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IS ECONOMICS PERFORMATIVE? OPTION THEORY AND THE CONSTRUCTION OF DERIVATIVES MARKETS

BY
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The thesis that economics is "performative" (Callon 1998) has provoked much interest but also some puzzlement and not a little confusion. The purpose of this article is to examine from the viewpoint of performativity one of the most successful areas of modern economics, the theory of options, and in so doing hopefully to clarify some of the issues at stake.[1] To claim that economics is performative is to argue that it *does* things, rather than simply describing (with greater or lesser degrees of accuracy) an external reality that is not affected by economics. But *what* does economics do, and what are the effects of it doing what it does?

That the theory of options is an appropriate place around which to look for performativity is suggested by two roughly concurrent developments. Since the 1950s, the academic study of finance has been transformed from a low-status, primarily descriptive activity to a high-status, analytical, mathematical, Nobel-prize-winning enterprise. At the core of that enterprise is a theoretical account of options dating from the start of the 1970s. Around option theory there has developed a large array of sophisticated mathematical analyses of financial derivatives. (A "derivative" is a contract or security, such as an option, the value of which depends upon the price of another asset or upon the level of an index or interest rate.)

Also since the start of the 1970s, financial markets themselves have been transformed. In 1970, many modern financial derivatives were still illegal, and trading in others was sparse. By December 2004, financial derivatives contracts totaling \$295

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[1] This article was to be the basis of the "Distinguished Guest Lecture" at the 2005 annual meeting of the History of Economics Society, which I was unfortunately unable to attend because of family illness. The article was made possible by a Professorial Fellowship awarded by the UK Economic and Social Research Council (RES-051-27-0062). It builds upon three existing papers on option theory and its practical applications—MacKenzie and Millo (2003), MacKenzie (2003), MacKenzie (2004)—and responds in particular to discussion of the thesis of "performativity" at the meeting on "The Performativities of Economics," Paris, August 29–30, 2005. For example, Didier's attack (Didier 2004) on linguistic notions of "performativity" convinced me that what I had been calling "Austinian performativity" was better called "Barnesian performativity," because the invocation of Austin could be read as suggesting that the performativity of economics was a linguistic matter. For historical details of the case discussed here, the above papers and MacKenzie (2006) should be consulted.

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trillion were outstanding worldwide,[2] an astonishing figure that corresponds to roughly $46,000 for every human being on earth. The figure overstates the economic significance of derivatives in a variety of ways, but even if we take account of that by reducing it by a factor of a hundred, which is probably the order of magnitude of an appropriate correction, financial derivatives remain one of the world's most important markets. What is the connection between these two developments? In particular, what has been the role of the theory of options and of similar derivatives in the transformation of the markets for such derivatives?

This article proceeds as follows. First comes a brief account of its substantive subject-matter: the economic theory of options. A second section discusses, in the context of option theory, two basic versions of the thesis that economics is performative: the versions that I call "generic performativity" and "effective performativity" (see figure 1). The former describes cases in which an aspect of economics such as option theory is used in economic practice. The latter designates the subset of cases in which the use of economics "makes a difference": for example, economic processes in which economics is drawn upon are different from those from which it is absent. The section illustrates "generic" and "effective" performativity by discussing how option theory was used in option trading, focusing on the key material mediator between the theory and the crowded trading floors of options exchanges (paper sheets of theoretical prices), on the role of option theory in making derivatives trading seem legitimate, and on the incorporation of the theory into market vernacular.

The article's third section distills out from effective performativity a particular, strong version of the thesis of performativity that I call "Barnesian performativity." In this, an effect of the use in practice of an aspect of economics is to make economic processes more like their depiction by economics, and evidence that this may have been the case for option theory is presented. A fourth section invokes the critique of J. L. Austin's linguistic philosophy of performativity by sociologist Pierre Bourdieu to examine why option theory was able to have the strong effects suggested by the preceding sections, while a fifth section examines the extent to which the use of the theory played a role in making its assumptions (originally greatly at odds with the empirical reality of markets) less unrealistic. The penultimate section of the article, however, examines ways in which classic option theory became "less true" after the 1987 stock market crash, and briefly points to the possibility (discussed in more detail in MacKenzie 2004) that a practical application of the theory—so-called "portfolio insurance"—exacerbated the crash. If it did, it would be an instance of what I call "counterperformativity": the use of a theory or model making economic processes *less* like their depiction by economics. The article's seventh section is its conclusion.

I. THEORIES OF OPTIONS

An option is a contract that gives the right, but does not impose the obligation, to buy (or, in an alternative form of contract, to sell) a set quantity of a particular asset at a set price on, or up to, a given future date. If the contract is an option to buy, it is referred to

[2] Data from Bank for International Settlements, www.bis.org, accessed August 10, 2005.

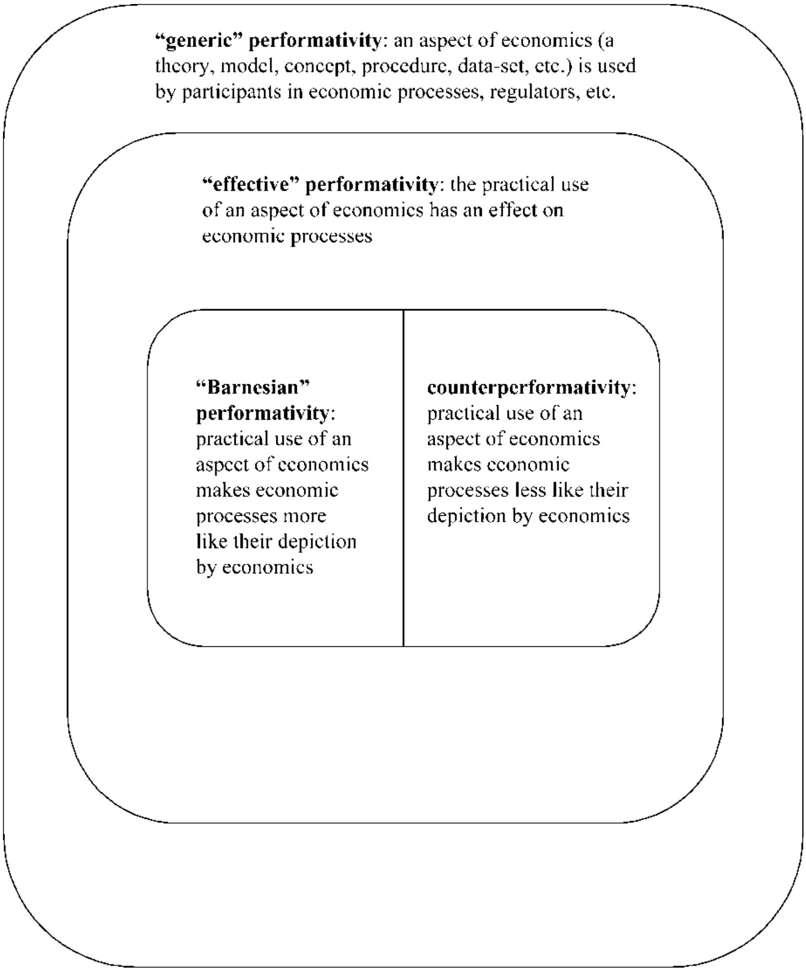

Figure 1. A possible classification of the performativity of economics. The depicted sizes of the subsets are arbitrary: I have not attempted to estimate the prevalence of the different forms of performativity

as a "call" option; an option to sell is a "put" option. If the option can be exercised at any point up to its expiration, it is called an "American" option; if it can be exercised only at its expiration, it is "European."[3] The asset in question is classically a block of stock (typically 100 shares), but options can also be written on many other assets: gold, oil, wheat, and other physical commodities; stock indices and other more abstract assets, and so on.

[3] The terms "European" and "American" originally pointed to geographical differences in typical options contract, but that is no longer the case: "European" as well as "American" options are now traded in the U.S., and "American" options in Europe. There are also forms of option more complex than these, but they need not concern us.

A central question for the theory of options is to explain how much options cost. Intuition suggests certain parameters that can be expected to play a role in determining the cost of an option: the current price of the underlying asset; the option's strike or exercise price (the price at which it permits the underlying asset to be bought or sold); the length of time to the option's expiration; the level of interest rates; whether the price of the underlying asset tends to be stable or to fluctuate considerably (in other words, the "volatility" of the price of the underlying asset); whether the price of the underlying asset is expected to rise or to fall. Unaided intuition is, however, not sufficient to go beyond this list to a formula for the option price. Nor is practical experience decisive in this respect. Options have been traded since at least the seventeenth century, and market practitioners developed rules of thumb for pricing options, but those rules of thumb did not add up to a precise or comprehensive theory.

Although there were efforts in Europe around the turn of the twentieth century to construct a theory of options,[4] the key developments from the viewpoint of this article took place in the U.S. from the late 1950s onwards. As a new specialty of "financial economics" coalesced (Whitley 1986a and b, Bernstein 1992, Mehrling 2005, MacKenzie 2006), particular attention was placed upon stock price movements. Those movements, it was suggested, had the form of what statisticians call a "random walk": the change in the price of a stock could be viewed as a random (probabilistic) variable, the distribution of which in any given time period was independent of its changes in previous time periods. The precise statistical form of the distribution was a matter of some controversy (of which more below), but increasingly one particular form, the log-normal distribution, was regarded as canonical. In other words, changes in the natural logarithms of stock prices were modeled as following the normal distribution, the well-known "bell-shaped curve" of statistical theory.

With a well-established mathematical model of stock-price changes, working out the value of an option seemed a tractable problem. Several researchers (including economists Paul Samuelson, Case Sprenkle, and James Boness, and mathematician and arbitrageur Edward Thorp) used the log-normal model to construct formulae for the value of an option (see MacKenzie 2003). Unfortunately, their solutions involved parameters the values of which were extremely hard to determine empirically, notably investors' expectations of returns on the stock in question and the degree of investors' risk-aversion (the extent to which they demand a higher expected return from an investment with an uncertain pay-off than from one whose pay-off is sure).

