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ABSTRACT

Minimum price variation rules help explain why stock prices vary substantially across countries, and other curiosities of share prices. Companies tend to split their stock so that the institutionally mandated minimum tick size is optimal relative to the stock price. A large relative tick size provides an incentive for dealers to make markets and for investors to provide liquidity by placing limit orders, despite its placing a high floor on the quoted bid-ask spread. A simple model suggests that idiosyncratic risk, firm size, and visibility of the firm affect the optimal relative tick size and thus the share price.

IN STOCK MARKETS AROUND the world, the average price per share differs substantially. The median U.S. stock, for example, sells for about \$40; a typical London stock sells for about £5 (\$7.50); and a typical Hong Kong share is about \$2. Furthermore, when stock prices rise above a country's usual trading range, firms often split their stocks to restore prices to that range. Why are these price ranges so different among countries?

These trading ranges can be remarkably stable over time. During the half century from 1943 to 1994, the S&P Composite Index increased over 1,500 percent, yet the average New York Stock Exchange (NYSE) share price was almost unchanged, from \$32 to \$31 as seen in Figure 1. During this period, the consumer price index increased over 500 percent, indicating that the real average share price dropped to a small fraction of its previous level. Why is this average nominal price so stable? There are other mysteries: A typical U.S. initial public offering is priced near \$10.[1] Why \$10 and not \$100? When foreign shares are packaged as American Depositary Receipts (ADRs), the ratio of foreign shares per ADR is designed so that the ADR trades in the same price range as other U.S. stocks. Sometimes ADRs split when the home country

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[1] For example, in Schultz and Zaman's (1994) sample of 72 U.S. initial public offerings, the mean price was \$10.94 and the median price was \$11.00 per share. The NYSE 1993 Fact Book lists 191 NYSE IPOs for 1993, which had a median opening price of \$15.125 and an average of \$17.91.

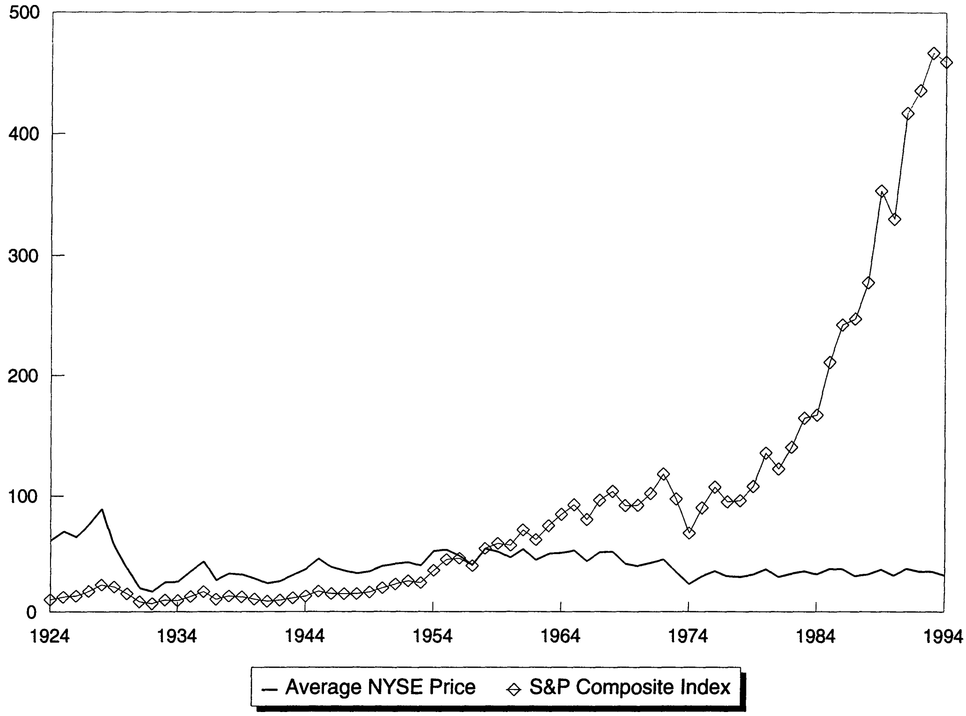

Figure 1. Average NYSE Stock Price 1924–1994. This figure displays the average nominal share price in dollars on the New York Stock Exchange from 1923 to 1994 from various editions of the NYSE *Fact Book* contrasted with Standard & Poor's Composite Index.

stock does not. Firm size and firm price are positively correlated in many countries.

This article argues that these phenomena are at least partly related to the rules on minimum price variation, or tick size, that govern stock trading. On the NYSE, for example, stocks priced over \$1 are traded in minimum increments of \$0.125.[2] Although the absolute level of the tick size in a given market may be fixed by that market's institutions, the firms themselves may establish the tick size relative to the stock price by deciding how many shares to issue when they go public or split their stock.

If the tick size as a fraction of the stock price is larger than optimal, a company can allow the long-term upward trend of stock prices to reduce it to the desired level. If the relative tick size is too small, the firm can split its

[2] Stocks between \$0.50 and \$1.00 trade in sixteenths (pronounced "steenths"), and cheaper stocks in thirty-seconds or less (known as "teenies"). The NYSE tick rules apply only to trades that take place on the NYSE. When NYSE-listed stocks trade on another market, the rules of the other market apply. The NASD and Instinet allow increments smaller than one-eighth. NYSE-listed stocks that trade in London through SEAQ International are quoted in dollars, often in intervals of sixteenths. NYSE-listed stocks that trade on the Tokyo Stock Exchange are quoted in yen with the same tick rules as normal Japanese stocks.

stock, as recognized by Harris (1994a). With a constant absolute tick size, as is the case for most stocks in the United States, a split has the effect of increasing the tick size relative to the share price.

The optimal tick size is not zero for several reasons. Harris (1991) noted that a nonzero tick simplifies trader's information sets, reducing time spent bargaining and the potential for costly errors. Second, a nontrivial tick enforces time and price priority in a limit order book, providing incentives for investors to provide liquidity with limit orders. Furthermore, a nonzero tick puts a floor on the quoted bid-ask spread, which provides incentives for dealers to make markets and thus increase liquidity. However, this increase in the minimum bid-ask spread also increases transaction costs to investors, offsetting some of the liquidity gains from dealers' incentives. The optimal tick represents a trade-off between the benefits of a nonzero tick and the costs that a tick imposes.

This argument helps to explain why a company prefers a specific price range for its stock. Since the absolute tick size is fixed by regulation or tradition, the tick size relative to the stock price will be close to optimal only within a certain price range, which a company can maintain through its stock split decisions. Since markets in different countries have adopted different conventions about tick size, the optimal price range will differ across countries as well. Although the tick rules for different equity markets vary considerably, the resulting relative tick sizes are similar.

The next section of this article examines the wide range of rules for minimum price variation used in different markets. Section II discusses the historical context of stock splits and summarizes previous research on stock splits. Section III explores the factors affecting the optimal tick size in more detail, and develops a simple model of optimal relative tick size that incorporates the effects of a firm's idiosyncratic risk, size, and visibility on its optimal tick size. Section IV examines some of the empirical implications of this theory. Section V concludes with a discussion of the implications for the current debate over the decimalization of stock prices.

I. Regularities in Minimum Price Variation Rules

Most equity markets have either formal rules or informal customs on minimum price variation that result in nontrivial relative tick sizes. The eighth of a dollar on the NYSE dates back to October 13, 1915, when the NYSE switched from quoting prices as a percentage of par value to quoting in dollars. Prior to that, the minimum price variation had been one-eighth of a percent, which dates back at least as far as 1817, when NYSE trading was formalized, and probably much further.[3] Although street lore claims that trading in eighths goes back to the Spanish "pieces of eight" coins that were chopped into eight

[3] The NYSE (1817) archives contain a resolution dated November 1, 1817 stating "that no offer under 1/8 pr (sic) be accepted at this board." I am indebted to NYSE archivist Stephen Wheeler for this information.

pieces for use as change in the colonies, a search for historical documents to support this claim has proved fruitless to date. The earliest NYSE stock price records are actually in predecimal British currency units, which means that the currency conversion to Spanish dollars would have created noninteger prices that eliminated any convenience from using the "pieces of eight." It is likely that trading in eighths arose naturally—just as the use of fractions has arisen naturally in other markets and measurement systems. Fractions arise from subdividing each difference by two, perhaps as traders split the difference between their positions.

