1

Wind Tunnel Markets

On a typical Monday, the floor of the New York Stock Exchange is a beehive of activity from the opening bell at 9:30 in the morning until the closing gavel at four in the afternoon. October 27, 1997, however, was not a typical Monday. For exactly 30 minutes and 5 seconds—from 2:35:55 P.M. until 3:06:00 P.M.—all trading stopped. Traders who would normally be milling from post to post, gesturing madly to get the attention of one of the specialists who maintain the order books for each stock, prepared for trading to resume. On a few previous occasions, the entire exchange had shut down for a computer or power outage or to help members deal with a snowstorm; trading halts in individual stocks pending important news are an everyday occurrence. Now, for the first time in history, the government had brought the New York Stock Exchange to a complete standstill.

The day had started out as just another in a string of bad days when news of financial woes in Asia weighed on the U.S. markets. The problems had begun in July with the devaluation of Thailand's currency—the baht—and, with each passing day, it seemed like the crisis had spread so far through Asia's other emerging economies that its impact would eventually be felt in the United States. On Friday, the Dow Jones Industrial Average had closed a tad above 7700, down from 8200 a month earlier, but still up 200 percent from the beginning of its latest climb in 1990. This had been a most impressive run for the market. The Dow continued lower on Monday, declining steadily throughout the morning to fall below 7550 shortly before noon. The market then attempted to stage a rally, making it feebly back to 7600 at the stroke of noon. As this rally faltered, panic began to spread through the market.

By one o'clock, the Dow had fallen to 7500 and the minds of traders on the floor, as well as those around the globe, undoubtedly focused on a market regulation that had never come into play before—the circuit breakers. This regulation required that all trading in U.S. stocks be automatically suspended for 30 minutes as soon as the Dow Jones Industrial Average declined 350 points from its previous close. Designed as a *time out* mechanism for the market, the circuit breakers forced traders to go back to their corners—providing them with the chance to reflect on their actions. This time could also provide the opportunity for a savior to step in and bail out the market. But, most important of all, the inventors of the circuit breakers hoped that their mere existence—even if they were never triggered—would reassure the market that a safety net was in place to catch a falling market, thereby nipping panic in the bud.

As two o'clock approached, it was clear that the circuit breakers overhanging the market had not allayed the panic; instead they had helped to fuel it. Disconcerted by the prospect of being locked into their positions when the market was shut down, many traders dumped stock while they still could. The very presence of the 350-point circuit breaker contributed to its being tripped soon after the half hour with the Dow just above 7360. Indeed, many traders believed that the circuit breakers had acted like a magnet. Instead of breaking the market's fall, each circuit breaker pulled the market down to it.

During their maiden voyage into market limbo, traders had time to contemplate something even more ominous—the next circuit breaker. If the Dow fell another 200 points, placing it down 550 points for the day, a second circuit breaker would be triggered—this one suspending trade for a full hour. Given that the first circuit breaker would not be lifted until after three o'clock and the market was scheduled to shut down at four o'clock, the tripping of the second circuit breaker would shut down the market for the day. This second circuit breaker proved to be an even stronger magnet than the first.

After mulling over the second circuit breaker, traders continued to sell like there was no tomorrow when the market reopened. For those traders whose capital would be wiped out by margin calls, forcing the liquidation of their positions at tremendous losses, there would indeed be no tomorrow. The anticipated plunge in the market tripped the second circuit breaker in just 24 minutes. The circuit breaker would have been tripped immediately except that the loss in each of the 30 stocks that made up the Dow would not register on the Average until buyers and sellers could agree upon a price at which to trade. With the market verging on mayhem, it took several minutes for most stocks to resume trading. As each Dow stock opened, the Average fell several more points to reflect its new, lower price. Because the market was now moving downward by leaps, the Dow overshot the second circuit breaker; trading halted for the day after the Dow had fallen 554 points to close at 7161.

Monday, October 27, 1997, quickly made a name for itself; indeed, it made several names for itself, the most popular of which was *Blue Monday*, which is how this book will refer to it. One name that was not available was *Black Monday*—it had already been taken by the record-breaking crash 10 years earlier on October 19, 1987. That plunge was so terrifying that the circuit breakers that were triggered on Blue Monday were instituted in an effort to prevent a replay of Black Monday's events.

After the market's early close at 3:30 P.M., the president of the New York Stock Exchange met with the press and proclaimed that the circuit breakers had worked as intended. Nonetheless, they were soon modified so that a 10 percent decline in the market rather than any specific point move would trigger them. In the future, changes in the settings for the circuit breakers would be largely automatic and would require only token administrative action. (The circuit breaker limits had only been minimally adjusted prior to Blue Monday.) Had the upgraded circuit breakers been in place on Blue Monday, it is doubtful that they would have been triggered at all. The only good thing that came out of the early close of the market was that it reset the circuit breakers. On the next day, another 350-point decline in the Dow would be needed to trip the first circuit breaker.