By the start of the 1970s, however, work by financial economists Fischer Black and Myron Scholes, with key additional input from their colleague Robert C. Merton, produced what has become the canonical theory of options (Black and Scholes 1973, Merton 1973). Although there were significant differences among the trio in how they approached the problem (MacKenzie 2003, Mehrling 2005), their core argument can be expressed as follows. They assumed that a stock price fluctuates log-normally (with a fixed level of volatility), that the stock can be bought or sold at any point in time without incurring transaction costs or causing market prices to move, that the stock "pays no dividends," that options are "European," that money can both be

[4] This early work on option theory includes the now celebrated work of Louis Bachelier (1900) and the more recently rediscovered work of a Trieste actuarial professor, Vinzenz Bronzin (1908; see also Zimmermann and Hafner n.d.).

borrowed and loaned at an identical, constant "riskless" rate of interest, and that short selling (sale of a borrowed asset) incurs no financial penalty (Black and Scholes 1973, p. 640). They showed that given these assumptions it was possible to construct a portfolio of an option and a continuously adjusted position in the underlying asset and lending/borrowing of cash that was riskless: changes in the value of the option would be cancelled out exactly by changes in the value of the position in the asset and cash. Since this perfectly hedged portfolio was riskless, it must earn exactly the riskless rate of interest. If not, there would be an opportunity for arbitrage: a way of making a profit that demands no net outlay of capital and involves no risk of loss. Such an opportunity could not persist: option prices would adjust so that it disappeared.

This argument sufficed to derive the famous Black-Scholes option pricing equation, a differential equation linking stock price, option price, stock volatility, the riskless rate of interest, and time (equation 1 in the appendix). The characteristics of the option in question (put or call, exercise price, expiration date) enter in the form of a boundary condition. There are complications—a correction for dividend-paying stocks needed to be developed, and the analysis had to be extended from European options, for which there is a simple boundary condition, to American options, which can be much more complicated (see Merton 1973)[5]—but in at least the simpler cases explicit closed-form mathematical solutions were found. The key such solution, the Black-Scholes formula for the price of a call option on a stock that pays no dividends, is given in the appendix (equation 2).

The Black-Scholes-Merton model was an elegant piece of reasoning that swept away many of the complexities of earlier work on options. Critical is the fact that the mechanism imposing Black-Scholes-Merton option pricing is arbitrage. The extent of investors' risk aversion and whether investors expect stock prices to rise or fall are irrelevant: if the price of an option deviates from its Black-Scholes value, a risk-free profit opportunity that demands no net capital investment is created.

The Black-Scholes-Merton model is a defining—perhaps *the* defining—achievement of modern financial economics: it won Scholes and Merton the 1997 Nobel Prize (Black died in 1995, and the prize is never awarded posthumously). Of course, option pricing theory did not end with their canonical work. It was elaborated rapidly and successfully by themselves, especially by Merton, and by others (MacKenzie 2006). The analysis was extended to corporate securities other than options (for example, debt securities) and broadened to stochastic processes other than the log-normal and to more general "martingale" models. To the analysis were added features such as variable rates of interest, differential rates for borrowing and lending, and stochastically fluctuating levels of volatility. A development of particular practical importance was the binomial model elaborated in Cox, Ross, and Rubinstein (1979), which especially lent itself to computerized numerical solution. It incorporated Black-Scholes-Merton as a special case, and facilitated the analysis of American options. Indeed, the pricing of options and of related "derivative" securities has become the central topic of modern quantitative finance (see, e.g., Hull 2000),

[5] The key difficulty in regard to American options is that early exercise of an American put can be optimal, causing its price to diverge from that of a European put: "there is almost always a positive probability of premature exercising of an American put, and hence, the American put will sell for more than its European counterpart" (Merton 1973, p. 158).

while the theory of "real options" (decisions that involve implicit options) is of wide interest as a methodology for the analysis and improvement of decision-making.

There is a sense in which, in the long run, the Black-Scholes-Merton model has been less important to quantitative finance than the novel methodology involved in its derivation by Scholes and Merton.[6] (In brief, to value a derivative, identify a "replicating portfolio" or perfect hedge—in other words, a continuously-adjusted portfolio of more basic assets that has the same pay-off as the derivative in all states of the world—and then invoke the fact that a position that consists of a perfectly hedged derivative is riskless, and thus can earn only the riskless rate of interest.) Nevertheless, the fact that this methodology had a canonical product—the Black-Scholes-Merton option model—is helpful from the viewpoint of this article, because it enables us to give a specific focus to an enquiry into the performativity of option theory.

II. PERFORMING ECONOMICS

What might it mean to say that an area of economics such as option pricing theory is "performative"? At the most general level, the term "performative" involves no specific reference to economics and connotes a general theoretical stance: the postulates that "phenomena only exist in the doing of them" and "they have to be continuously performed to exist at all" (Callon 2004). The performances that are of interest will normally involve acts by human beings, but typically not by unaided human beings: central to the "actor-network theory" developed by Callon and his colleague Bruno Latour is the view that the "actants" involved in the production of phenomena include non-human entities as well as human beings (see Callon 1986 and Latour 1987).

Clearly, there are tricky questions of scope here. For example, only an extreme biological determinist would consider denying that gender is a phenomenon that is performed; but it is harder to see what might be involved in a claim that a mountain is performed. Fortunately, these more general questions can be set aside for the purposes of this article, because it is clear that markets are among the phenomena that "only exist in the doing of them." However, the fact that matters could hardly be imagined to be otherwise suggests that we have to narrow the terms of the discussion to escape truism.

One way of doing so is to follow Callon in the investigation of the way in which entities have to be "disentangled" (for example, the ties between goods and people must be made capable of being cut in such a way that the ownership of goods becomes transferable) and calculations have to be "framed" (for example, the costs that need to be calculated have to be separated from the "externalities" that need not be taken into account) so that transactions can take the form of markets, rather than the myriad of other forms in which human beings can organize their relations to each other and to the world of non-human entities. (An example of the often-hidden work of market construction is Petter Holm's examination of the way in which the creation of a definable, measurable "cyborg fish" was the foundation for the establishment of a market in individual, transferable fishing quotas: see Holm

[6] The original derivation by Black was a direct invocation of the capital asset pricing model, see MacKenzie (2003) and Mehrling (2005).

2003.) A related direction of inquiry is to focus on one or more of the clusters of practices—law, marketing, accounting, and so on—that contribute to the performance of markets.[7]

Economics, argues Callon (1998), is among the practices that perform markets. What does this claim mean? The most basic level of its meaning is what I call "generic performativity": an aspect of economics (a procedure, a model, a theory, a data set, or whatever) is used in economic practice. However, though that is in principle something that can readily be determined by simply observing those who take part in the economic process in question, it is not in itself of great interest. For a claim of performativity to be interesting, for the use of economics to constitute what I call "effective" performativity, an aspect of economics must be used in a way that has effects on the economic processes in question. The incorporation of the aspect of economics into the collective calculation devices (Callon and Muniesa 2003) that constitute markets must *make a difference*: economic processes incorporating the aspect of economics must differ from their analogues in which economics is not incorporated.

To what extent was option theory used in economic processes and what effects did that use have? The first modern organized options exchange opened in Chicago on April 26, 1973. The key paper (Black and Scholes 1973) had not yet appeared in print (it was in the May-June issue of the *Journal of Political Economy*), but before or immediately after the options exchange opened at least two participants, Mathew Gladstein (see below) and arbitrageur Ed Thorp (MacKenzie 2003), were aware of the model and ready to employ it. Within a couple of years, they were joined by many others.

The Black-Scholes-Merton model's core was a differential equation (equation 1 in the appendix) that would have been opaque to anyone without college-level training in mathematics. Even in the simple case of a call option on a non-dividend-bearing stock (appendix, equation 2), an unaided human cannot realistically be expected to calculate a Black-Scholes price. At the very least, tables of natural logarithms and of the distribution function of a normal distribution are needed.[8] However, calculating prices manually in this way is clearly both time-consuming and tedious. It was far more attractive to program computers (or the programmable calculators that were becoming available in the mid 1970s) to produce Black-Scholes prices.

Both computers and calculators had limitations, however, as material mediators between the Black-Scholes-Merton model and the key arenas within which options were bought and sold: the "open-outcry" trading floors of Chicago and of the other options exchanges, in which contracts were made by voice and by hand signals. The computer systems of the 1970s could not in practice be used while trading on such floors and, despite a widespread impression to the contrary in sources such as Passell (1997), most traders seem to have regarded the calculators as too slow: even the few seconds it would take to input parameter values and obtain a solution could mean

[7] A collection of such studies, informed to varying degrees by Callon's analysis, can be found in Callon (1998).

[8] Experienced option traders can in practice mentally estimate Black-Scholes prices. However, they do not do this by inputting parameter values into formulae such as equation 2 of the appendix. Rather, they seem to draw upon their long experience of Black-Scholes pricing. Their "mental" solutions are thus in a sense derivative of the "material" solutions described in the text.

loss of profitable trading opportunities. Few "use [programmable calculators] regularly for option evaluation after the initial novelty wears off" (Gastineau 1979, p. 270).[9]

Instead, an old technology formed the key mediator between the model's mathematics and the shouting, sweating, gesticulating, jostling human bodies on the trading floors: paper. Away from the hubbub, computers were used to generate Black-Scholes prices. Those prices were reproduced on sets of paper sheets which floor traders could carry around, often tightly wound cylindrically with only immediately relevant rows visible so that a quick squint would reveal the relevant price. While some individual traders and trading firms produced their own sheets, others used commercial services. Perhaps the most widely used sheets were sold by Fischer Black himself: see figure 2. Each month, Black would produce computer-generated sheets of theoretical prices for all the options traded on U.S. options exchanges, and have them photocopied and sent to those who subscribed to his pricing service. In 1975, for example, sheets for 100 stocks, with three volatility estimates for each stock, cost $300 per month, while a basic service with one stock and one volatility estimate cost $15 per month (Black 1975b).

At first sight, Black's sheets look like monotonous arrays of figures. They were, however, beautifully designed for their intended role in "distributed cognition" (Hutchins 1995a and b). Black included what options traders using the Black-Scholes-Merton model needed to know, but no more than they needed to know—there is virtually no redundant information on a sheet—hence their easy portability. He found an *ad hoc* but satisfactory way of dealing with the consequences of dividends for option pricing (an issue not addressed in the original version of the model), and devoted particular care to the crucial matter of the estimation of volatility.[10] Even the physical size of the sheets was well-judged. Prices had first to be printed on the large computer line-printer paper of the period, but they were then photo-reduced onto standard-sized paper, differently colored for options traded on the different exchanges.[11] The resultant sheets were small enough for easy handling, but not so small that the figures became too hard to read (the reproduction in figure 2 is smaller than full-scale).