The primary difference between countries is whether they use a single absolute tick size that applies to most stocks, as in the United States, or a tick size that is a step function of share price. An example of the step function approach is seen in Tokyo, where a typical stock under ¥1,000 has a tick size of ¥1; at ¥1,000 the tick size jumps to ¥10; and at ¥10,000 the tick size jumps to ¥100. Hong Kong has the most extreme version of a step function, with 10 different tick sizes in its rule book. Figure 2 demonstrates these polar opposites of tick rules, and how each affects the absolute and relative tick sizes.

Exchanges that do not have formal rules or that allow extremely small variations usually have strong customs that limit the smallest price variations in use. The London Stock Exchange and the Irish Stock Exchange have no formal rules, but most stocks trade in pence and a few in half-pennies. In the words of Irish Stock Exchange General Manager Tom Healy (1994), "Extreme fractions would . . . elicit an uncivil or amused response from traders." Although the National Association of Securities Dealers (NASD) allows traders to use fractions smaller than one-eighth, Christie and Schultz (1994) find that Nasdaq market makers rarely use fractions smaller than one-quarter for large actively traded stocks, noting that there could be "an implicit agreement to post quotes only on the even price fractions."

Although tick rules vary from country to country, the tick size as a percentage of stock price seems remarkably consistent across countries, much more so than the stock price ranges themselves. Table I provides descriptive statistics on cross-sectional stock prices and tick sizes. For each of the 22 countries in the Morgan Stanley Capital International Indices, data are obtained on tick size rules from the primary stock exchanges or other reliable sources. The relative tick size is then calculated in basis points for each of the 2,517 stocks listed in the Morgan Stanley Capital International *Perspectives* (1994) in January 1994. While these stocks make up the majority of the capitalization of the world equity market, they are primarily large firms, so the sample is biased toward large capitalization firms in more developed countries. Results may differ for smaller firms and for firms in the so-called emerging markets. The median relative tick size for the stocks in this study is 25.9 basis points. There is much less dispersion in tick sizes than in share prices: Worldwide, the coefficient of variation for relative tick sizes is 141.5 percent, while the coefficient of variation in dollar stock prices is 761.4 percent. This regularity in the size of the relative tick implies a lack of money illusion and suggests that a similar process may determine tick sizes and share prices in different countries.

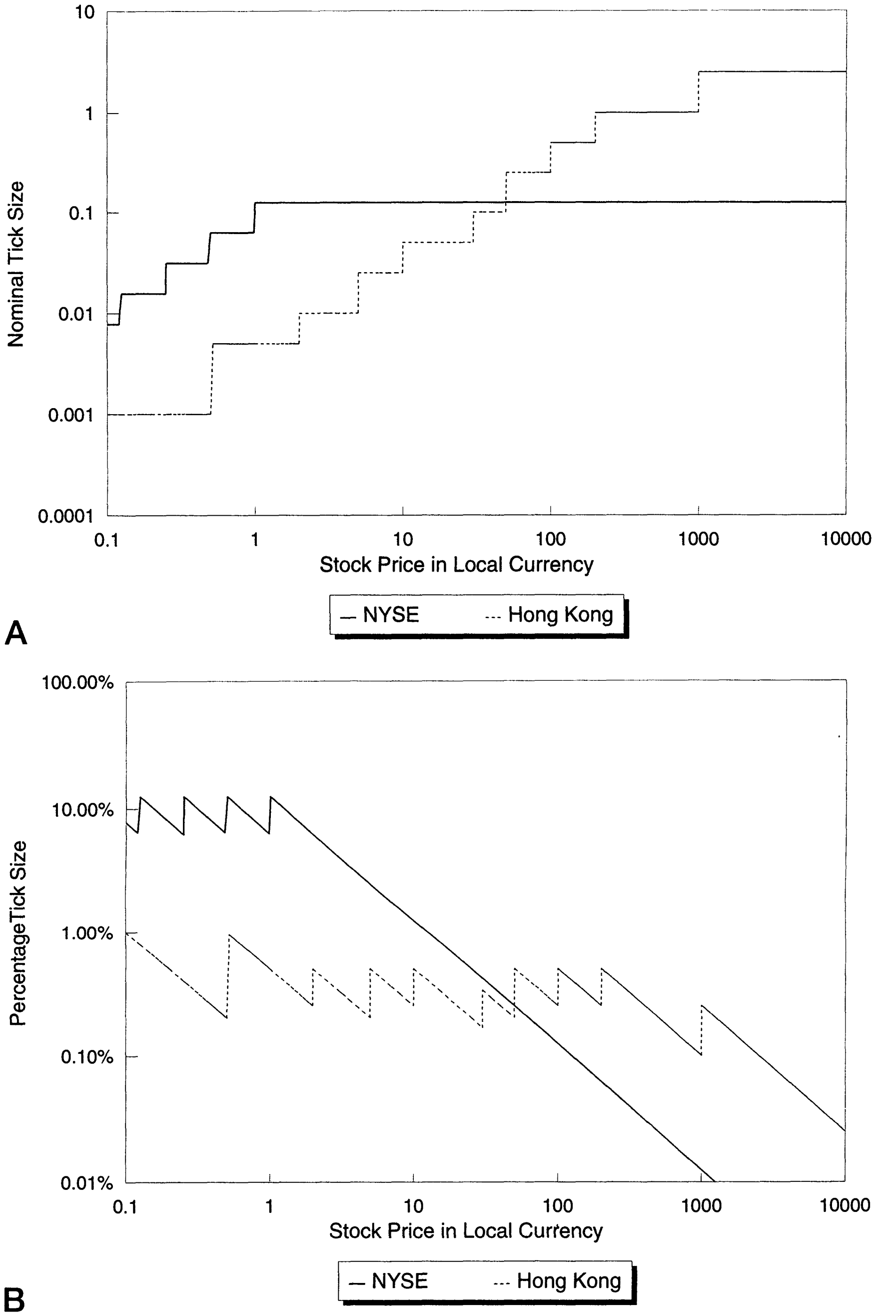

Figure 2. Minimum Price Variation Rules. This figure displays the minimum price variation (tick size) as a function of share price for the New York Stock Exchange and the Stock Exchange of Hong Kong. Panel A displays the tick size in local currency as a function of share price, and Panel B displays the tick size as a percentage of the share price.

Table I

Relative Tick Sizes for Morgan Stanley Capital International Stocks—January 1994

This table presents data on the prices for 2517 stocks covered by Morgan Stanley Capital International's *Perspectives* at the beginning of January 1994, as well as the minimum price variations, or tick sizes for those stocks based on minimum price variation rules. Data on the tick rules for each country are obtained from the dominant stock exchange in each country. For the United Kingdom and Ireland, which have no formal tick rules, 0.005 is used as the tick size to reflect the minimum price variation often observed in practice.

Country	Number of Stocks	Mean Stock Price (Local Currency)	Median Stock Price (Local Currency)	Median Price (Dollars)	Spearman Correlation of Price and Capitalization	Median Tick (Absolute)	Mean Relative Tick Size (Basis Points)	Median Relative Tick (Basis Points)
Australia	95	5	4	3	0.54	0.01	44.3	27.2
Austria	33	1,292	1,014	83	0.24	1.00	13.2	9.9
Belgium	39	7,849	5,830	163	−0.01	10.00	17.5	15.0
Canada	116	20	19	14	0.63	0.125	78.7	65.8
Denmark	30	11,440	544	80	0.12	1.00	37.5	30.1
Finland	25	173	139	25	−0.23	1.00	40.5	34.6
France	127	959	609	103	0.14	1.00	8.6	7.3
Germany	131	629	464	266	0.36	0.10	2.7	2.2
Hong Kong	70	22	15	2	0.70	0.05	33.6	33.2
Ireland	24	3	3	4	0.39	0.005	65.5	19.4
Italy	146	6,612	3,824	2	0.40	25.00	48.1	37.3
Japan	486	3,595	800	7	0.46	1.00	35.5	23.8
Malaysia	105	9	7	3	0.38	0.05	68.2	62.9
Netherlands	47	97	77	39	0.29	0.10	15.8	13.0
New Zealand	17	4	4	2	0.34	0.01	183.1	28.1
Norway	28	161	127	17	0.45	1.00	59.4	57.3
Singapore	51	7	6	4	0.63	0.05	62.5	59.9
Spain	65	3,798	2,305	16	0.46	5.00	21.6	18.0
Sweden	53	218	161	20	0.32	1.00	54.1	52.6
Switzerland	100	1,783	888	605	0.22	1.00	15.9	12.3
United Kingdom	226	5	4	7	0.48	0.005	19.2	11.2
United States	503	43	38	38	0.55	0.125	44.2	33.2
Overall	2,517	1,624	100	14	0.33	0.125	37.6	25.9

The smallest relative tick sizes are seen in Germany, which has a median relative tick size of 2.7 basis points. The tick on the Deutsche Börse is 0.1 deutschemark (DM) for stocks over 20 DM. One reason for the small relative tick is that Section 8 of the Germany Companies Act required a minimum nominal value per share of 50 DM, which dropped to 5 DM at the end of 1994. This minimum nominal value has prevented many Germany firms from splitting their shares, resulting in many high-priced stocks. Switzerland is also in the process of relaxing its par value restrictions, and more splits are occurring there according to Kunz (1996).