The market opened for trading on Tuesday the 28th with considerable fear. U.S. stocks had traded sharply lower overnight on the Tokyo, London, and world's other stock exchanges, but not low enough to make the tripping of the first circuit breaker a *fait accompli*. After an immediate decline of nearly 200 more points to clear out the so-called *weak hands* in the market—mostly traders receiving margin calls—the market abruptly reversed course. By the end of the day, it had rocketed up 334 points, recouping much of Monday's loss. Figure 1.1 shows the swiftness of both the decline and the subsequent recovery. Although few people felt the need to tag Tuesday with a name, *Happy Tuesday* was a common choice.

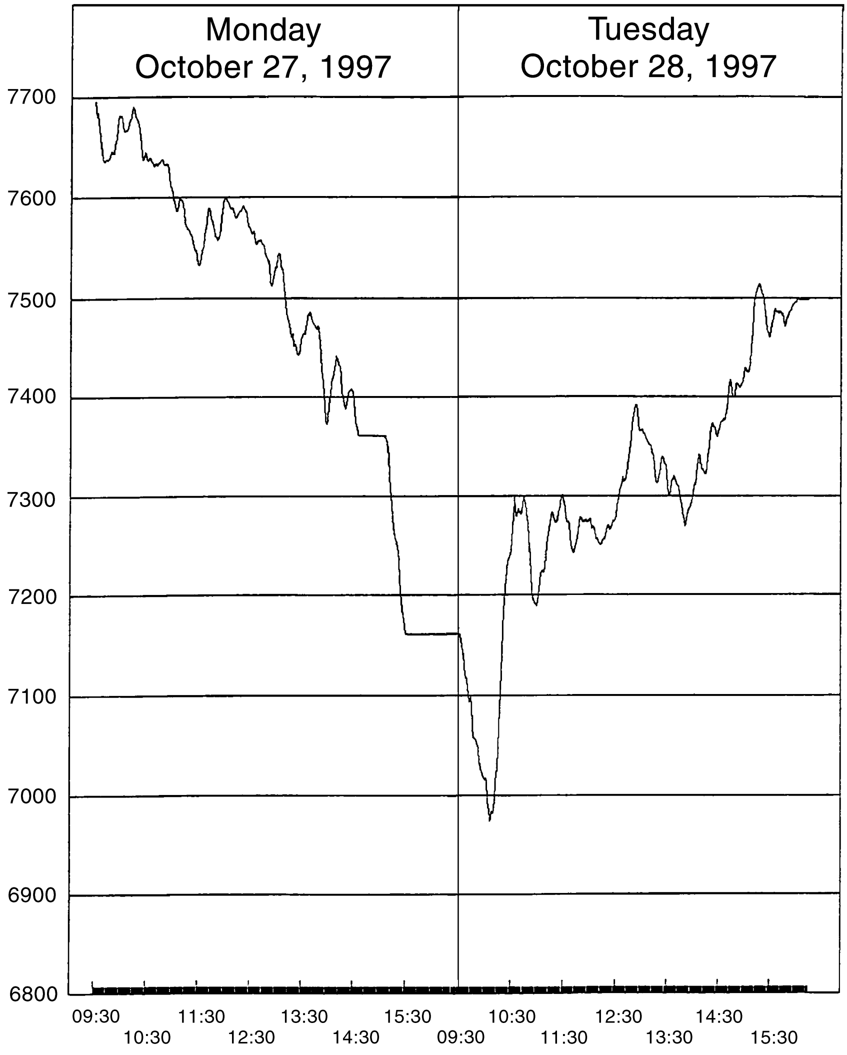

Figure 1.1 **Dow Jones Industrial Average on Blue Monday and Happy Tuesday**

Courtesy of the U.S. Securities and Exchange Commission.

Despite making banner headlines in newspapers and magazines around the world, Blue Monday has become little more than a footnote to financial history. The great bull market of the 1990s stampeded back to life, with the Dow topping 10,000 in less than two years. Monday did set a record for the largest daily point decline in the Dow; however, viewed in relative terms, the 7.2 percent decline was only the twelfth-worst percentage decline at the time. In addition, the rise in the Dow and the trading volume for the next day's rebound both set records. But all these records were quickly and repeatedly eclipsed as the U.S. stock market continued to grow in value and volatility.

The aftermath of Blue Monday and Happy Tuesday is as important as what happened to the market on those days. The change in circuit breakers most likely took the market from one bad system to another, but at least the new circuit breakers would take much longer to trigger. Even if we ignore the fact that any type of circuit breaker is likely to be counterproductive regardless of how it is structured, as technology stocks continued their unprecedented climb, the Dow was becoming less representative of the dangerously volatile part of the market. Indeed, on several occasions in 2000 and 2001, the Dow would move strongly higher on many days where the Nasdaq and S&P (Standard & Poor's) averages plummeted. The Dow had become a *safe haven* for the rest of the market and so investors could sustain enormous losses without their being reflected in the Dow.