How were Black's sheets and similar option pricing services used? They could, of course, simply be used to set option prices. In April 1976, options trading began on the Pacific Stock Exchange in San Francisco, and financial economist Mark Rubinstein became a trader there. He told me in an interview that he found his fellow traders on the new exchange initially heavily reliant on Black's sheets: "I walked up [to the most active option trading 'crowd'] and looked at the screen [of market prices]

[9] An additional particular difficulty was making the necessary adjustment to Black-Scholes to take into account the payment of dividends, which "on a hand calculator is difficult and time-consuming" (Gastineau 1979, p. 269).

[10] Black (1975b, p. 5):

> My initial estimates of volatility are based on 10 years of daily data on stock prices and dividends, with more weight on more recent data. Each month, I update the estimates. Roughly speaking, last month's estimate gets four-fifths weight, and the most recent month's actual volatility gets one-fifth weight. I also make some use of the changes in volatility on stocks generally, of the direction in which the stock price has been moving, and of the "market's estimates" of volatility, as suggested by the level of option prices for the stock.

[11] I am grateful for this information to Clay Struve, who as a MIT undergraduate in the 1970s earned money doing such tasks for Black's option service.

— I UNITED STATES STL CORP

EXPIRATION	ANN INT	ANN DEV	DIV AMT	EX DATE
JLY 16 76	5.650%	21.00%	$.4700	8/ 4/76
OCT 15 76	6.230%	21.00%	$.4700	11/ 3/76
JAN 21 77	6.630%	21.00%		

ANEX I 2 OF 7

		06/04/76			06/11/76			06/18/76			06/25/76			07/02/76		
		JLY 76	OCT 76	JAN 77	JLY 76	OCT 76	JAN 77	JLY 76	OCT 76	JAN 77	JLY 76	OCT 76	JAN 77	JLY 76	OCT 76	JAN 77
45																
	40	5.31	5.85	6.50	5.25	5.78	6.43	5.19	5.70	6.36	5.18	5.63	6.29	5.09	5.56	6.22
	45	1.43	2.52	3.39	1.29	2.43	3.32	1.16	2.34	3.24	.977	2.25	3.17	.787	2.16	3.09
	46.7	.727	1.77	2.63	.609	1.69	2.56	.488	1.61	2.49	.352	1.53	2.42	.213	1.48	2.35
	50	.127	.796	1.51	.083	.736	1.45	.046	.676	1.39	.019	.617	1.33	.004	.559	1.27
	53.3	.013	.313	.809	.006	.278	.766	.002	.244	.724	.000	.212	.682	.000	.181	.641
	55	.003	.187	.580	.001	.162	.544	.000	.139	.509	.000	.117	.475	.000	.097	.442
	60	.000	.034	.197	.000	.027	.180	.000	.021	.163	.000	.016	.147	.000	.012	.132
	66.7	.000	.003	.040	.000	.002	.035	.000	.001	.030	.000	.001	.026	.000	.000	.022
	70	.000	.001	.017	.000	.000	.015	.000	.000	.012	.000	.000	.010	.000	.000	.008
46																
	40	6.28	6.73	7.33	6.23	6.66	7.27	6.18	6.59	7.20	6.13	6.52	7.13	6.09	6.45	7.06
	45	2.04	3.12	4.00	1.90	3.03	3.92	1.76	2.96	3.85	1.60	2.88	3.77	1.42	2.75	3.69
	46.7	1.19	2.26	3.15	1.00	2.17	3.08	.854	2.08	3.01	.693	1.99	2.93	.508	1.90	2.86
	50	.283	1.08	1.87	.175	1.01	1.80	.111	.937	1.74	.057	.867	1.68	.018	.797	1.61
	53.3	.031	.451	1.04	.016	.406	.990	.006	.363	.941	.001	.321	.892	.000	.281	.843
	55	.009	.278	.758	.004	.246	.716	.001	.214	.675	.000	.185	.634	.000	.157	.594
	60	.000	.056	.271	.000	.046	.250	.000	.037	.229	.000	.029	.208	.000	.022	.189
	66.7	.000	.005	.059	.000	.003	.052	.000	.002	.046	.000	.002	.040	.000	.001	.034
	70	.000	.001	.026	.000	.001	.022	.000	.001	.019	.000	.000	.016	.000	.000	.013
47																
	40	7.27	7.64	8.20	7.22	7.58	8.14	7.17	7.51	8.07	7.13	7.45	8.00	7.09	7.38	7.96
	45	2.76	3.78	4.66	2.63	3.69	4.58	2.50	3.60	4.50	2.37	3.51	4.42	2.22	3.41	4.35
	46.7	1.67	2.81	3.73	1.52	2.72	3.65	1.37	2.63	3.58	1.20	2.53	3.50	1.00	2.44	3.42
	50	.430	1.42	2.28	.334	1.34	2.21	.239	1.26	2.14	.147	1.18	2.07	.065	1.10	2.00
	53.3	.068	.630	1.31	.040	.576	1.26	.019	.523	1.20	.006	.470	1.14	.001	.419	1.09
	55	.022	.403	.972	.011	.360	.924	.004	.319	.876	.001	.280	.828	.000	.243	.781
	60	.000	.098	.366	.000	.078	.339	.000	.061	.313	.000	.049	.288	.000	.038	.264
	66.7	.000	.008	.085	.000	.006	.076	.000	.005	.067	.000	.003	.059	.000	.002	.051
	70	.000	.002	.039	.000	.002	.034	.000	.001	.029	.000	.001	.025	.000	.000	.021
48																
	40	8.26	8.58	9.10	8.22	8.52	9.03	8.17	8.45	8.97	8.13	8.39	8.90	8.09	8.33	8.84
	45	3.57	4.50	5.36	3.46	4.41	5.29	3.35	4.32	5.21	3.24	4.23	5.13	3.14	4.14	5.05
	46.7	2.31	3.43	4.36	2.17	3.34	4.28	2.03	3.24	4.20	1.87	3.15	4.12	1.69	3.05	4.04
	50	.707	1.82	2.75	.589	1.74	2.67	.458	1.65	2.60	.325	1.56	2.52	.188	1.47	2.45
	53.3	.135	.857	1.63	.088	.793	1.57	.049	.729	1.50	.020	.666	1.44	.004	.603	1.38
	55	.047	.562	1.23	.027	.511	1.17	.012	.461	1.12	.003	.411	1.06	.000	.363	1.01
	60	.001	.135	.485	.000	.115	.453	.000	.096	.421	.000	.080	.390	.000	.064	.360
	66.7	.000	.015	.120	.000	.011	.108	.000	.008	.096	.000	.006	.085	.000	.004	.075
	70	.000	.004	.057	.000	.003	.050	.000	.002	.043	.000	.001	.038	.000	.001	.032

IF YOU HAVE ANY QUESTIONS, PLEASE CALL FISCHER BLACK AT 617-253-6691

DATE: 05/25/76 TIME: 23:13 I 2 OF 7

Figure 2. One of Black's sheets (private papers of Mark Rubinstein; reproduced courtesy of the estate of Fischer Black). The numbers on the extreme left hand side of the table are stock prices, the next set of numbers are strike prices, and the large numbers in the body of the table are the Black-Scholes values for call options with given expiry dates (e.g., July 16, 1976) on the Fridays of successive weeks (e.g., June 4, 1976). The smaller numbers in the body of the table are the option "deltas" (see text). The data at the head of the table are interest rates, Black's assumption about stock volatility, and details of the stock dividends

and at the sheet and it was identical. I said to myself, 'academics have triumphed'" (Rubinstein 2000).

It was unusual to find such a close fit between the "sheets" and market prices. However, if there was a divergence, sheets such as Black's could be employed to identify over-valued options to sell (and sometimes also under-valued options to buy). None of the option pricing models directly yielded a theoretical options price: all required input of parameters, the values of which had to be determined by empirical estimation and sometimes by judgment. Black-Scholes-Merton was the most parsimonious in this respect, but even it requires an estimate of stock volatility that cannot be formed solely by analysis of past stock-price fluctuations, since it is *future* volatility that matters to the price of an option. There were, however, plentiful cases in the early months of the operation of the Chicago Board Options Exchange and in the *ad hoc* New York "put and call" market that preceded it, in which, according both to contemporary testimony (Wellemeyer 1973) and to retrospective accounts (in the oral history interviews drawn on in this paper),[12] there was a clear discrepancy between the market prices of

[12] For details of the interviewing, see MacKenzie and Millo (2003) and MacKenzie (2006).

options and the Black-Scholes prices generated by plausible volatility estimates. Typically, market prices tended to be substantially *above* Black-Scholes prices.

The Black-Scholes-Merton model and many of its successors (its predecessors were generally less explicit in this respect) did more than provide a guide to option prices: they also suggested how the risks involved in taking positions in the options market could be minimized. The continuously-adjusted offsetting position in the underlying asset and cash invoked in the mathematical derivation of the Black-Scholes equation could, at least in principle, be constructed in reality, via the practice that market participants came to call "delta hedging." The requisite size of the position in the underlying asset is determined in the Black-Scholes analysis by the option's "delta," the constantly-changing but readily-calculable partial derivative of the option price with respect to the stock price. As will be seen in figure 2, the subscribers to Black's option service received not just theoretical prices but also delta values. A delta of 96, for example, indicated to a trader who had sold a call option (on a block of 100 shares) that the number of shares that had to be bought to hedge the call was 96.

Because deltas constantly changed, the practical implementation of more than a rough proxy for delta hedging would in most cases incur excessively high transaction costs. However, even an options market participant who would find it too expensive to delta hedge using stock could nonetheless draw upon the Black-Scholes-Merton model to perform the arbitrage operation that participants called "spreading" (see, for example, Galai 1977, pp. 189–94). This operation, which appears to have been practiced widely, involved using the model to identify pairs of options on the same underlying stock, in which one option was, according to the model, underpriced relative to the other. Traders could then buy the underpriced option and sell its overpriced counterpart, and a simple modification to the Black-Scholes analysis showed how to minimize exposure to the risk of fluctuations in the price of the underlying stock by making the sizes of purchases and sales inversely proportional to the options' deltas.