To demonstrate the different tick rules used in practice, the modal absolute tick size and the percentage of stocks that were quoted at that tick size are calculated. As shown in Table II, over 90 percent of the stocks in eight countries—Austria, Canada, Germany, Ireland, Netherlands, New Zealand, United Kingdom, and the United States—were quoted at the same tick size. In four countries—Belgium, Hong Kong, Malaysia, and Singapore—fewer than

Table II

Relative Tick Sizes for Morgan Stanley Capital International Stocks—January 1994

This table displays the most frequent tick size used in each market and the percentage of stocks that are quoted at the modal tick for 2517 stocks covered by Morgan Stanley Capital International's *Perspectives* at the beginning of January 1994. The number of ticks used is the number of ticks used in the sample of stocks, not the total number of ticks in the rule book, which may be higher. For the United Kingdom and Ireland, which have no formal tick rules, 0.005 is used as the tick size to reflect the minimum price variation often observed in practice. Scale is a measure of the degree to which a country depends on a step function for its tick rule. It is measured for each country by the Ordinary Least Squares (OLS) regression coefficient of the log nominal tick on the log price. A higher value indicates that price has more impact on the nominal tick.

Country	Modal Tick (Local Currency)	Percent MSCI Stocks at Modal Tick	Number of Ticks Used for MSCI Stocks	Scale	Price Coefficient of Variation	Interquartile Range/Median Price
Australia	0.01	88.4	2	0.14	80.2	1.11
Austria	1.00	100.0	1	0.00	77.0	0.90
Belgium	5.00	35.9	5	0.72	96.2	1.13
Canada	0.125	91.4	4	0.52	63.2	0.90
Denmark	1.00	70.0	3	0.84	354.7	1.30
Finland	1.00	60.0	2	0.97	79.7	1.30
France	1.00	61.4	4	1.04	106.8	1.25
Germany	0.10	100.0	1	0.00	92.5	1.02
Hong Kong	0.05	47.1	6	0.91	93.5	1.58
Ireland	0.005	100.0	1	0.00	157.7	0.80
Italy	25.00	60.3	4	0.73	114.0	1.96
Japan	1.00	62.6	4	1.21	1076.0	0.94
Malaysia	0.05	37.1	5	1.20	75.1	1.04
Netherlands	0.10	100.0	1	0.00	63.9	1.09
New Zealand	0.01	94.1	2	0.07	74.7	1.42
Norway	1.00	64.3	2	0.48	58.4	0.82
Singapore	0.05	27.5	5	1.24	75.1	1.46
Spain	5.00	53.9	3	0.65	101.4	1.69
Sweden	1.00	88.7	3	0.58	67.6	1.05
Switzerland	1.00	63.0	4	0.58	226.7	1.30
United Kingdom	0.005	100.0	1	0.00	60.3	0.89
United States	0.125	100.0	1	0.00	85.7	0.73

half of the stocks were quoted at the modal tick. Table II also gives some information on the dispersion of prices.

Another regularity of tick sizes around the world is that they are often quite large compared to the bid-ask spread. For typical NYSE stocks, the bid-ask spread is usually either one, two, or three ticks wide. This pattern holds true for a number of different countries. Table III combines data from Birinyi Associates (1994) on the bid-ask spread for major market indices for fifteen countries with the data on median relative tick sizes from this study. Although the stocks in the Birinyi data are only a subset of the stocks used in Table I, making a direct comparison problematic, it is clear that the average bid-ask spread for major stocks is a small number of ticks in each country, averaging less than four ticks. Since the tick size is large compared to the spread, it signifies that the tick size is an important consideration in equity market design. Note that the coefficient of variation is lower for the relative bid-ask spread than it is for the median tick size or the spread expressed in ticks,

Table III
Comparison of Bid-Ask Spreads with Tick Sizes

This table compares data on the median tick size as a percentage of stock price for stocks covered by Morgan Stanley Capital International's *Perspectives* at the beginning of January 1994 with median bid-ask spread data from Birinyi Associates (1994). The combined column divides the median bid-ask spread by the median relative tick size. For the United Kingdom, which has no formal tick rule, 0.005 is used as the tick size to reflect the minimum price variation often observed in practice.

	MSCI Data		Data from Birinyi Associates			Combined
Country	Number of Stocks	Median Tick Size Percentage	Number of Stocks	Median Bid-Ask Spread Percentage	Index	Ratio of Median Bid-Ask Spread to Median Tick Size
Australia	95	0.27%	19	0.31%	20 Leaders	1.1
Belgium	39	0.15%	20	0.39%	BEL 20	2.6
Denmark	30	0.30%	19	0.81%	Copenhagen	2.7
France	127	0.07%	40	0.30%	CAC 40	4.1
Germany	131	0.02%	30	0.35%	DAX	16.2
Hong Kong	70	0.33%	33	0.72%	Hang Seng	2.2
Malaysia	105	0.63%	19	0.77%	Selected Issues	1.2
New Zealand	17	0.28%	40	0.99%	NZSE 40	3.5
Norway	28	0.57%	21	1.10%	OBX	1.9
Singapore	51	0.60%	30	0.83%	ST	1.4
Spain	65	0.18%	35	0.44%	IBEX	2.4
Sweden	53	0.53%	30	0.89%	OMX	1.7
Switzerland	100	0.12%	18	0.31%	SMI	2.5
United Kingdom	226	0.11%	100	1.22%	FTSE 100	10.9
United States	503	0.33%	30	0.32%	DJIA	1.0
Total			484			
Average		0.30%		0.65%		3.7
Standard deviation		0.19%		0.31%		4.1
Coefficient of variation		64.3%		47.7%		110.0%

suggesting that the relative bid-ask spreads are the most "regular" of these variables in that common factors help determine bid-ask spreads in different markets.

Another interesting pattern in minimum price variation rules is that changes in such rules are infrequent in equity markets, but less so in futures markets. As noted above, trading in eighths goes back at least as far as 1817 on the NYSE and probably much further.[4] For U.S. futures contracts, however, changes in the tick size occur more frequently. For example, Brown, Laux, and Schachter (1991) list ten tick size increases and eight decreases between 1979 and 1988. Since changing the size of a futures contract does not change the relative tick size, the only way to change the relative tick for a futures contract is to modify it directly, leading to more direct changes in tick rules.

[4] The AMEX did, however, change its Rule 127 in 1992 to allow trading in sixteenths for stocks between $1.00 and $5.00. See Ahn, Cao, and Choe (1996) for more on the impact of this change. In 1995 the AMEX again changed Rule 127 to allow trading in sixteenths for stocks up to $10.00.

II. Stock Splits

A. The Historical Context of Stock Dividends and Stock Splits

Large stock dividends date back to at least 1682, when the East India Company declared a 100 percent stock dividend. Dewing (1934) reports that British firms "quite frequently" declared stock dividends during the eighteenth century. A casual look at nineteenth century U.S. stocks reveals many large stock dividends. *Capital Changes Reporter* (1991), for example, records that Westinghouse Air Brake Co. paid a 400 percent stock dividend in 1886, a 100 percent stock dividend in 1898, and several smaller stock dividends. Nevertheless, splits were quite rare.[5] Dolley (1933a) describes stock splits as "distinctively a post-war phenomenon," and reports that he is unable to find a single split prior to April 1915; most of his sample is from the boom years of the 1920s, when splits became common.

