on date T for sure.

By the law of one price, if two portfolios yield the identical payoffs then they must cost the same. Hence we get the formula

$$S + P - C = X(1 + r)^{-T}$$

where S is the spot price, P is the put price, C is the call price, X is the exercise price and T is the time to expiration. If prices in any economy ever violate this formula, then riskless profits can be obtained by a suitable combination of puts, calls and shares.

In summary, put–call parity links up the price of a call and the price of a put. If one is known, then we can infer the other.

6 The Black–Merton–Scholes Analysis

This was the situation when Fischer Black, Robert C. Merton and Myron Scholes entered the picture. Black was a Ph.D. in applied mathematics, who was then working at the consulting firm Arthur D. Little Inc. Merton had studied mathematics at CalTech and then become a Ph.D. student of Paul Samuelson. Scholes was a fresh Ph.D. in economics from Chicago who had joined the faculty of the MIT finance department. The research strategy that they uncovered was, in fact, an arbitrage–based argument, but it was not the simple arbitrage of the variety discussed above.

In fact, a simple arbitrage argument such as that used in our gold example, or that used in obtaining put–call parity, cannot be found in option pricing. These "simple" arguments rely on a single transaction, which buys what is cheap and sells what is costly, and accomplishes riskless profits – no such arbitrage can be found with options. The first major insight was the idea that a *dynamic* arbitrage can be setup between the underlying and the call option.

Let us define Δ as the change in the price of the call option for a Rs.1 change in the spot price of the underlying. Then a portfolio which invests $+\Delta$ in the share and -1 in the option is riskless. However, it turns out this position is temporary, because Δ changes as the spot price changes. This suggests a *dynamic trading strategy*: from time to time, when S changes, we would need to recalculate Δ and adjust the portfolio to stay on target. If the portfolio is continually maintained correctly, i.e. -1 in the option and $+\Delta$ in the underlying, the portfolio would be riskless and would be worth as much as a bond.

Hence we have a new situation, where a riskless position (which can readily be priced) is obtained, but the portfolio associated with this riskless position is adjusted continuously. Black, Merton and Scholes pioneered the use of powerful mathematical methods in analysing this problem. They brought about the new field of "continuous time finance", in which trading takes place in continuous time. The analysis of these models required the use of stochastic calculus and differential equations.

In the case of a european call option on a non–dividend paying stock, the analysis of the model described above (the details of which we omit) led to the differential equation:

$$\frac{\partial f}{\partial t} + rS\frac{\partial f}{\partial S} + \frac{1}{2}\sigma^2 S^2 \frac{\partial^2 f}{\partial S^2} = rf$$

which is often called the Black–Scholes differential equation. Remarkably enough, this differential equation has an analytical solution, the Black–Scholes formula:

$$C = S\Phi(d_1) - Xe^{-r(T-t)}\Phi(d_2)$$

where

$$d_1 = \frac{\log(S/X) + (r + \sigma^2/2)(T-t)}{\sigma\sqrt{T-t}}$$

and

$$d_2 = d_1 - \sigma\sqrt{T-t}$$

This formula tells us C, the price of this call option. Here, $\Phi()$ is the cumulative normal distribution. The formula consumes as input: S, the spot price, X, the exercise price, T, the time to expiration, σ, the future volatility of the underlying, and r, the riskless interest rate. What is conspicuous by its absence in the formula is the expected future *returns* on the underlying. The Black–Scholes formula is an arbitrage–based link between the spot price and the price of the call option; the future expected returns on the underlying asset does not matter.[5]

There is only one unknown in the Black–Scholes formula: σ, the future standard deviation of returns on the underlying asset. Calculating the Black–Scholes price of an option is hence synonymous with forecasting the future volatility of the asset.

6.1 More General Problems

The Black–Scholes analysis, and the field of continuous time finance, is a powerful technology for dealing with a wide variety of financial instruments. In all cases, differential equations defining the price of the asset of interest can be derived, but usually it is not possible to find analytical solutions to these equations (the call option on a non–dividend paying stock, which led to the celebrated formula above, is a rare exception). In these cases, computers are used to solve the differential equations and thus obtain prices.

[5] Once the price of the call option is known, put–call parity gives us the price of the put option. For those interested in numerically experimenting with these formulas, there are numerous Internet websites which evaluate the formulas.

7 Impact of the 1973 Paper

7.1 Impact upon options markets

Options have been traded informally, in what are known as “over the counter” markets, for centuries. It was as late as 1973 when the first trading of options at an *exchange*, which was the Chicago Board Options Exchange (CBOE). Thus there was a happy coincidence between the arrival of the analytical understanding of options and the development of market institutions to trade in options.