Although "spreading" was in use before Black began his option service, the introduction to it that Black provided to its subscribers told them, in his characteristically clear and straightforward prose, how to use the sheets to exploit opportunities for spreading:

> An investor who wants to set up a spread between two maturities or two striking prices can use the option values [theoretical prices] to decide when to do the spread, and the delta factors to decide how many contracts to have on each side. A spread makes sense if the short side [the options to be sold] is overpriced and the long side [the options to be bought] is underpriced; or if the short side is more overpriced than the long side; or if the short side is less underpriced than the long side.
>
> To find out how many contracts to use on each side of a spread to make it low in risk for small movements of the stock, divide the two delta factors. If a January option has a delta factor of 15, and the corresponding April option has a delta factor of 30, then a low risk spread between these two options would involve two January contracts for each April contract (Black 1975b, p. 7).

Spreading was a direct, instrumental use of option theory. The theory could also be drawn upon to defend the legitimacy of the very idea of a market in options. Throughout their history, options had often been suspected of being simply wagers, bets upon stock-price movements. In the U.S. in the 1960s and 1970s, this suspicion was a basis for hostility on the part of regulators to permitting an options exchange (MacKenzie and Millo 2003). However, the Black-Scholes-Merton analysis disentangled options from the moral framework in which they were dangerously close to gambling, and framed them by showing how they could be priced and hedged as part of the normal operations of mature, efficient capital markets. Burton R. Rissman, the former counsel of the Chicago Board Options Exchange, told me in an interview:

> Black-Scholes was really what enabled the exchange to thrive ... [I]t gave a lot of legitimacy to the whole notions of hedging and efficient pricing, whereas we were faced in the late 60s-early 70s with the issue of gambling. That issue fell away, and I think Black-Scholes made it fall away. It wasn't speculation or gambling, it was efficient pricing. I think the SEC [Securites and Exchange Commission] very quickly thought of options as a useful mechanism in the securities markets and it's probably—that's my judgment—the effects of Black-Scholes. I never heard the word "gambling" again in relation to stock options traded on the Chicago Board Options Exchange (Rissman 1999).

Option theory was thus used as a guide to trading and to hedging, and also to legitimate options markets. For these uses to qualify as effective performativity, economic processes with the theory being used must differ from processes without it being used. It could be, for example, that option theory did no more than capture patterns in market prices that were already empirically present before the theory was developed. If that were so, the performativity involved would be so weak that the term that Didier (2004) draws from Deleuze, "expression," could well be preferable: option theory would just be expressing patterns that were already there, in the markets, in a "state of potentiality" (Didier 2004, p. 28). Alternatively, it could be that economists were operating simply as "hired hands" whose intervention did not change economic processes in any truly significant way.[13] If either were the case, we would be dealing only with generic, not effective, performativity.

Broad features of the Black-Scholes-Merton model were already present in the patterns of prices in markets prior to the formulation of the model.[14] However, there were also significant discrepancies between the model and pre-existing price patterns. One of Scholes's students obtained access to the diaries of a broker in the *ad hoc* put-and-call market for the years 1966–1969, and Black and Scholes used the prices recorded in the diaries to test the model, finding that "in general writers [the issuers of options] obtain favorable prices, and ... there tends to be a systematic mispricing of options as a function of the variance of returns of the stock" (Black and Scholes 1972, p. 413). Similarly, when the Chicago Board Options Exchange opened for trading "initially prices were not in line with prices predicted from using the Black-Scholes model" (Scholes 1998, p. 486).

[13] See Mirowski and Nik-Khah (2004).

[14] Thus, empirical investigation of the prices of warrants (a form of call option written by corporations themselves) by Thorp and Kassouf had confirmed the intuitively obvious conclusion that "Warrants that are closer to expiring are worth less, all other factors being equal" (Thorp and Kassouf 1967, p. 31), a feature shared by the Black-Scholes-Merton model (Black and Scholes 1973, p. 638).

These discrepancies suggest that the Black-Scholes-Merton model did more than simply express price patterns that were already there. As I shall argue below, there is reason to think that the use of the model altered price patterns. The model also provided capacities for coordinated action that did not exist prior to its development. That is at its clearest with respect to the notion of "implied volatility." In this, Black-Scholes-Merton or a similar option-pricing model is run "backwards," to work out by iterative solution the level of volatility of the underlying asset consistent with the price of options on the asset. The procedure condenses considerable complexity (a plethora of differently priced put and call options with different strike prices and different expiry dates, and perhaps more complex forms of option as well) to a single set of easily compared and easily understood numbers. In the case of stock-index options, for example, implied volatilities of twenty percent per annum or less are generally taken to indicate "normal" conditions; thirty percent per annum indicates serious disquiet about the future; forty percent per annum indicates deep crisis.

"Implied volatility" is an inherently theoretical notion: its values cannot be calculated without an option pricing model. By simplifying the options markets' complexity to a common metric, "implied volatility" allowed the burgeoning trading firms of the 1970s, such as O'Connor and Associates, to expand and extend their activities by coordinating teams of floor traders operating on geographically dispersed options exchanges. What was being traded on these exchanges, the firms reasoned, was the Black-Scholes-Merton model's fundamental parameter: volatility. O'Connor traders were provided with "sheets" from which they could calculate the implied volatilities of the options being bought and sold on trading floors. They would report these implied volatilities by hand signals to the O'Connor booths beside the trading floors and thus to the firm's headquarters. For example, "I can buy Arco [oil company Atlantic Richfield] on a 15," in other words, purchase options the price of which implied a fifteen percent per annum volatility of Atlantic Richfield stock. As the trader who told me this said, there would be "two or three people sitting upstairs saying 'Mickey can buy Arco on a 15. Someone in San Francisco can buy Santa Fe on a 13.' They're both big oil companies ... if you thought all oil stocks were similar ... you'd certainly rather buy one on 13 than a 15 ... [So] they'd say 'don't buy any'." Coordination was greatly facilitated by the way in which strategies involving a multiplicity of different transactions could be talked about very simply: "we would have a morning meeting, and [Michael] Greenbaum [founder of O'Connor and Associates] would say, 'The book isn't long enough volatility. We're looking to buy some,' or 'We bought too much yesterday. We're looking to be less aggressive'."[15]

Later, paper sheets were replaced by more sophisticated material mediators between option pricing models and floor traders, such as the "Autoquote" system described in MacKenzie and Millo (2003). The key point, however, is that option theory was and is embedded in artifacts that play essential roles in the operation of options exchanges. Just as "speed cards" and "speed bugs" are part of "How a Cockpit Remembers its Speeds" (Hutchins 1975b), so material implementations of the Black-Scholes-Merton model and its variants became part of how an options exchange calculates options.

[15] See MacKenzie and Millo (2003).

III. BARNESIAN PERFORMATIVITY

That the Black-Scholes-Merton model was not originally a close empirical description of patterns of option prices, and that it was widely used as a guide to trading by participants in options markets raise the intriguing possibility that the model was performative in an especially strong sense: that its use brought about a state of affairs of which it was a good empirical description. Let me call this possibility Barnesian performativity, after the sociologist of science and social theorist Barry Barnes.

"I have conceived of a society," writes Barnes, "as a distribution of self-referring knowledge substantially confirmed by the practice it sustains" (1988, p. 166). Consider the simple example of money.[16] A metal disc or piece of paper is not money by virtue of its physical and chemical properties alone; it is money because it is believed to be a medium of exchange and store of value, and that belief is validated by the practices it informs. Our shared belief that the pieces of paper we call "dollar bills" are money leads us to treat those pieces of paper in ways that make them constitute money. Space prohibits exploration of the underlying social theory advanced by Barnes (see Barnes 1983, 1988). Instead, I use the term "Barnesian" simply as a label for a particular subset of the performativity of economics: the subset in which an aspect of economics is used in economic practice, its use has effects, and among those effects is to alter economic processes so as to make them more like their depiction by economics. The Black-Scholes-Merton model would have been performative in the Barnesian sense if practices informed by the model altered economic processes towards conformity with it—for example, if they shifted patterns of market prices towards what the model postulated—thus making the model an instance of "knowledge substantially confirmed by the practice it sustains."

Another way of expressing Barnesian performativity is in the idiom of actor-network theory. As Bruno Latour puts it: "Knowledge ... does not reside in the face-to-face confrontation of a mind with an object ... The word 'reference' designates the quality of the chain in its entirety ... Truth-value circulates" (Latour 1999, p. 69, emphases in original deleted). The suggestion that the Black-Scholes-Merton model may have been performative in the Barnesian sense is the conjecture that the use of the model was part of the chain by which its referential character—its fit to "reality"—was secured.

That this might be the case is suggested by the way in which the discrepancies between model and market seem to have diminished rapidly in the years after the model's publication in 1973. The key difficulty in judging the fit between model and market is the need to input an estimate of volatility before the model yields an option price. As noted above, what is at issue is not past volatility, which can be measured statistically, but market participants' estimates of future volatility, which are not observable. The resultant difficulty was neatly sidestepped by Mark Rubinstein (1985), who, in the most thorough test of the fit of the Black-Scholes-Merton model to 1970s' prices, judged the fit without independently estimating volatility.

[16] See also Searle (1996).

Rubinstein constructed from matched pairs of observed option prices the estimate of volatility that minimized deviations from Black-Scholes values. Using a huge database of nearly all Chicago Board Options Exchange price quotations and transactions between August 1976 and August 1978, Rubinstein calculated the maximum deviations from the Black-Scholes prices implied by the deviation-minimizing volatility estimate. In the case of options on the same stock with the same time to expiration but different exercise prices, Rubinstein found typical deviations of around two percent. The fit of the model was by no means exact—some residual discrepancies were much higher than two percent—but by social-science standards it was strikingly good. When index options were introduced in the 1980s, the fit improved further: residual discrepancies for index options fell to around one percent (Rubinstein 1994, p. 774). By 1987, it could with some justice be said that: "When judged by its ability to explain the empirical data, option pricing theory is the most successful theory not only in finance, but in all of economics" (Ross 1987, p. 332).