The NYSE changed its method of quoting stock on October 13, 1915 from a percentage of par value to dollars, a subtle difference that may have paved the way for more stock splits. This caused little change for stocks with a par value of $100, which were the majority of NYSE stocks at that time, but for the so-called "half stocks" with lower par values (mostly $50), the stocks were quoted in lower numbers. The tick remained at one eighth. An examination of the NYSE (1914, 1918) rule books before and after this change indicates that there was no change in the round lot of 100 shares or its dollar value. Thus, there was no change in the affordability of a round lot to small investors. Other than the psychological effect of changing the number, the only real change was a doubling of the relative tick size for the half stocks. In an article calling for more stock splits, the *Wall Street Journal* (1915) reported two days after the change that it ". . . has been well received and the sentiment is that the principle should be extended as respects some high priced stocks."

Companies could split their stocks prior to this rule change by the NYSE, but did so rarely. Before the change, a split would have reduced the dollar cost of a round lot, but would have had no effect on either the absolute or relative tick size, since the stock still would have been quoted as a percentage of par value. After the rule change, however, a stock split both reduced the cost of a round lot and increased the relative tick size, and stocks began splitting regularly. Before 1915, some firms paid large stock dividends rather than split, which would reduce the par value without affecting the relative tick size. This resulted in prices that were a lower percentage of par value, and thus a higher relative tick size. Post hoc does not prove propter hoc, however. The increase in splits could also have been affected by other changes in financial markets in the early twentieth century, including changes in state corporation laws that permitted the issuance of low-par and no-par stock.

[5] The primary difference between a stock dividend and a split is an accounting one: in a stock dividend, the par value of the stock remains unchanged. The company thus transfers an amount from the surplus accounts to the paid-in-capital accounts. In a stock split, the par value per share is reduced by the split factor, and no change is made in the surplus accounts.

B. Previous Explanations of Stock Splits

The reasons for and the effects of stock splits have long intrigued researchers. Splits appear to be cosmetic changes, affecting only the number of outstanding shares without changing the relative ownership among shareholders. Splits do not affect a firm's sales or earnings. Since the additional costs of splitting are substantial—probably more than one million dollars for a major stock like Disney—companies would not split unless there were some perceived benefits.[6] Surveys of managers indicate that their motivations for splitting include attracting more shareholders to the company, increasing the liquidity of the stock, and keeping the stock price in the optimal trading range.[7]

One argument often made for stock splits is that the reduction in prices following a split makes it easier for small investors to afford a round lot of the stock. Back in the days when odd-lot investors were charged a differential, a stock split would have reduced the odd-lot charges paid by some investors, but the increase in brokerage fees would have offset the savings.[8] The odd-lot differential on the NYSE was eliminated in January, 1991, yet stock splits continue to occur regularly.

Numerous empirical studies have documented that stocks usually go up on the announcement of a split.[9] Academic investigations of splits have focused primarily on signaling and liquidity. A firm may use a split to signal that a recent increase in share price is permanent, not transitory. However, Lakonishok and Lev (1987) conclude that stock splits are "mainly aimed at restoring stock prices to a 'normal range'" rather than signaling. McNichols and Dravid (1990) study the information in earnings forecast errors for firms that split and conclude that splits signal private information about a firm, but that signaling alone is an incomplete explanation of split behavior.

[6] Usually, shareholders must approve a split, so firms may have to hold a special vote of their shareholders, with all the expenses of sending out prospectuses and soliciting proxies. If the firm is listed on the NYSE, the new shares incur additional listing fees, both for the shares issued in the split and the annual maintenance fee. There are expenses in printing new stock certificates for the additional shares and mailing them out to shareholders. Furthermore, some states levy franchise taxes based on the number of shares authorized. In Delaware, for example, a firm with 15 million authorized shares that split two for one would see its annual franchise tax under section 503 of the Delaware code increase from $75,000 to $150,000. See McGough (1993) for details on some of the administrative aspects involved in a stock split.

[7] See Baker and Gallagher (1980) and Baker and Powell (1992) for surveys of managers who split their stock.

[8] Odd-lots typically paid an additional eighth each way for stocks under $40 and an additional quarter for stocks over $40.

[9] A few of the studies of stock splits in the United States include Fama, Fisher, Jensen, and Roll (1969), Charest (1978), Grinblatt, Masulis, and Titman (1984), Ohlson and Penman (1985), Dravid (1987), Lamoureux and Poon (1987), Lakonishok and Lev (1987), Brennan and Copeland (1988a,b), Asquith, Healy, and Palepu (1989), Sheikh (1989), McNichols and Dravid (1990), Dubofsky (1991), Wiggins (1992), and Maloney and Mulherin (1992). Kryzanowski and Zhang (1991) have found similar results for stock splits in Canadian data. Woolridge and Chambers (1983) and Peterson and Peterson (1992) have looked at reverse splits and find that prices usually drop on the announcement of a reverse split.

Liquidity-based explanations for the stock price reaction to splits examine the impact of the split itself on trading in the firm's stock. Managers often assert that a split makes a stock more liquid, which in turn should make it more valuable. The increase in value could be due to reduced trading costs in the tradition of Amihud and Mendelson (1986, 1987, 1988) or to a larger pool of investors willing to invest in the stock along the lines of Merton (1987). However, some measures of liquidity are actually lower after a split. Copeland (1979) finds that trading volume declines in the year following a split, but Lakonishok and Lev (1987) find that the presplit volume was exceptionally high, and that stock splits seem to have no permanent impact on trading volume. Furthermore, Conroy, Harris, and Benet (1990) find that bid-ask spreads increase after splits.

If the bid-ask spread was the only measure of liquidity, the increase in spreads after a split would contradict practitioners' beliefs that a stock becomes more liquid after a split. However, there is more to liquidity than quoted bid-ask spreads. As pointed out by Merton (1987), increasing the fraction of investors who "know about" a security reduces its required return. The number of a firm's shareholders usually increases after a split, as documented by several studies.[10]

Brennan and Hughes (1991) provide one explanation for this increase in the number of shareholders by focusing on the role of brokerage firms in providing research coverage to firms. Since stock splits increase the brokerage fees paid by most investors, splitting a firm's stock gives brokers more incentive to do research on and promote a given firm. Consistent with their model, Brennan and Hughes find that security analyst coverage increases after splits. While this argument may help to explain splits by smaller and less well-known firms, it is less likely that large firms such as Disney, Merck, and Coca-Cola were in need of additional analyst coverage when they recently split. Indeed, since 1980, at least 24 of the 30 constituents of the Dow Jones Industrial Average have split. A general explanation of stock splits must explain why large as well as small firms split.

Additional evidence for the role of liquidity comes from ADRs, which sometimes split when the home country stock does not. Muscarella and Vetsuypens (1996) find positive stock returns in these situations, where there is presumably no signaling about the firm's underlying prospects, unless home country regulations prevent stock splits.

In addition to signaling and liquidity, tax laws and other regulations also affect corporate decisions on how many shares to issue and when to split stocks. For example, regulations such as those in Switzerland and Germany that require a minimum nominal share value may impede splits. Regulations designed to prevent fraud in penny stocks also are an impediment to splits, since legitimate companies would not want to issue securities that might

[10] See Dolley (1933b), Barker (1958), Lamoureux and Poon (1987), Brennan and Hughes (1991), and Maloney and Mulherin (1992) for evidence that the number of shareholders increases after a split.

become difficult to trade because of the penny stock rules.[11] Furthermore, some jurisdictions levy taxes based on the number of shares issued, which would also hinder companies from splitting.

However, neither the signaling nor liquidity arguments mentioned thus far explain why the average share price is about $30. If splitting a stock signals good news, raises the stock price, increases liquidity, and expands the number of shareholders, why stop at $30 per share? Why not split several more times and reap even greater benefits? The recent attention paid to the role of tick size helps provide an explanation. Harris (1994a) notes that stocks may split in reaction to a change in tick size. Anshuman and Kalay (1993) develop a model following Admati and Pfleiderer (1989) in which the optimal relative tick size is designed to minimize losses to noise traders. The next section explores in more detail the economic considerations behind an optimal relative tick size.