Within just a few months after the Black–Scholes paper was published, Texas Instruments started selling hand calculators which had the capability of evaluating the Black–Scholes formula! Today, every MBA student in the world is taught the Black–Scholes formula.

As mentioned earlier, options have existed for centuries, but a major constraint upon their usefulness was the enormous difficulties of their pricing. In a world where very little was known about how options should be priced, trading options was a mixture of guesswork and gambling, and very few economic agents participated in options markets. With the analytical capabilities created by Black, Merton and Scholes, the option has become a mainstream instrument, with millions of users all over the world being able to meaningfully think about option pricing.

7.2 Portfolio insurance

The dynamic arbitrage described in Section 6 was once considered a mathematical artifact, which was useful in deriving the Black–Scholes formula but not present the real world.

By the middle of the 1980s, a trading strategy called “portfolio insurance” became widely used, where put options on a portfolio were often *created* by actually calculating the Δ and adopting the appropriate position on the market. The Δ values associated with these options were recalculated from time to time, and trading activities undertaken to preserve the riskless character of the position. These put options are said to be “synthetically” created in the sense that the trading strategy creates the option; there is no seller of the option.

This was a remarkable situation where the strategy for deriving an equation turned out to later be useful, ten years later, as an operational trading strategy.

7.3 Implied volatility

If a market equilibrium price of an option is observed, then the Black–Scholes formula can be turned on its head, to calculate the $\hat{\sigma}$ which traders must be having in their minds in order to justify the observed C. This $\hat{\sigma}$ is the markets consensus forecast of future volatility; it is called *implied volatility.* Many studies have found that this $\hat{\sigma}$ is an extremely accurate forecast of future volatility, outperforming known econometric models which forecast σ. In this sense, the combination of an active options market coupled with the Black–Scholes formula *reveals* new information to the economy, i.e. a good forecast of future volatility of the underlying asset becomes visible [BM95].

7.4 A self–fulfilling prophecy?

The Black–Scholes formula is considered by some economists to be a "self fulfilling prophecy" [CJ94] in the following sense. The formula relies on several unrealistic assumptions, the most important of which is the assumption that transactions costs are zero. In reality, the trading involved in maintaining the riskless position in continuous time would involve significant transactions costs. Yet, *option prices in the real world are remarkably close to those predicted by the Black–Scholes formula.* One possibility is that if a sufficiently large mass of traders uses the Black–Scholes formula as a working approximation, then the formula becomes true. In this sense, it may be the case that the modern economy has been steered in a certain direction because the Black–Scholes formula was discovered in 1973.

7.5 Options in corporate finance

Very early in the story of option pricing, Black, Merton and Scholes realised a remarkable facet of corporate finance, on the relationship between equity and debt financing. Equity holders can be viewed as "having an option on the value of the firm". When a firm goes into liquidation, the debt holders get their dues, when possible, and the equity holders get what is left. Hence the payoffs of the equity holder is exactly like that of a call option.

Suppose we write V as the total liquidation value of the firm, and D as the debt which is owed to the bondholders. The shareholders of the firm get $V - D$ if it is positive, and 0 otherwise, i.e. they get $\max(V - D, 0)$. Hence they have a call option on the value of the firm, with a strike price of D.

This understanding of the relationship between equity and debt has led to thousands of research papers in the field of corporate finance.

7.6 The scientific achievement

The best achievements in economics are creations of the mind which meet three conditions: (a) they should be elegant and insightful, (b) they should be useful in the real world and (c) they should be highly successful when predictions are compared with reality.

The work of Black, Merton and Scholes is a success on each of these three metrics, and is quite likely to be considered one of the best achievements, to date, of modern economics. The analysis of finance in continuous time is some of the most elegant and satisfying branches of economic theory. The practical usefulness and the impact upon the real world of the Black–Merton–Scholes analysis is enormous. Finally, the empirical accuracy of the prices forecasted by the Black–Scholes formula is unrivalled in all economics.

Today, many engineers and mathematicians, who know no economics, learn how to setup differential equations based on the Black–Merton–Scholes analysis, and solve these differential equations in pricing financial derivatives. Every large finance company in the world hires such individuals in positions of enormous significance.

This is in sharp contrast with other areas of economics, where the analytical techniques that are valuable in the hands of highly insightful researchers can rarely be usefully passed on to others.

In civil engineering, it does not take a researcher to build a bridge: the building of bridges is a routine technique which can be taught to undergraduate students, who can then go out and reliably build bridges. In contrast, a good macroeconomist cannot teach students the *techniques* which will enable them to understand and predict the macroeconomy; there is a large element of wisdom and experience that goes into the the making of a good macroeconomist.