Although the evidence is only circumstantial, it seems plausible that the "spreading" strategy helps explain the way in which the Black-Scholes-Merton model largely passed its key econometric tests by Rubinstein. In respect to strike prices,

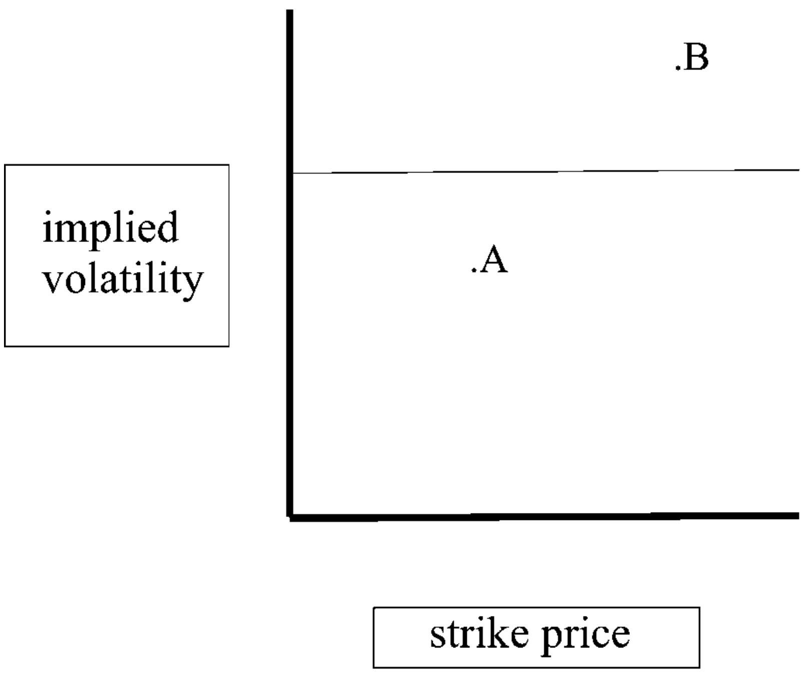

Figure 3. If the Black-Scholes-Merton model is correct, the implied volatility of all options on the same stock with the same time to expiration should be the same, so the graph of implied volatility against strike price should be a flat line. Rubinstein used this as a test of the empirical validity of the model. "Spreaders" used it as a way of profiting from price discrepancies. They used the model to identify relatively cheap options to buy (such as point A on the graph) and, simultaneously, relatively expensive options to sell (point B). Such trading could be expected to have the effect of flattening the graph

Rubinstein's test is essentially whether the graph of implied volatility against strike price is a flat line, as it should be on the model (see figure 3). It was precisely deviations from that flat line that "spreaders" were looking for, exploiting, and thus probably causing to diminish. Indeed, even the chief elegant feature of Rubinstein's test—its avoidance of the need independently to estimate volatility—had its counterpart in a practical virtue of spreading: the strategy of constructing offsetting options positions was "less sensitive to the estimated volatility of the stock" (Black 1975a, p. 40) than strategies that required taking a position in the stock. The crucial econometric test of the Black-Scholes-Merton model was thus isomorphic with the practical use of the model in spreading.

IV. CONDITIONS OF FELICITY

The philosopher J. L. Austin coined the term "performative" to designate utterances that *do* something: if I say "I apologize," or "I name this ship the *Queen Elizabeth*," or "I bet you sixpence it will rain tomorrow," then "in saying what I do, I actually perform the action" (Austin 1970, p. 235). There is a sense then that in invoking the notion of "performativity" one is always also invoking the critique of Austin by Pierre Bourdieu.

To analyze performative utterances using only linguistic philosophy is (as Didier also suggests, 2004, p. 1) to treat them as "magic." The "conditions of felicity" of a performative utterance "are social conditions," as Bourdieu (1991, p. 73) rightly points out. Only by analyzing these conditions can we understand the difference between the successful performance when a member of the Royal Family names a ship the *Queen Elizabeth* and the unsuccessful performance when a shipyard worker seeks to name it the *Mr Stalin* (Austin 1962, p. 23).

Thus, that sheets based upon the Black-Scholes-Merton model were available does not explain why they were bought and used. Even if the use of sheets was thought necessary, and not all options traders believed it was (MacKenzie and Millo 2003), Black's sheets were not the only options advisory service available in the late 1970s. Gastineau's *Stock Options Manual* (1975) listed three such services; the book's second edition (1979) listed fifteen. Of the latter, six did not offer option values, so were not directly comparable with Black's service. Five services, including Black's, offered theoretical prices generated from the Black-Scholes-Merton model or variants thereof. The remaining four services, however, used a different approach, offering option values based not upon theoretical reasoning but upon econometric analyses of observed option patterns: these analyses seem mainly to have been variants of the econometric work of Sheen Kassouf (1965).

Why might an options market participant in the 1970s have chosen to use Black's sheets or another material implementation of the Black-Scholes-Merton model? The answer might simply be because the sheets were a good guide to market prices, but, as noted above, the fit between model and market was not always close, especially in the earlier part of the decade. Although it is difficult to be certain of the reasons for the dominance of the Black-Scholes-Merton model, a number of factors seem likely to have been significant. One factor, perhaps the factor closest to Bourdieu's emphasis on the inter-relations of language, power, legitimacy, and cultural hierarchy, was the authority of economics. Financial economists quickly came to see the Black-Scholes-Merton model as superior to its predecessors. As noted above, it involved no non-observable parameters except for volatility, and it had a clear theoretical basis closely linked to the field's dominant viewpoint of efficient market theory. The Black-Scholes-Merton model thus "inherited" the general cognitive authority of financial economics in a political culture in which economics was a useful source of legitimacy, and in which, in particular, the status of financial economics was rising fast (MacKenzie 2006).

That the Black-Scholes-Merton model thus embodied the most authoritative account of what options "ought" to cost might well have been a factor for market participants with links to academia. However, while there were a number of such participants, Chicago floor traders in general were and are not in awe of professors. From their viewpoint, however, the model had the advantage of "cognitive" simplicity. The underlying mathematics might be complicated, but the model could be talked about and thought about relatively straightforwardly; its one free parameter of volatility was easily grasped, discussed, and reasoned about. Kassouf's model, in contrast, involved a regression equation with six coefficients that required econometric estimation (Kassouf 1965, p. 55). An options pricing service based on Kassouf's model would perform the requisite calculations, but from the user's viewpoint such a model was a black box: it could not be reasoned about and talked about in as simple a way as the Black-Scholes-Merton model could. The many variants of, modifications of, and alternatives to Black-Scholes-Merton that quickly were offered by other financial economists also had a crucial drawback in this respect: they typically involved a mental grasp of, and estimation of, more than one free parameter, and often three or more. As *The Stock Options Manual* put it, "the user of these complex models is called upon to deal with more unknowns than the average human mind can handle" (Gastineau 1979, p. 253).

Another factor underlying the success of the Black-Scholes-Merton model was simply that it was publicly available in a way many of its early competitors were not. As U.S. law stood in the 1960s and 1970s, it was unlikely that an options pricing model would be granted patent or copyright protection, so there was a temptation not to disclose the details of a model. Black, Scholes, and Merton, however, did publish the details, as did Sheen Kassouf (whose model was described in his PhD thesis). Keeping the detail private may have been perfectly sensible for those who hoped to make money from their models, but it was a barrier to the adoption of those models by others.[17]

Not only was the Black-Scholes-Merton model public, but the necessary material mediators, especially Black's sheets, were also available ($300 a month in dollars of the mid-1970s was no trivial cost, but it was within the means of major market participants, and it could of course be shared, with traders banding together to subscribe and then photocopying the sheets). In contrast, Gary Gastineau (author of *The Stock Options Manual*) developed, along with Albert Madansky of the University of Chicago, a model that Gastineau believed remedied what he felt were the deficiencies

[17] See Gastineau (1975, p. 184).

of Black-Scholes-Merton (see below). However, not only did he publish only "an outline of the general form" of his model, but he used its results "solely for the benefit of certain individual and institutional clients" (Gastineau 1979, pp. 203, 269), rather than making them available more widely in the form of an options pricing service. So Gastineau was in the paradoxical situation of being a critic of the Black-Scholes-Merton model who, nevertheless, felt compelled to recommend Black's sheets to the readers of his *Stock Options Manual*, which seems to have been the guide most widely used by newcomers to options trading: "Until another weekly service incorporates Black's service, his tables ... are the best evaluation data available to the average investor" (Gastineau 1979, p. 269).[18]

The situation was perhaps akin to the triumph of the publicly available IBM personal computer (PC) architecture over its proprietary rivals, especially Apple. Whether or not IBM's architecture was better than Apple's can be debated endlessly, but a key factor was that it (likewise the Black-Scholes-Merton model) was available for others to adopt in a way in which Apple's was not.

These three factors—the Black-Scholes-Merton model's high academic standing, its cognitive simplicity, and its PC-like public availability—were reasons for options traders to adopt it, for example by subscribing to Black's sheets and using them as a guide to trading. Beyond those factors, however, were two ways in which the model's use influenced the behavior of those who did not agree with it and even of those who did not know what it was. (One interviewee at the Chicago Board Options Exchange reported being asked "what's this Black-Scholes?" even in the early 1980s.)

The first such route of influence was market competition. As noted above, with plausible estimates of volatility the Black-Scholes-Merton model tended to generate option values that were below the market prices prevalent in the *ad hoc* put-and-call market and in the early months of the Chicago Board Options Exchange. For a critic of the model such as Gastineau, that was an indication that the model undervalued options. However, it also meant that market competition tended to drive option prices down towards Black-Scholes values. There is no fixed supply of options. Individuals and institutions can "write" (that is, issue) options whenever they believe that the prices for which they can be sold are advantageous.[19] If such individuals or institutions believe that Black-Scholes values are "correct," market prices above those values will be taken to indicate just such a situation.[20]

[18] See also Gastineau (1975, pp. 177–78). A specific factor influencing Gastineau's 1979 recommendation was that Black had been quick to incorporate into his service the results of analysis (by Parkinson 1977) of the pricing of American puts, a problem to which, as noted above, the Black-Scholes approach did not yield an immediate solution. Initially, the organized options exchanges in the U.S. were allowed to trade only calls, but in June 1977 put trading began (Cox and Rubinstein 1985, p. 24), creating a need for pricing puts.

[19] Assuming, that is, that they have the funds to meet the necessary brokers' commissions and requirements for "margin" deposits.