III. Optimal Relative Tick Size

This section investigates how a wider relative tick size can enhance some aspects of liquidity by providing incentives for market makers and for limit order traders. These incentives, however, are counterbalanced by the upward pressure that a wider tick size puts on the bid-ask spread. Part A discusses these incentives and provides empirical evidence that liquidity-providing limit orders are used more frequently for stocks with higher relative ticks. Part B builds on Merton's (1987) model to estimate the optimal relative tick size as a trade-off between the cost of an increased bid-ask spread and the benefit of an expanded pool of investors.

A. Factors Affecting Optimal Tick Size

The optimal relative tick size for a given firm reflects a trade-off between incentives that a larger relative tick size provides to liquidity providers such as market makers and limit order traders, and the costs that a larger tick imposes on investors.

As Harris (1991) points out, traders use discrete prices to reduce the cost of negotiating. Since traders' time is limited, reducing the number of possible price outcomes decreases the time needed to negotiate and complete trades, which means they can go on to the next profitable trading opportunity. By increasing the tick size, there are fewer possible price outcomes in a given range. For example, trading in eighths results in only seven prices between $10 and $11, while trading in pennies would permit 99 outcomes. Brown, Laux, and Schachter (1991) model trading as a prisoners' dilemma in which both parties would have incentives to spend too much time negotiating, and the tick size serves as a mechanism to prevent excessive bargaining costs.

[11] SEC Rules (17 CFR 204.15g-9) impose additional requirements on brokers selling unlisted stocks less than $5.00 in value. Brokers in such transactions must, among other things, obtain written purchase agreements prior to such transactions.

The reduction in possible prices from a wider relative tick not only reduces the time needed to negotiate, but also decreases the information that traders need to track. Cognitive researchers have found that human short-term memory can hold only a few pieces of information at once, although the exact amount is open to debate. Miller (1956) holds that the number of items is seven "plus or minus two" and Simon (1974) holds that it is about five. It is easier to remember the contents of an order book if they are concentrated on seven different levels rather than 99. Eliminating economically insignificant information means that a trader's finite mental capacity can be used for more profitable activities, such as making markets in additional stocks.

This simplification of the information environment also reduces the possibility of trading errors. In a trading environment a simple clerical error may result in catastrophic losses that could cost a trader his or her job or even bankrupt the firm. For this reason, traders prefer a simpler and thus safer trading environment. Brown, Laux, and Schachter (1991) quote traders' claims that the number of trading errors in coffee futures declined after the January 1990 increase in the tick size of the contract.

A large relative tick size also encourages dealers to make a market in a stock. Grossman and Miller (1988) and Harris (1991) note that the minimum price variation puts a floor on the quoted bid-ask spread. Niemeyer and Sandås (1994) examine the Swedish market, which has different tick sizes based on share price, and find that the tick size is a significant influence on the bid-ask spread. Thus, a larger tick provides a higher minimum round-trip profit to a dealer who can buy at the bid and sell at the offer.[12] However, dealers are not guaranteed this profit, and, as demonstrated by Silber (1984) and Kuserk and Locke (1993), scalpers' profits are often substantially less than one tick per trade. If the relative tick size is too big, the profits from a wider tick size may be dissipated through vigorous competition for order flow and payment for order flow.

Furthermore, if the market makers are also brokers, a wider relative tick increases incentives to conduct research on and promote the stock, since additional order flow will be more profitable on the market making side. This increases the pool of investors who know about a firm. This point is similar to the Brennan and Hughes (1991) model, in which firms split their stocks to increase brokerage commissions, and thus create incentives for brokerage firms to promote a stock. Here the incentives go to the firms through their market making activities rather than brokerage commissions. It should also be noted that many investors in the United States now pay commission rates that are less than the tick size. A brokerage firm that acts as a market maker may earn more from the bid-ask spread on an order than it does in brokerage commissions.

The use of the term market maker does not mean that this liquidity effect is limited to stocks that trade only in dealer markets such as Nasdaq. There are

[12] Anshuman and Kalay (1994) model the tick size as an attempt by an exchange to cartelize trading in this way.

multiple market makers in most NYSE-listed stocks, including the regional exchange specialists and NASD market makers such as Bernard L. Madoff Investment Securities. These other market makers can choose whether or not to make markets in these stocks. Since the tick size affects the profitability of trading, it is likely to affect decisions about making a market in a particular stock. Several large brokerage firms own specialist firms on the NYSE or the regional exchanges and thus can benefit by promoting stocks both through commissions and trading revenues.[13]

With more market-making capital in a given stock, investors can usually trade larger quantities of stock on short notice without moving the stock price unacceptably. By making it easier for investors to get in and out of a stock, this increase in liquidity makes more investors willing to consider holding the stock.

The limit order book is also an important provider of liquidity to the market, since limit orders supplement the capital provided by dealers. Harris (1990, 1994b) also point out that a nontrivial tick size is important for enforcing time priority in a limit order book. Without a minimum price variation, an investor could jump the limit order queue by placing an order at a price trivially better than the existing orders on the book. This hurts those who have previously placed limit orders and lost their place in the queue. Placing an order to trade reveals information to the market that in itself can move the price against the investor. As Copeland and Galai (1983) note, a limit order essentially gives a free option to the market. But, since the limit order can be withdrawn at any time and thus has a very short maturity, its option value is quite small.[14] The real cost of a limit order is that it reveals part of an investor's information set by revealing a willingness to trade.[15] Unless investors are compensated for revealing this information, they will not do it. A larger relative tick size gives investors more incentive to provide liquidity by using limit orders.

Empirical support for the assertion that a larger relative tick size provides more incentive for limit orders may be obtained from the NYSE Trades, Orders, and Quotes (TORQ) database described in Hasbrouck (1992), which contains information on orders submitted to the NYSE via its SuperDot system for 144 firms between November 1990 and January 1991. This information includes whether the orders were limit or market orders. All 541,374 regular way intraday buy or sell orders for all 144 stocks in the sample are examined for this study. For each stock, the percentage of orders placed as limit orders, as market orders, and as "marketable limit" orders, that is, limit orders with limit prices such that they could be filled immediately at the best consolidated

[13] The SEC's (1994) *Market 2000* notes that over a third of the specialist units on U.S. exchanges were affiliated with upstairs firms.

[14] Valuing the limit order option is an interesting exercise. Since an order may be filled before a cancellation of that order reaches the floor, the effective maturity of the limit order option may be as long as a few minutes. Applying standard option pricing models with typical parameters results in a value much smaller than the tick size.

[15] For this reason, Toronto's CATS and the Paris Bourse, as well as many proprietary trading systems that display the limit order book, allow "hidden" orders to be placed that are not displayed.

Table IV

Effects of Relative Tick Size on Liquidity
TORQ Data
November 1990 Through January 1991 for 144 Firms

This table examines 541,374 intraday regular way buy and sell orders (not including stop orders) that were placed through the NYSE SuperDot system for 144 stocks between November 1, 1990 and January 31, 1991, by price category. Marketable limit orders are orders that are placed as limit orders but that have a limit price that can be executed immediately at the current quotes. For each firm, the percentage of orders of each type is calculated. The table displays the average percentage across firms in each price category.

Price Category	Percentage of Limit Orders	Standard Deviation of Percent Limit Orders	Percentage of Market Orders	Standard Deviation of Percent Market Orders	Percentage of Marketable Limit Orders	Standard Deviation of Percent Marketable Limit Orders	Number of Stocks	Number of Orders
Less than $1	25.7	5.2	61.6	7.5	12.7	2.7	9	1,847
$1–$5	45.8	1.5	36.5	1.6	17.8	0.7	24	19,293
$5–$10	44.2	1.6	38.3	1.5	17.5	0.9	18	36,756
$10–$20	36.9	1.7	50.4	2.2	12.7	0.9	39	74,538
$20–$30	29.3	2.1	61.7	2.8	9.0	0.8	29	80,254
$30–$50	28.9	2.0	62.3	2.4	8.8	0.6	16	159,645
Over $50	26.2	1.5	62.9	3.9	10.9	3.0	9	169,041
Overall	35.5	1.0	51.6	1.4	12.9	0.5	144	541,374

quote, are calculated. Table IV breaks down these percentages by price category. Because the tick size on the NYSE is constant at $0.125 for stocks over $1, higher stock prices have lower relative tick sizes. As may be seen from Table IV, limit orders are used less frequently for higher-priced stocks. With the exception of penny stocks, which have different tick sizes, the relationship is monotonic: The higher the stock price, the lower the fraction of limit orders.