Continuous time finance is the clearest success of the *science* of economics, in the sense that it can be taught, and reliably used, by practitioners who need not be remarkably insightful researchers. In some ways, pricing options is now as routine, unremarkable, and uncontroversial as the building of bridges. This perspective highlights the *scientific* achievement of continuous time finance, and best motivates the Nobel Prize in Economics of 1997.

8 Financial Derivatives in India

8.1 Informal options markets

As in other countries, informal options markets have existed in India for centuries. Today, they go by names like *teji–mandi*, *bhav–bhav*, etc. Lacking formal market institutions, these markets are fairly small. The anachronistic legal prohibition upon derivatives contracts in India has also served to impede the growth and institutionalistion of these markets.

8.2 Badla

On the equity market, many observers have noted that the institution of *badla* (on the Bombay Stock Exchange) and derivatives markets are similar *insofar as they are both vehicles for leveraged trading.* This fact has been widely, and incorrectly, mutated into the notion that "*badla* is an indigenous alternative to derivatives".[6] This fact is incorrect insofar as *badla* is not indigenous (it has existed in stock markets in London, Paris and Milan). It is also incorrect insofar as *badla* does not achieve what either futures or options markets achieve, which is hedging risk. Hence, *badla* does not belong in the analysis of derivatives markets in India.

[6] There is an element of linguistic confusion also here. The term "carryforward" which is rightly applied to *badla* has been wrongly mutated to "forward trading", which *badla* is not.

8.3 Futures and options markets

By May 1996, the National Stock Exchange (NSE) had substantially completed the development of systems and software required to start trading futures and options on the NSE-50 index. The commencement of trading on this market has been awaiting approval from SEBI since then. In November 1996, SEBI created the twenty–member L. C. Gupta Committee in order to draft a policy framework governing derivatives markets. As of early December 1997, the report of this committee is awaited.

Many of the fears about equity index derivatives as “highly leveraged instruments” are essentially misplaced on the equity market. This is because the distorted trading practices presently used on the *spot* market for equity in India involve more leverage, and much more unsafe leverage, than what is involved in the NSE index derivatives proposal. In this sense, the attempts at formulating a stringent regulatory apparatus to govern the index derivatives market are somewhat misplaced, and risk stifling the market in its formative phase. A superior approach towards regulation would have involved an early onset of equity index derivatives, coupled by a policy initiative to diminish the leveraged trading which is found on the *spot* market.

8.4 Currency derivatives

In the report on capital account convertibility, the Tarapore Committee has recommended that the existing dollar–rupee forward market should be augmented by a dollar–rupee *futures* market, and that a currency options market should be created. These initiatives would give improved hedging methods through which economic agents could reduce their exposure to currency fluctuations, and improve market quality on the dollar–rupee spot market.

9 Further Reading

The lifework of Black, Merton and Scholes is not limited to options and their pricing alone. Black and Scholes did pioneering work in theory and testing of asset pricing models [BJS72, MS72]. More than 25 years ago, Black was the pioneer in seeing a major role for computerised order–matching, which has revolutionised markets in India and all over the world [Bla71]. He also took great interest in general equilibrium theory and market microstructure.

In the last decade, Merton has devoted much effort to deep questions about the interactions between the financial system and the economy, and the appropriate role for public policy. This work is accessible in [CMF$^+$95], a book of great importance for students of India’s financial system.

The 1996 edition of the perennial classic of finance, *A Random Walk down Wall Street* by Burton G. Malkiel [Mal96] has a chapter on derivatives. It provides a basic perspective on financial markets, from the viewpoint of an investor in the markets, and integrates a treatment of derivatives with this. Two valuable introductory books on derivatives are [Hul91] and [Kol96].

The history of these ideas is presented in [Ber92], a highly readable account of the development of modern financial economics, and includes a treatment of option pricing. The more recent book [Ber96] is a history of risk and human ideas in measuring and controlling it, and has a considerable treatment of derivatives. [Bla89] tells the story of the option pricing formula from Fischer Black's point of view. The option pricing formula has been the subject of intense interest in many unexpected quarters, an example of this is [Cor90]. Fischer Black died on 30 August 1995, and his partners take stock of his work in [MS95].

Turning to thorough textbooks, a good book where the pricing of derivatives can be learned is [Hul96]. The book [Hul91] can be viewed as a bridge to [Hul96] for those lacking the requisite preparation. Another useful book, with a greater focus on applications and institutional details, is [Dub92]. One of the best thorough treatments of futures markets is found in [Kol94]. The companion book on options markets is [Kol95]. Classic articles from the derivatives literature are collected together in [Kol97] and [Mal97].

Background material on India's financial markets, and the role for derivatives therein, is found in [ST97] and [ST00]. Some of the policy issues concerning derivatives in India are addressed in [ST00].

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