[20] Of course, the question arises of why the "downward pressure" on prices discussed in the text was not counterbalanced, as it appears not to have been, by purchases of options by those who believed that Black-Scholes prices were too low. Among the factors that may have been important were different budgetary constraints on those who were not market-makers but used the options exchanges (a) to write options or (b) to buy options. When organized options trading began in the early 1970s, "[o]ne of Wall Street's most widely held beliefs is that option buyers consistently lose money and option writers consistently make money" (Gastineau 1975, p. 138), a factor that may

The process began the very day the Chicago Board Options Exchange opened for trading. Mathew Gladstein of the securities firm Donaldson, Lufkin, and Jenrette had contracted with Scholes and Merton to provide theoretical prices ready for its opening:

> [T]he first day that the Exchange opened . . . I looked at the prices of calls and I looked at the model and the calls were maybe 30–40 percent overvalued! And I called Myron [Scholes] in a panic and said, "Your model is a joke," and he said, "Give me the prices," and he went back and he huddled with Merton and he came back. He says, "The model's right." And I ran down the hall . . . and I said, "Give me more money and we're going to have a killing ground here" (Gladstein 1999).

From Gastineau's viewpoint, the resultant process was alarming: "Widespread use of the Black-Scholes model by institutional investors may have the effect of both depressing and distorting actual option premiums" (Gastineau 1975, p. 200), but from another viewpoint it was a performative effect of the model. Black-Scholes prices were, in a sense, imposed even upon those writers of options who believed such prices to be too low: they either had to lower the prices at which they sold options, or see their business taken away from them by the adherents of Black-Scholes.

The second mechanism by which others' adherence to Black-Scholes-Merton influenced the behavior of traders who did not believe in it was via risk-management practices (see Millo forthcoming). If a trader on an organized options exchange became bankrupt, his or her clearing firm inherited his or her liabilities; if a clearing firm failed, the other such firms bore its liabilities. There was, therefore, a strong incentive to monitor traders' risk-taking: as an anonymous interviewee put it, "If you're guaranteeing people's trades, you don't want them making stupid bets with your money."

Assessing the risks being taken by a trader was far from simple: he or she might hold dozens of option positions and perhaps positions in the underlying stock as well. The Black-Scholes-Merton model's deltas could, however, be aggregated to a single measure of exposure to the price movements of a given stock. If a trader's aggregate delta was close to zero, his or her positions were "delta-neutral" and could be considered reasonably well-hedged; if the delta was substantial, then his or her positions were, in aggregate, risky. Sophisticated risk managers learned not to stop at delta, but also to consider the other measures colloquially known as "the Greeks," such as gamma (the second derivative of option value with respect to the price of the underlying asset, in other words the rate at which delta changes as the price of the underlying asset changes).

Just how effectively the Black-Scholes-Merton model was deployed in the 1970s and 1980s as a "disciplinary" tool of risk management is questionable; a clearing firm that attempted too closely to control its traders' risk-taking faced the possibility of them defecting to a different clearer with a more liberal approach. However, if a trader's clearer cared whether his or her positions were delta-neutral, or had other model-dependent characteristics, then the trader might at least have to consider the matter, which required that Black's sheets or some other instantiation of the model

explain why in the early years the purchasers of options seem to have been mainly private individuals, with institutional investors involved, if at all, only in writing options. The initial period of organized options trading coincided with a "bear market," so the early experience of buying calls (as noted above, puts were not traded until 1977) is likely to have done little to disturb the above widespread conviction among professionals (Gastineau 1975, pp. 138–39, 152).

be consulted. Furthermore, the Black-Scholes-Merton model had a *communicative* function in respect to risk (Millo forthcoming). Unlike its predecessors, from which measures of risk could often be extracted only clumsily,[21] the Black-Scholes-Merton model allowed the risks of options trading to be *talked about* amongst traders, clearing firms, the Options Clearing Corporation, exchange officials, and regulators.

V. A CHANGING WORLD

Given its theoretical elegance and its practical advantages, why might the Black-Scholes-Merton model nevertheless be considered by some to be deficient? The model's developers, and all sophisticated users of it, knew that the market conditions it posited were idealizations. Black repeatedly warned of this (see, for example, Black 1988), and some of Merton's work was directed precisely at supplementing the model: see, for example, Merton (1976), which analyzes option pricing when stock prices can "jump" discontinuously, as they can in actuality but not in the original model.

It was, indeed, straightforward for anyone with experience of the markets of the 1970s to list ways in which the Black-Scholes-Merton model's assumptions were unrealistic: Gastineau, for example, provided such a list, asserting that their aggregate consequence was a tendency for the model to generate theoretical prices that were "on average too low" (Gastineau 1975, pp. 198–200). For example, transaction costs were not zero, and the continuous rehedging posited in the model's derivation was therefore unfeasibly expensive. Short selling was often difficult and generally subject to financial penalties. The proceeds on a short sale were held as collateral by the broker from whom stock had been borrowed, and in the 1970s the entirety of the interest on such proceeds was typically retained by the broker. Gastineau especially emphasized a further point: work in financial economics in the 1960s had shown that stock price movements, at least over short timescales, did not follow the log-normal distribution of the Black-Scholes-Merton model. Such movements were "fat-tailed": extreme movements happened far more frequently than implied by log-normality.

However, during the 1970s and 1980s many of the Black-Scholes-Merton model's assumptions became less unrealistic. Transaction costs generally fell. For instance, New York Stock Exchange commissions on stock transactions (a major transaction cost for any options-market participant other than members of the New York exchange) fell rapidly after a prolonged battle ended with the abolition of fixed commissions on May 1, 1975 (see Seligman 1982). As short selling, stigmatized since the 1930s as an alleged tool of market manipulation and cause of crashes, gradually regained acceptability, and as pension funds began to be prepared to earn extra returns by lending their stock for short selling,[22] the latter's costs also fell, albeit less dramatically than in the case of commissions.

[21] Most mathematical models of the relationship between stock and option prices, Kassouf's for example, allow the equivalent of delta to be calculated. However, the calculation was often far more complicated than glancing at the values of delta on Black's sheets. In the most influential version of Kassouf's model (Thorp and Kassouf 1967), calculating the equivalent of delta involves drawing a graph of the relationship between stock and option price and estimating the slope of the graph at the appropriate point.

Above all, the introduction in the U.S. in 1982 of stock-index futures, especially the Standard and Poor's S&P 500 index futures bought and sold on the Chicago Mercantile Exchange, meant that when index options began to be traded in 1983 they inhabited a world in which key Black-Scholes-Merton assumptions had indeed become more realistic. Buying a future permitted the "virtual" purchase of a large block of stock (the stock of the corporations comprising the index), but with much lower transaction costs than incurred in actual purchase, and with the purchase price of the stock being, in effect, borrowed almost in its entirety. Selling such a future was in effect equivalent to short sale of the same block of stock, but with none of the difficulties and little of the expense of conventional short selling.

Most of these changes had little directly to do with the Black-Scholes-Merton model. Factors such as technological change, the growing influence of free-market economics, and the shifting political climate (crystallized in the 1980 election of President Reagan) were more important. Some effects of the model can nonetheless be pointed to. As noted above, the Black-Scholes-Merton analysis helped grant legitimacy to options trading. Another factor was that earlier upsurges of such trading had typically been reversed, arguably because option prices had usually been "too high" in the sense that they made options a poor purchase—options could too seldom be exercised profitably (Kairys and Valerio 1997). The availability of the Black-Scholes formula, and its associated hedging and risk-measurement techniques, gave participants the confidence to write options at lower prices, helping options exchanges to grow and to prosper.

High-volume trading of options in organized options exchanges (rather than in the earlier, much lower-volume, *ad hoc* put-and-call market) permitted far lower transaction costs. The discrepancies between the model and put-and-call market prices identified by Black and Scholes (1972) could not, they noted, be exploited economically because transaction costs were too high. As such costs fell, even quite small discrepancies could be exploited and so could be expected to diminish. To the extent that the availability of the Black-Scholes-Merton model played a part in the processes reducing transaction costs, the increased capacity to exploit discrepancies was a performative effect of the model because the model facilitated the trading that moved patterns of prices towards its postulates.

The capacity to generate theoretical prices was also important in the growth of the "over-the-counter" (direct, institution-to-institution) derivatives market, the overall volume of which came to exceed that of exchange-traded derivatives. Many of the instruments traded in the over-the-counter market are highly specialized and sometimes no liquid market, or easily observable market price, exists for them. However, both the vendors of them (most usually investment banks) and at least the more sophisticated purchasers of them can often calculate theoretical prices, and thus have a benchmark "fair" price.

The Black-Scholes-Merton analysis and subsequent developments of it are also central to the capacity of an investment bank to operate at large scale in this market. They enable the risks involved in derivatives portfolios to be decomposed mathematically. Many of these risks are mutually offsetting, so the residual risk

[22] See Swensen (2000, p. 145).

that requires hedged is often quite small in relation to the overall portfolio. Major investment banks can thus "operate on such a scale that they can provide liquidity as if they had no transaction costs" (Taleb 1998, p. 36; see also Merton and Bodie 2002). So the Black-Scholes-Merton assumption of zero transaction costs is now close to true for major investment banks, in part because the use of that theory and its development by those banks allows them to manage their portfolios in a way that minimizes transaction costs.

VI. COUNTERPERFORMATIVITY?

All this may seem a smooth tale of performativity: of generic performativity, effective performativity, and probably at least some elements of Barnesian performativity. But the tale has a twist: the gigantic one-day fall of the U.S. stock market on October 19, 1987. The fall was a grotesquely unlikely event on the assumption of log-normality: for example, Jackwerth and Rubinstein (1996, p. 1612) calculate the probability on that assumption of the actual fall in S&P index futures as 10^{-160}. What the crash led to was more than a disembodied rejection of the null hypothesis of log-normality. The fall in stock prices came close to setting off a chain of market-maker bankruptcies that would have threatened the very existence of organized derivatives exchanges in the U.S., and perhaps even of the New York Stock Exchange. The subsequent systematic departure from Black-Scholes option pricing—the so-called "volatility smile" or "volatility skew," a pattern of option pricing in which the graph of implied volatility against strike price (figure 3) is no longer a flat line—is more than a mathematical adjustment to empirical departures from log-normality: it is too large fully to be accounted for in that way (see, for example, Jackwerth 2000). It can in a sense be seen as the options market's collective defense against systemic risk (MacKenzie and Millo 2003).

The empirical history of option pricing has, therefore, not two phases but three. The initial phase of relatively poor fit between the Black-Scholes-Merton model and market prices was followed by the second phase, described above, in which the fit improved rapidly (in part, I have conjectured, as a performative effect of the model's use). That second phase, and thus the Barnesian performativity of classic option pricing theory, ended on October 19, 1987. In the third phase—from 1987 to the time of writing—option pricing theory is still performed in the generic and effective senses (it is used, and its use makes a difference), but its canonical model has lost its Barnesian powers. When Rubinstein's test (sketched in figure 3) was repeated after 1987, the flat line that is the Black-Scholes-Merton model's trace had vanished (Rubinstein 1994). It has not reappeared and the volatility skew that has replaced it seems enduring.