To control for other factors that might affect placement of limit orders, such as volume and the bid-ask spread, regression models are estimated as shown in Table V for stocks priced over $1 per share. The ratio of the volume of limit orders to market and marketable limit orders, *Limit2Mark*, is regressed on the relative tick size and other explanatory variables. Because the nominal tick is a constant $0.125, the relative tick size is measured by the inverse price, denoted by *InvPri*. Since limit order placement is strongly affected by the width of the bid-ask spread, the regressions are run separately for spreads of one, two, and three ticks. The other explanatory variables include *LogVolume*, the natural logarithm of the average daily trading volume, *LogCapt*, the logarithm of market capitalization, and *StdDev*, the standard deviation of the daily stock return. The intercept term increases as the spread increases, indicating that more limit orders are placed when the spread is wider. As expected, the coefficient on InvPri is positive in all three regressions, and significantly so in two of the three. This suggests that more limit orders are placed for stocks with a larger relative tick size.

A larger relative tick size, however, provides costs as well as benefits. A wider bid-ask spread may be an incentive for a market maker, but it is a higher transaction cost to an investor. An increase in transaction costs, ceteris paribus, can be expected to reduce overall liquidity for the stock. This offsets some

Table V

Effect of Tick Size and Bid-Ask Spread on Limit Order Placement

Limit2Market = α + β_1 InvPri + β_2 LogVolume + β_3 LogCapt + β_4 StdDev

This table displays Ordinary Least Squares (OLS) regression results investigating the impact of tick size and bid ask spread on the rate of SuperDot limit order placement for the Trades, Orders, and Quotes (TORQ) stocks with average share prices greater than $1 per share from November 1, 1990 through January 31, 1991. *Limit2Market* is the ratio of the volume of limit orders placed at or within the quotes divided by the volume of market and marketable limit orders. *InvPri* is the inverse of the average price, a measure of the relative tick size since the minimum price variation is a constant $0.125 for stocks priced over $1 per share on the New York Stock Exchange (NYSE). *LogVolume* is the natural logarithm of the average daily share volume. *LogCapt* is the natural logarithm of the market capitalization of the stock. *StdDev* is the standard deviation of the daily return on the stock. Heteroskedasticity adjusted t-statistics are in parentheses.

	Bid-Ask Spread = One Tick ($0.125)	Bid-Ask Spread = Two Ticks ($0.25)	Bid-Ask Spread = Three Ticks ($0.375)
Intercept(α)	0.90 (4.07)	1.62 (2.57)	2.07 (1.42)
InvPri(β_1)	0.77 (1.96)	4.48 (2.67)	14.48 (1.38)
LogVolume(β_2)	−0.01 (−0.19)	−0.16 (−0.63)	−0.47 (−1.15)
LogCapt(β_3)	−0.06 (−2.43)	0.05 (0.28)	0.24 (0.68)
StdDev(β_4)	0.03 (0.78)	0.14 (0.73)	0.06 (0.16)
Adjusted R^2	27.6%	17.5%	9.7%
Number of firms	129	131	96

of the advantages to a larger tick size. Theoretically, traders can get around a large tick size through so-called "ginzy" trading, in which a trade is broken down into two parts and each part is executed at a different price to get around the tick size restrictions. However, this may be hard to accomplish in a market like the NYSE, since an existing order in the book may have precedence over one of the legs of a ginzy trade.

The impact of tick size on bid-ask spreads can be seen in Table VI, which examines the bid-ask spreads for all NYSE-listed common stocks by price category. As expected, the percentage spread declines as share prices increase (and the relative tick sizes decrease) except for the two largest categories, which are not statistically significantly larger.[16] The rate of decrease, however, in the bid-ask spread becomes very slow over $30.

Tables IV through VI may explain why the average NYSE share price does not move above $40. Because there is little improvement in the bid-ask spread above $40, letting the price move higher means that there may be fewer liquidity-enhancing limit orders without much improvement in the bid-ask spread.

The type of market mechanism used may also affect the optimal relative tick size. Obviously, incentives for limit orders may have different results depend-

[16] If preferred stocks are examined as well, there is a U-shaped pattern to the bid-ask spread with spreads increasing above $40 per share. This is the result of several hundred relatively inactive but high-priced preferred stocks.

Table VI

Bid-Ask Spreads By Price Category
NYSE Quote Data for January 11, 1993

This table presents information based on all New York Stock Exchange (NYSE) specialist quotes for common shares made on January 11, 1993, from the NYSE Trades and Quotes (TAQ) data. The size represents the number of round lots of 100 shares quoted by the specialist as the sum of the sizes for the bid and offer quotes. The dollar amount of the size is also calculated by multiplying the size by the price of the stock. Preferred stocks are not included in this table. Stocks are classified into price categories based on their average midpoint quotes. The percentage bid-ask spread represents the average across stocks.

Price Category	Number of Stocks	Percentage Bid-Ask Spread	Standard Error of Percent Spread	Bid Size + Offer Size in 100s	Standard Error of Size	Dollar Size ($000)	Standard Error of Dollar Size
Less than $1	38	14.7	1.19	543	86.8	27	5.2
$1–$5	126	6.6	0.30	335	38.0	98	11.8
$5–$10	305	2.4	0.05	292	25.3	238	21.7
$10–$20	618	1.5	0.02	164	9.8	226	12.3
$20–$30	425	1.0	0.02	97	5.8	238	14.2
$30–$40	243	0.7	0.02	108	7.7	369	26.6
$40–$50	137	0.5	0.01	107	7.4	480	33.6
$50–$60	76	0.5	0.02	95	8.6	521	47.7
$60–$70	50	0.4	0.03	96	12.0	618	75.4
$70–$200	51	0.6	0.22	78	15.1	665	119.4
Over $200	3	4.3	3.85	8	5.1	365	25.5

ing on how a market treats limit orders. In a dealer market such as Nasdaq or London, the lack of a central limit order book with price and time priority and protection against trade-throughs may deter investors from placing limit orders. The incentives for market makers also differ across markets. This implies that optimal tick sizes may vary across markets that use different mechanisms.

B. A Simple Model of Optimal Relative Tick Size

By combining the Merton (1987) model of an informationally incomplete capital market with Amihud and Mendelson's (1986) finding that higher bid-ask spreads are associated with higher rates of return, it is possible to construct a simple ad hoc model that may shed some light on the optimal relative tick size. In the Merton (1987) model, the fraction, q_k of investors who "know about" a stock k is less than the total number of investors. This causes an increase, λ_k, in the required rate that is also a function of firm size and idiosyncratic risk:

$$\lambda_k = \frac{(1 - q_k)}{q_k} x_k \delta \sigma_k^2. \tag{1}$$

Here, x_k is the weight of the firm in the market portfolio, δ is the common risk aversion parameter for each investor in the model, and σ_k^2 is the idiosyncratic risk of the stock.

As noted above, a wider tick may increase the fraction of investors who "know about" a firm by increasing the incentive for market makers to trade the stock and for their affiliated brokerage firms to promote the stock. The supplemental liquidity increase from the limit order book also may increase the pool of people willing to hold a given stock and who thus "know about" the stock. For simplicity and tractability, this is modeled as a linear function of the relative tick size T:

$$q_k = q_0 + \alpha_1 T \tag{2}$$

where q_0 is the fraction that would know about the firm with an infinitesimal relative tick size and α_1 is a constant.

In the Amihud and Mendelson (1986) model, the impact of bid-ask spread on the observed market return is an increasing and concave, yet piecewise linear function of the spread. The extra required return γ is assumed to be proportional to the relative bid-ask spread S, with a constant of proportionality α_0:

$$\gamma = \alpha_0 S. \tag{3}$$

Tick size, however, also has an impact on the bid-ask spread, which is again modeled as a linear function of the relative tick size:

$$S = S_0 + \alpha_2 T \tag{4}$$

where S_0 is the intercept and the constant of proportionality is α_2.

A manager who wants to minimize the part of the cost of capital that stems from the sum of these trading frictions, r, would minimize, subject to T being greater than zero:

$$r = \frac{1 - (q_0 + \alpha_1 T)}{(q_0 + \alpha_1 T)} x_k \delta \sigma_k^2 + \alpha_0 (S_0 + \alpha_2 T). \tag{5}$$

Simple calculus reveals that these frictions are minimized at T^*:

$$T^* = \frac{\sqrt{\alpha_1 x_k \delta \sigma_k^2 / \alpha_0 \alpha_2} - q_0}{\alpha_1}. \tag{6}$$

Inspection of the partial derivatives reveals that a firm that is already highly visible (higher q_0) has a lower optimal relative tick size than a less visible firm. Thus, firms that produce well-known consumer goods or are otherwise highly visible (e.g., Apple and IBM) would choose a higher price level than firms producing lesser-known products. Ceteris paribus, a firm that has more idiosyncratic risk (higher σ_k^2) should have a wider tick, as should a firm with a larger fraction of the total market value (x_k). Higher risk aversion for investors (δ) should lead to a wider relative tick size.

These results may shed new light on another curiosity of share prices, that firm size and price are positively correlated in most markets, as demonstrated in Table II. Unfortunately, the ad hoc model predicts that larger firms should have, ceteris paribus, a wider tick size and thus a lower share price, the opposite of what is observed. Thus, this model shares the problem of the original Merton model, a seeming inability to explain the observed effects of size. However, as Merton himself points out, the partial derivatives alone do not tell the whole story. Since larger firms tend to have lower idiosyncratic risk, the size effect may be offset by idiosyncratic risk; the total derivative may have a different sign from the partial derivative. Similarly, since larger firms tend to be already well known (high q_0), the effect of their already large pool of investors may overwhelm the size effect predicted by the model.

The insights suggested by the ad hoc model may help explain why the issue prices of IPOs are usually lower than the average share price: IPOs are usually lesser known and have higher idiosyncratic risk than seasoned firms. An issue price lower than the average price for seasoned stocks provides a relatively larger, yet more optimal relative tick size. Alternatively, since it is costly to split stocks, firms will issue stocks at prices below the optimal price so that the stock will spend more time in the neighborhood of the optimal price before it splits.

These considerations might also help to explain why the average Nasdaq share price is so much lower than the NYSE share price, and why the minimum price increments used in practice are larger than the minimum permitted by the NASD.[17] The larger effective ticks for Nasdaq stocks may be appropriate for the riskier and lesser known stocks that trade there. Furthermore, Nasdaq stocks tend to be younger than NYSE stocks and thus have had less time to grow from their initial offering prices.

IV. Empirical Evidence

A. Postsplit Prices in the United States

The above model implies that firm size, idiosyncratic risk, and the fraction of investors who "know about" a firm could be important considerations in determining the optimal stock price. These implications are testable by looking at the prices that companies choose immediately after a stock split, before their stock prices have had time to wander far from the optimal price. As noted above, companies may choose a target price below the optimal price so that the stock spends more time close to its optimal price before it is time to split again. Nevertheless, the target price should be closely related to the optimal price.

Data on firms that split their stock at least 5:4 are obtained from the CRSP NYSE/AMEX monthly file, along with accounting information from COMPUSTAT and data on the number of analysts from Zacks. Only NYSE and AMEX-listed firms are used, since Nasdaq uses a different market mechanism and may not be comparable to NYSE and AMEX stocks. Each split firm is matched with a control firm in the same two digit Standard Industrial Classification

[17] The average Nasdaq share in 1991 was $12.73, according to the NASD (1992).

Table VII

Factors Affecting the Target Share Prices
NYSE/AMEX Splits between January 1, 1984 and December 31, 1993

$$Price = \alpha + \beta_1\, IdioRisk + \beta_2\, Age + \beta_3\, LogSize + \beta_4\, NumAnalysts + \beta_5\, RegInd$$

These regressions investigate the impact of proxies for idiosyncratic risk, firm size, and the fraction of investors who "know about" a firm on the target stock prices selected by firms when they split their stock. The splitting firms are those New York Stock Exchange/American Stock Exchange (NYSE/AMEX) firms from the Center for Research in Security Prices (CRSP) file that split 5:4 or more between January 1, 1984 and December 31, 1993. The control firms are the firms in the same industry (defined by the two digit Standard Industrial Classification (SIC) code) that did not split in that month and are matched through the Harris (1989) method. The dependent variable for the splitting firms is the target price, defined as the price at the announcement of the split adjusted by the split factor. For the control firms, the dependent variable is the price at the time of the split. Idiosyncratic risk, *IdioRisk*, is the variance of the residual from a 60 month beta regression using the CRSP Value Weighted Index. *Age* represents the length of time for which price information is available for the firm on the CRSP NYSE/AMEX monthly file. *LogSize* is the natural logarithm of the book value of the firm from COMPUSTAT. The number of analysts, *NumAnalysts*, is obtained from Zacks. The regulated industry dummy, *RegInd*, is set to one for industries with an SIC code in the 4000 range. Heteroskedasticity-adjusted t-statistics are in parentheses. The out of sample forecast error is tested in the holdout sample by randomly separating the splitting firms into two groups. The model is estimated for the first half of the sample, and then the fitted model coefficients are used to forecast the target price for the other half of the sample and the controls. The dummy *Control* is set to one for the controls. The absolute value of the forecast errors is then regressed on the explanatory variables from the model plus *Control* to measure the difference in fit of the model between the splitting firms and the controls.

	Splitting Firms	Control Firms	Holdout Sample
Dependent variable	Target stock price	Stock price	Absolute forecast error
Intercept(α)	3.09 (1.75)	17.84 (5.90)	−6.51 (−3.20)
IdioRisk(β_1)	−38.06 (−3.60)	−156.04 (−9.11)	37.43 (3.68)
Age(β_2)	0.04 (2.23)	0.11 (3.00)	0.03 (1.45)
LogSize(β_3)	4.27 (14.82)	3.32 (8.33)	1.69 (5.87)
NumAnalysts(β_4)	0.10 (1.58)	0.54 (5.23)	0.00 (0.03)
RegInd(β_5)	−4.59 (−6.20)	−0.75 (−0.33)	−0.69 (−0.42)
Control			6.25 (9.42)
Number of observations	1,160	1,160	553 splitting firms with 553 controls
Adjusted R^2 (percent)	50.18%	34.47%	11.48%
F Value	234.7	123.1	25.3

(SIC) code that trades on the same exchange but did not split in the same month. The controls are selected using the method of Harris (1989) on the other explanatory variables.[18] Complete data and control firms are available for 1,160 stock splits between January 1, 1984 and December 31, 1993.

Table VII demonstrates the results of regressions of the postsplit target

[18] Firms with share prices over $500 are not used as controls. Thus, Berkshire Hathaway, which has a unique policy of not splitting its stock, is not used as a control since its share price is over $10,000 per share. The maximum price of a splitting stock in the sample is $343 per share.

stock price and the control stock price on proxies for idiosyncratic risk, firm size, and the number of investors who "know about" a stock. The idiosyncratic risk, *IdioRisk*, is based on the variance of the residuals from a 60-month beta regression using the CRSP value weighted index. The model predicts that firms with a higher idiosyncratic risk should choose a lower stock price, so the predicted coefficient is negative, as is the case for both split firms and control firms. *Age*, defined as the number of years the firm has been listed on the CRSP NYSE/AMEX monthly tape, is used as one proxy for the fraction of investors who "know about" the firm. Since better-known firms should choose a higher stock price, the coefficient should be positive, as it is in both cases. The number of analysts, *NumAnalysts*, is another proxy for how many investors "know about" the firm, with the positive coefficients predicted in the model. However, the coefficient is not significant for the splitting firms.

Firm size is proxied by *LogSize*, the natural logarithm of the book value of equity. Here the result is the opposite of that predicted by the partial derivatives in the model: Large firms choose higher share prices even after correcting for the other explanatory factors. It may be that firm size is capturing other aspects of how well known the firm is beyond age and number of analysts. A better proxy for the number of investors who "know about" a firm is needed.

Finally, a dummy for regulated industries, *RegInd*, is set to one for SIC codes in the 4000 range. The negative coefficient shows that regulated firms choose lower share prices at split time than nonregulated firms, although the result is not significant for the control firms. A regulated firm may desire to give incentives to market makers and brokerage firms to widen the firm's investor base so that it will have more political clout with regulators.