There is an intriguing possibility that among the factors exacerbating the 1987 crash was an application of option pricing theory: portfolio insurance. This involves using the theory to synthesize a put option, and thus a "floor" below which the value of an investment portfolio will not fall. The synthesis of a put requires sales of stock (or of index futures) as stock prices fall, and such sales have been cited as a major process in the crash, for example by the main official inquiry (Brady Commission 1988). That portfolio insurance exacerbated the crash cannot be proved, but neither is there a decisive way of showing it played no part (see MacKenzie 2004). If it did have a role, it would be an instance of what one might call "counterperformativity." This is Barnesian performativity's opposite: the use of an aspect of economics altering economic processes so that they conform less well to their depiction by economics. If portfolio insurance exacerbated the crash, it made at least the classic form of the option theory underpinning the technique not more true, but less.

Whatever the causes of the 1987 crash, that empirical patterns of option prices since 1987 no longer follow the Black-Scholes-Merton model has an analytical advantage from the viewpoint of this article. It answers a possible objection: that the model is simply right, that it captures the only stable way a mature, efficient market can price options, and that talk of the model's "performativity" is therefore just a fancy way of saying something that could thus be said much more simply. The existence of the skew since 1987 reveals the historical contingency of what I have suggested is the phase of the Barnesian performativity of the model. In that phase, price patterns followed the model (to at least a fair degree of accuracy) not because they were the only patterns that were possible but, at least in part, because of the model's existence and use. The model made a difference, and if this article's conjecture is correct, part of that difference was that market prices moved towards the postulates of the model.

VII. CONCLUSION

In the societies of high modernity, the generic, and probably also the effective, performativity of economics seems pervasive.[23] Callon and Muniesa argue that markets are collective calculation mechanisms, in other words sociotechnical apparatuses that allow a good to be made comparable with other goods, to be evaluated, and a "result"—"a price, a classification, a choice"—produced (Callon and Muniesa 2003, p. 205). Economic practices such as marketing and accounting clearly play constitutive roles in such mechanisms, and economics in the academic, disciplinary sense is increasingly involved too. The financial derivatives market may be an unusually clear case of the generic performativity of economics—today's huge volumes of derivatives trading would scarcely be possible without the calculative resources that option theory and its many developments provide—but it is surely not unique.

In this article, however, I have sought to do more than to document how economic models and their products such as "implied volatility" make it possible to "calculate" derivatives: to legitimate, to compare, to evaluate, to price, and to hedge them. From within the overall domain of the generic performativity of economics, I have suggested isolating two particular cases: Barnesian performativity, in which the use of an aspect of economics alters economic processes so that they are more like their depiction by economics, and counterperformativity, in which the effect of use is to make those processes less like their depiction.

Are "Barnesian performativity" and "counterperformativity" simply new names for self-fulfilling and self-negating prophecies, which are old topics (see Merton 1948)? If, as Krishna (1971) and Barnes (1983) advocate, the notion of self-fulfilling prophecy is

[23] See, for example, Faulhaber and Baumol (1988) and MacKenzie (2006).

generalized beyond the original predominant attention to pathological forms of inference (in which the "true reality" of a social situation is over-turned by a widespread misconception, as in a sound bank failing as the result of a bank run), then the notion becomes perfectly applicable to financial markets (see, for example, MacKenzie 2001) and one which is, of course, used frequently by economists.

However, the notions of "Barnesian performativity" and "counterperformativity" have the advantage that they locate the processes to which they point as subsets of the wider topic of the generic and effective performativity of economics. The notions also avoid the frequent, albeit entirely unnecessary, association of self-fulfilling prophecy with arbitrariness. It would, for example, be quite mistaken to imagine that any arbitrary option-pricing formula, proposed by sufficiently authoritative people, could have been performative in the Barnesian sense other than very fleetingly. If, for example, the use of such a formula gave rise to substantial arbitrage opportunities, then it would have been unlikely to "make itself true" in anything other than an evanescent sense. Barnesian performativity is not arbitrary self-fulfilling prophecy.

To invoke Austin's coinage, "performative," can, of course, give rise to a misconception of a different sort: that we are dealing with some mysterious power of words. Bourdieu's point is essential: we must not imagine we can identify performativity purely as a linguistic process, and we must also always inquire into the social, cultural, and political nature of the "conditions of felicity" of the process. Nor should we forget one of Callon's main arguments: the collective calculation mechanisms that constitute markets are *material*. The Black-Scholes-Merton model could not have been performed in the markets had it remained simply a conceptualization in economists' heads. The reason I have emphasized the role of Black's sheets is to highlight their significance as material means of calculation, as aspects of "distributed cognition," as ways of connecting the apparently abstract mathematics of the model to the sweaty, jostling bodies on exchange trading floors.

While one can be reasonably sure that the generic performativity and effective performativity of economics are widespread, matters are not so clear in respect to Barnesian performativity and counterperformativity, which may be rare and hard to identify unequivocally. What is probably unusual about the case of option theory (one cannot be entirely sure about its frequency until far more empirical work is done) is the existence of a single, stable, canonical form of the theory: the Black-Scholes-Merton model. Option theory developed and diversified, but there remains a sense in which the Black-Scholes-Merton model is the benchmark. The very conceptualization of the empirical phenomenon that undermines it—the post-1987 volatility "skew"—is testimony to the model's canonical role: it is a skew with respect to the Black-Scholes-Merton flat-line relationship between strike price and implied volatility.

If an area of economics is too diverse and is changing too fast, empirical enquiry into Barnesian performativity and counterperformativity becomes very difficult. If different theories or models are used by different participants, and if they are frequently discarded and replaced, then their use may have effects on their "truth," but identifying those effects will be problematic: it will be difficult to know where to start.[24]

[24] These difficulties would attend any investigation of whether post-1987 patterns of option pricing are Barnesian performative effects of models other than Black-Scholes-Merton.

The circumstances that make the enquiry feasible in the case of option pricing theory—a widely-used canonical model, and decades of empirical tests of the model—are probably not unique, but they may not be common.

Although empirical investigations of Barnesian performativity and counterperformativity may therefore be difficult, one virtue of the notions is that in respect to an economic theory or model they prompt us to ask a question additional to the two natural questions (that is, is the theory or model analytically tractable, and does it adequately represent some economic process?). The additional question is this: what would be the effects of the widespread use of the theory or model? That third question *was*, for example, asked prior to 1987 of the use of option theory in portfolio insurance, but not often enough and influentially enough (see MacKenzie 2004).

It is possible that there are circumstances in which the answer to the third question should be given greater weight than the answers to the other two. That, for example, was implicitly the post-1987 judgment of the Options Clearing Corporation, the ultimate guarantor of U.S. exchange-traded options. It adopted a model that mainstream financial economics had rejected: Benoit Mandelbrot's infinite-variance Lévy distributions (see Mirowski 1995). These distributions capture the feature whose absence from the Black-Scholes-Merton model's log-normal random walk had disturbed Gastineau: "fat tails," in other words the high probabilities of extreme events. However, mainstream financial economics came to view infinite-variance distributions as analytically unattractive (they undermine standard statistical techniques), and as having features that are unintuitive and difficult to square with empirical price data (MacKenzie 2006). After being the focus of much attention in the 1960s, they were discarded from the academic mainstream at the start of the 1970s.

The virtue that the Options Clearing Corporation saw in infinite-variance Lévy distributions twenty years later was, in effect, their potential counterperformativity. An infinite-variance distribution assigns high probabilities to extreme events, so when such events take place the estimators of the distribution's parameters change only modestly. Compared to the normal distribution, the estimator of whose variance is very sensitive to extreme events, infinite-variance distributions thus have an advantage as the basis for determining the margin deposits demanded from options market participants (which is the role in which the Options Clearing Corporation uses them). Infinite-variance distributions do not exacerbate a crisis by generating sudden demands for hugely increased margin deposits. By adopting a model that assigns high probabilities to extreme, dangerous events, the Options Clearing Corporation hopes to reduce the chances of such events (see MacKenzie 2006).

As I have acknowledged, Barnesian performativity and counterperformativity can be difficult to investigate, and (in any full sense) they may be rare. They point us, however, to a vital issue. An economic theory or model posits a world, so to speak. It is too simple to ask only if that world is realistic (as in standard critiques of economics' lack of realisticness). We must also ask if the widespread use of the theory or model will make the world it posits more real, or less real. If either is the case, we need to ask whether that world is to be desired or to be avoided. Sometimes that is easy to answer: few will see a world of frequent financial crises akin to the 1987 crash as desirable, and the Options Clearing Corporation's wish to avoid such a world is entirely understandable. Other cases, however, will be more nuanced and more controversial. Difficult as the resultant issues are, they are too important to be settled by default. The desirability of markets is debated often, but frequently at a high level of generality, while the crucial detail of the collective calculation mechanisms that constitute them usually escapes widespread scrutiny. If attention to the performativity of economics encourages such scrutiny, then it is indeed worthwhile.

APPENDIX: THE BLACK-SCHOLES EQUATION FOR AN OPTION ON A NON-DIVIDEND-BEARING STOCK AND ITS SOLUTION FOR A CALL

The Black-Scholes option-pricing equation is:

$$\frac{\partial w}{\partial t} = rw - rx\frac{\partial w}{\partial x} - \frac{1}{2}\sigma^2 x^2 \frac{\partial^2 w}{\partial x^2}, \tag{1}$$

where w is the price of the option, x is the price of the stock, t is time, r is the riskless rate of interest and σ the volatility of the stock price. ("Volatility" is the extent of the fluctuations of the stock price, measured by the annualized standard deviation of continuously-compounded returns on the stock. The "riskless rate" is the rate of interest paid by a borrower who creditors are certain will not default.)