Note that the fit of the ad hoc model, in terms of R^2, and F-Value, is stronger for split firms than for control firms, indicating that these variables have an impact on the target price decisions made through stock splits. To test this proposition formally, the model is estimated on a randomly chosen half of the firms that split, and then the coefficients from that regression are used to estimate the target price for both the splitting firms and the controls in the holdout sample. The absolute forecast errors are then regressed on the original explanatory variables (to control for heteroskedasticity) and a dummy variable, *Control*, for the firms in the control sample. The highly significant and positive sign on Control indicates that the regression model forecasts the target price much more accurately for firms that split than for the control firms.

B. International Evidence

Another implication of the informal theory presented here is that markets for which the absolute tick size is a step function based on price should have fewer splits and a higher cross-sectional dispersion of share prices. A step function of tick sizes would reduce the need to split stocks to adjust tick sizes.

Data on international rates of stock splits were not available for this study, so it is not possible to test directly the implication that markets with a "one tick fits all" policy have more splits than markets with step-function tick rules. It is possible, however, to examine the implication that countries with a step function for tick sizes will have higher price dispersion than single-tick countries. Since many countries have step functions for tick size in their rule books, but the majority of their stocks trade at a single nominal tick size, it is necessary to quantify the degree to which a country uses different tick sizes. This is done by regressing the log nominal tick size on price across all stocks for each country to create the measure *Scale*. In a country such as the United States, where a single tick predominates, the Scale measure is zero. The measure of price dispersion, *Dec2Pri*, is measured by taking the range between the 10th and 90th percentiles and dividing by the median price. Regressing the measure of dispersion, *Dec2Pri* on the degree to which a country uses a step function, Scale, gives the following results:[19]

$$\underset{}{\text{Dec2Pri}} = \underset{(10.18)}{2.10} + \underset{(2.10)}{1.18}\ \text{Scale} \qquad \text{Adjusted } R^2 = 11.76\%.$$

As expected, the coefficient on *Scale* is positive, suggesting that countries that use a step function for tick size are associated with a higher dispersion of share prices.

The effects of the tick size regime should also be visible in the relationship between relative tick size and the market capitalization. Since firm size and capitalization are usually positively correlated, firm size and relative tick size should show a negative correlation in markets that have a single nominal tick, such as the United States. This relationship should be less strong in countries that use a number of different ticks, however. To investigate this, the Spearman correlation between market capitalization and relative tick size, *CapTick*, is regressed on the measure of the tick rule *Scale* as follows:

$$\text{CapTick} = \underset{(-9.52)}{-2.44} + \underset{(5.98)}{0.39}\ \text{Scale} \qquad \text{Adjusted } R^2 = 62.4\%.$$

As expected, the correlation becomes less negative as the variation in nominal tick sizes increases. Results for other measures of the tick rule are similar.

Although not a direct test, this empirical evidence is consistent with the hypothesis that tick size considerations affect stock splits and price dispersion. However, the exogeneity of absolute tick size rules in these simple regressions is open to question, since tick size rules not only help to determine the standard range of share prices, but may also be determined by that range. Nevertheless, tick size rules in most equity markets change very infrequently, and share prices have had ample time to adjust to the present tick rules: The great majority of NYSE firms have either split after the NYSE adopted trading in dollars in 1915, or did not exist in 1915.

[19] The results are generally robust to using different measures of price variability and of the tendency for countries to adopt a single tick size. Results of the different specifications are available upon request.

Interestingly enough, Israel still quotes prices as a percentage of the par value, just as the NYSE did prior to 1915. The dispersion of prices also is quite high, with prices ranging from several tenths to millions, and splits are rare.[20]

V. Conclusions

In equity markets, companies can affect the relative minimum price variation, or tick size, of their stocks through stock splits. A company may split its stock to move its share price into the range where the institutionally mandated minimum absolute tick size is optimal relative to the share price. A wider tick size enhances liquidity by reducing bargaining and processing costs and by providing more incentives for limit orders and market makers to provide liquidity. A wider relative tick size, however, also increases the minimum quoted bid-ask spread. A simple ad hoc model suggests that the optimal relative tick size for a particular firm may be a function of its idiosyncratic risk, market size, and the fraction of investors who know about the firm. Although tick size is an important consideration, other factors such as brokerage commission rate schedules or the desire to signal good news may also affect stock split behavior.

Tick rules are an important factor in determining why price levels per share differ across countries. Since these rules vary across countries, the optimal trading ranges vary accordingly. However, the tick size relative to stock prices is comparable from country to country.

One objection to the argument that stock splits are affected by tick size considerations is that practitioners do not cite tick sizes when discussing splits. A Lexis search of proxy statements filed with the Securities and Exchange Commission (SEC) fails to find a single proxy statement that discussed tick sizes when proposing a stock split. However, the fact that a practitioner is not consciously thinking about tick size when splitting a stock does not necessarily mean that it is unimportant. Practitioners know from experience what price range is the most liquid, even if they do not know or are unable to articulate why: The fact that a professional swimmer may know nothing about the physics of fluid mechanics does not mean that the viscosity of water does not affect the way the swimmer moves.

Another counter-argument could be drawn from reverse stock splits, which usually result in negative price effects, as shown by Woolridge and Chambers (1983). If a reverse split were to move a stock back into its optimal trading range, this should, ceteris paribus, affect the price positively. For splits that are voluntarily undertaken, the negative signal from management that the low share price is permanent apparently dominates the increased liquidity from moving back into the optimal price range. However, Peterson and Peterson (1992) find that when firms had to reverse split to remain listed on an exchange, which presumably did not signal information about the firm, the

[20] This information is based on private correspondence with Tel Aviv Stock Exchange spokesperson Haya Oz, who was unaware of any studies of stock splits in Israel.

effect on price was positive, similar to a decision to list on an exchange. This increase in value is consistent with an increase in liquidity resulting from a stock's return to the optimal trading range. Han (1995) documents decreases in the bid-ask spread subsequent to reverse splits.

The tendency toward stability for the relative tick size has implications for the current debate over changing the tick size in the U.S. equity market. Several proponents of quoting U.S. stock prices in decimals, including Hart (1993) and Peake (1995), claim that doing so would have the advantage of reducing the tick size. The SEC staff (1994) has proposed in its *Market 2000* study that the "one-eighth" pricing system be eliminated, either by pricing in sixteenths or through conversion to a decimal system. Quoting stock prices in decimals does not necessarily mean reducing the minimum tick size to one penny or less; prices could be quoted in decimals with a tick of a nickel or even a quarter.

Furthermore, changes in minimum tick sizes, either by exchange or government fiat, may eventually be undone as companies split their stocks into the new preferred trading range. A reduction in the minimum price variation from \$0.125 to \$0.01 could eventually lead to a reduction in the average share price by the same factor, 12.5, resulting in an average share price around \$3. This price range is seen in other countries with a 0.01 minimum price variation. The adjustment could take several years, if not decades, as practitioners learn through experience where the new optimal trading range is: Just after the NYSE switched to dollar pricing in 1914, the average NYSE share price was \$96. By 1924 it had fallen to \$62 and in the 1930s reached today's under \$40 range.

This is not to say that switching to a decimal pricing system would be bad, only that a reduction in the relative tick size is not likely to be a lasting effect of such a change. Nevertheless, an advantage of quoting stock prices in decimals is that it would reduce the class time spent by professors trying to answer the perennial question of why U.S. equities trade in eighths! More seriously, the fact that fractional pricing is still used in many markets where it is not required by regulation seems to indicate that it may have some value. Regulators should not rush to force the adoption of decimal pricing just because it looks cleaner, although simplicity—and consistency with other equity and derivative markets—is a real advantage that should not be overlooked. A change to decimal pricing should be made only if the benefits exceed the costs of conversion.

This analysis also has implications for new stock markets, or for stock markets considering modification of their rules on minimum price variation. One decision they face is whether to have a "one tick fits all" rule or a step function based on share price. With a single absolute tick size, a firm can split its stock to adjust its relative tick size. Over time, practitioners will find the most liquid trading range through experience. If the exchange adopts a step function, however, it may find that it has set relative tick sizes either too high or too low, without giving firms a means to adjust them. For this reason, it seems prudent for an exchange to a set a small number of absolute tick sizes and give firms the flexibility to modify their own relative tick sizes through stock splits. Similarly, regulators should not take any steps that would reduce the flexibility of firms to influence their relative tick size through splits, since the optimal relative tick size for each firm may be different.

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