A European call option gives the right to buy the stock at price c at time t^*. Its value is thus zero if x^*, the stock price at time t^*, is less than or equal to c, and $x^* - c$ if x^* is greater than c. This known set of values for w at time t^* forms a boundary condition, and equation (1) can then be solved to yield the following expression for the value of a European call option:

$$\begin{aligned} w = {} & xN\left[\frac{\ln(x/c) + (r + {}^1/{}_2\sigma^2)(t^* - t)}{\sigma\sqrt{t^* - t}}\right] \\ & - c[\exp\{r(t - t^*)\}]N\left[\frac{\ln(x/c) + (r - {}^1/{}_2\sigma^2)(t^* - t)}{\sigma\sqrt{t^* - t}}\right], \end{aligned} \tag{2}$$

where N is the (cumulative) distribution function of a normal or Gaussian distribution, and ln indicates natural logarithm. The result also holds for an American call option with expiration t^*: Merton (1973, pp. 143–44) showed, under quite general conditions, that the early exercise of an American call on a non-dividend-bearing stock is never optimal, so its theoretical value is equal to that of a European call.

REFERENCES

Austin, J. L. (1962) *How to Do Things With Words* (Oxford: Clarendon).

Austin, J. L. (1970) *Philosophical Papers*, 2nd edition (Oxford: Clarendon).

Bachelier, Louis (1900) Théorie de la speculation, *Annales Scientifiques de l'Ecole Normale Supérieure*, third series, (17), pp. 22–86.

Barnes, Barry (1983) Social Life as Bootstrapped Induction, *Sociology*, 17 (4), pp. 524–45.

Barnes, Barry (1988) *The Nature of Power* (Cambridge: Polity).

Bernstein, Peter L. (1992) *Capital Ideas: The Improbable Origins of Modern Wall Street* (New York: Free Press).

Black, Fischer (1975a) Fact and Fantasy in the Use of Options, *Financial Analysts Journal*, 31 (4), pp. 36–41, 61–72.

Black, Fischer (1975b) The Option Service: An Introduction, Personal papers of Mark Rubinstein.

Black, Fischer (1988) The Holes in Black-Scholes, *Risk*, 1/4 (March), pp. 30–32.

Black, Fischer, and Scholes, Myron (1972) The Valuation of Option Contracts and a Test of Market Efficiency, *Journal of Finance*, 27 (2), pp. 399–417.

Black, Fischer, and Scholes, Myron (1973) The Pricing of Options and Corporate Liabilities, *Journal of Political Economy*, 81 (3), pp. 637–54.

Bourdieu, Pierre (1991) *Language and Symbolic Power* (Cambridge: Polity).

Brady Commission (1988) Report of the Presidential Task Force on Market Mechanisms (Washington, D.C.: U.S. Government Printing Office).

Bronzin, Vinzenz (1908) *Theorie der Prämiengeschäfte* (Leipzig and Vienna: Franz Deuticke).

Callon, Michel (1986) Some Elements of a Sociology of Translation: Domestication of the Scallops and the Fishermen of St Brieuc Bay, in: John Law (Ed) *Power, Action and Belief: A New Sociology of Knowledge?* (London: Routledge and Kegan Paul), pp. 196–233.

Callon, Michel (1998) *The Laws of the Markets* (Oxford: Blackwell).

Callon, Michel (2004) Economies as Co-Performances: Economics's Contribution: How to Get Rid of Austin without Losing Him. Powerpoint presentation to workshop, The Performativities of Economics, Paris, August 29–30.

Callon, Michel, and Muniesa, Fabian (2003) Les marchés économiques comme dispositifs collectifs de calcul, *Réseaux*, 21 (122), pp. 189–233.

Cox, John C., and Rubinstein, Mark (1985) *Options Markets* (Englewood Cliffs, N.J.: Prentice-Hall).

Didier, Emmanuel (2004) Les statistiques "performent" elles l'économie? Paper presented to workshop at The Performativities of Economics, Paris, August 29–30.

Faulhaber, Gerald L., and Baumol, William J. (1988) Economists as Innovators: Practical Products of Theoretical Research, *Journal of Economic Literature*, 26 (2), pp. 577–600.

Galai, Dan (1977) Tests of Market Efficiency of the Chicago Board Options Exchange, *Journal of Business* 50 (2), pp. 167–97.

Gastineau, Gary L. (1975) *The Stock Options Manual* (New York: McGraw-Hill).

Gastineau, Gary L. (1979) *The Stock Options Manual*, 2nd edition (New York: McGraw-Hill).

Gladstein, M. L. (1999) Interview conducted by author, New York, 15 November 1999.

Holm, Petter (2003) Which Way is Up on Callon? *Sociologisk Årbok*, 1, pp. 125–56.

Hull, John C. (2000) *Options, Futures, & Other Derivatives* (Upper Saddle River, NJ: Prentice-Hall).

Hutchins, Edwin (1995a) *Cognition in the Wild* (Cambridge, MA: MIT Press).

Hutchins, Edwin (1995b) How a Cockpit Remembers Its Speeds, *Cognitive Science*, 19 (3), pp. 265–88.

Jackwerth, Jens Carsten (2000) Recovering Risk Aversion from Option Prices and Realized Returns, *Review of Financial Studies*, 13 (2), pp. 433–51.

Jackwerth, Jens Carsten, and Mark Rubinstein (1996) Recovering Probability Distributions from Option Prices, *Journal of Finance*, 51 (5), pp. 1611–31.

Kairys, Joseph P., Jr., and Valerio, III, Nicholas (1997) The Market for Equity Options in the 1870s, *Journal of Finance*, 52 (4), pp. 1707–23.

Kassouf, Sheen T. (1965) *A Theory and an Econometric Model for Common Stock Purchase Warrants* (Brooklyn, NY: Analytical Publishers).

Krishna, Daya (1971) "The Self-Fulfilling Prophecy" and the Nature of Society, *American Sociological Review*, 36 (6), pp. 1104–107.

Latour, Bruno (1987) *Science in Action* (Cambridge, MA: Harvard University Press).

Latour, Bruno (1999) *Pandora's Hope: Essays on the Reality of Science Studies* (Cambridge, MA: Harvard University Press).

MacKenzie, Donald (2001) Physics and Finance: S-terms and Modern Finance as a Topic for Science Studies, *Science, Technology, and Human Values*, 26 (2), pp. 115–44.

MacKenzie, Donald (2003) An Equation and its Worlds: Bricolage, Exemplars, Disunity and Performativity in Financial Economics, *Social Studies of Science*, 33 (6), pp. 831–68.

MacKenzie, Donald (2004) The Big, Bad Wolf and the Rational Market: Portfolio Insurance, the 1987 Crash and the Performativity of Economics, *Economy and Society*, 33 (3), pp. 303–34.

MacKenzie, Donald (2006) *An Engine, Not a Camera: How Financial Models Shape Markets* (Cambridge, MA: MIT Press).

MacKenzie, Donald and Millo, Yuval (2003) Constructing a Market, Performing Theory: The Historical Sociology of a Financial Derivatives Exchange, *American Journal of Sociology*, 109 (1), pp. 107–45.

Mehrling, Perry (2005) *Fischer Black and the Revolutionary Idea of Finance* (New York: Wiley).

Merton, Robert C. (1973) Theory of Rational Option Pricing, *Bell Journal of Economics and Management Science*, 4 (1), pp. 141–83.

Merton, Robert C. (1976) Option Pricing when Underlying Stock Returns are Discontinuous, *Journal of Financial Economics*, 3 (1–2), pp. 125–44.

Merton, Robert C., and Bodie, Zvi (2005) The Design of Financial Systems: Towards a Synthesis of Function and Structure, *Journal of Investment Management*, 3 (1), pp. 1–23.

Merton, Robert K. (1948) The Self-Fulfilling Prophecy, *Antioch Review*, 8 (Summer), pp. 193—210.

Millo, Yuval (Forthcoming) Talking about Risk: Risk Assessment Methods as Communicative Media in Financial Markets, *Science, Technology, and Human Values*, (under consideration).

Mirowski, Philip (1995) Mandelbrot's Economics after a Quarter Century, *Fractals*, 3 (3), pp. 581–600.

Mirowski, Philip and Nik-Khah, Edward (2004) Markets Made Flesh: Callon, Performativity, and a Crisis in Science Studies, augmented with consideration of the FCC auctions, Paper presented to workshop, The Performativities of Economics, Paris, August 29–30.

Parkinson, Michael (1977) Option Pricing: The American Put, *Journal of Business*, 50 (1), pp. 21–36.

Passell, Peter (1997) 2 Get Nobel for a Formula at the Heart of Options Trading, *New York Times* October 15: D1 and D4.

Rissman, Burton R. (1999) Interview conducted by Author, Chicago, IL, November 9.

Ross, Stephen A. (1987) Finance, in: John Eatwell, Murray Milgate, and Peter Newman (Eds) *The New Palgrave Dictionary of Economics, vol. 2*, (London: Macmillan), pp. 322–36.

Rubinstein, Mark (1994) Implied Binomial Trees, *Journal of Finance*, 49 (3), pp. 771–818.

Rubinstein, Mark (2000) Interview conducted by Author, Berkeley, CA, June 12.

Scholes, Myron S. (1998) Derivatives in a Dynamic Environment, in: *Les Prix Nobel 1997* (Stockholm: Almquist), pp. 475–502.

Searle, John R. (1996) *The Construction of Social Reality* (London: Penguin).

Seligman, Joel (1982) *The Transformation of Wall Street: A History of the Securities and Exchange Commission and Modern Corporate Finance* (Boston: Houghton Mifflin).

Swensen, David F. (2000) *Pioneering Portfolio Management: An Unconventional Approach to Institutional Investment* (New York: Free Press).

Taleb, Nassim (1998) How the *Ought* Became the *Is: Futures and OTC World*, Black-Scholes-Merton Supplement, pp. 35–36.

Thorp, Edward O. and Kassouf, Sheen T. (1967) *Beat the Market: A Scientific Stock Market System* (New York: Random House).

Wellemeyer, Marilyn (1973) The Value in Options, *Fortune* 88/5 (November), pp. 89–96.

Whitley, Richard (1986a) The Rise of Modern Finance Theory: Its Characteristics as a Scientific Field and Connections to the Changing Structure of Capital Markets, *Research in the History of Economic Thought and Methodology*, 4, pp. 147–78.

Whitley, Richard (1986b) The Transformation of Business Finance into Financial Economics: The Roles of Academic Expansion and Changes in U.S. Capital Markets, *Accounting, Organizations and Society*, 11 (2), pp. 171–92.

Zimmermann, Heinz and Hafner, Wolfgang (n.d.) Professor Bronzin's Option Pricing Models (1908), typescript.