The other fallout from Blue Monday was that the SEC, almost a year after the incident, produced a report indicating that the system worked while grudgingly admitting that the circuit breakers likely contributed to the rapid decline through their *magnet effect* rather than abating it. Still, they gave the overall concept of circuit breakers a clean bill of health even though they had provided no hard evidence to support this conclusion.

Step into the Wind Tunnel

It is instructive to compare the collapse of a market with its counterpart in the physical world. Although Wall Street ends at the East River, those wishing to continue across need only look to the north and there, less than half a mile away, is that monumental feat of engineering—the Brooklyn Bridge. This legendary structure of the nineteenth century, frequently sold to the unsuspecting and the subject of the first Ken Burns documentary, gave the world a glimpse of what might be possible in the twentieth century. But the frenzy of bridge construction that the Brooklyn Bridge inspired had to be reconsidered when engineers eventually pushed the limits of the physical world.

As engineerng failures go, the 1940 collapse of the Tacoma Narrows Bridge ranks among the most visually arresting. When it was unveiled in June 1940, the bridge was the third-longest suspension bridge in the world. It did not stay open for long, however, because the bridge's inclination to sway violently in the wind soon became apparent and so all traffic was banned from its roadway. This penchant for twisting in the wind was so pronounced that it earned the bridge its sobriquet—Galloping Gertie.

On November 7, 1940, Galloping Gertie did more than just sway; hit with a brisk 42-mile-per-hour wind, the bridge galloped into the waters of Puget Sound below. The popular reason given for the collapse was that the sustained gales caused the bridge to resonate (like a tuning fork) until it shook itself to bits. Such problems with bridges have been known since ancient times; indeed, soldiers have long been trained to break step when marching across a bridge to prevent it from resonating with their collective footsteps.

It is fortunate both that no one was injured in the collapse and that a camera crew was present to capture the event on film. This amazing footage has become the classic example of an engineering blunder; indeed, many engineering students must have the pleasure of viewing it several times in the course of their education as an object lesson.

Although the collapse of the Tacoma Narrows Bridge was a multimillion-dollar embarrassment, it led to improvements in bridge design that have helped prevent any further wind-induced collapses. The key improvement, which is now standard engineering practice, was to test the aerodynamic properties of the bridge during the design process by placing a model of the bridge in a wind tunnel. (Engineers at the University of Washington had already started wind tunnel testing of a modified bridge; however, Gertie collapsed before any of their fixes could be applied to the bridge.) Using powerful fans to create a sustained breeze, the wind tunnel provides a controlled, simulated environment in which to subject a bridge to the conditions that it could encounter out in the "real world," only on a much smaller scale. The wind tunnel works because the tendency for a bridge to resonate in the wind is approximately the same at both the small scale of the model and the large scale of reality.

As long as the scale-model bridge captures the essential aerodynamic features of the real bridge, what we learn from placing the model in the wind tunnel can be applied to the bridge in its natural setting because the same physical laws apply to both. For the purposes of wind tunnel testing, the model bridge does not have to be an exact replica of the proposed bridge. Only those *salient* features that contribute significantly to the aerodynamic properties of the bridge need to be included in the model. In addition, many of the finer details of the bridge, such as the electrical and drainage systems, can be omitted. Finally, because even scale-model bridges are costly, wind-tunnel tests are designed not to destroy the model, only stress it. This type of testing is far more convenient and cost effective than building the real bridge and hoping that the right gust of wind comes along to provide an adequate test of stability prior to its opening.

In general, the type of model that we should construct is dictated by what we expect to learn from it. A wind tunnel model is likely to be very different from an architect's display model, where physical appearance rather than structural stability is the reason for building the model.

Luckily for those of us who cross bridges, the government did not just issue a report saying that despite Gertie's collapse, suspension bridges were fundamentally safe, and then suggest some minor changes in their construction. Without testing a bridge before constructing it, one could only guess as to whether any recommended changes in engineering specifications would have the desired result. Although wind tunnel testing, like any simulation procedure, has its limitations, it provides an inexpensive way to avoid costly, and even life-threatening, mistakes.

It is natural to wonder why, if wind tunnels and related simulation methods work so well in the physical world, something like them cannot be used for markets, which after all provide a bridge between buyers and sellers. The economic cost of a crash in a major financial market can be trillions of dollars and the human cost is immeasurable. With that much on the line, it would seem that something well beyond a standard bureaucratic response is appropriate.

One need not spin conspiracy theories in order to find a reason why experimentation has taken so long to appear on the radar screens of many economists (and has yet to appear on the screens of some). For the bridge, the transition from blueprint to model and then on to the real world is quite smooth. The universality of physical law ensures that the basic properties of the blueprint bridge are manifested in the model.

Only occasionally will the nuances of the physical reality of the model differ significantly from the idealized world of physics. Indeed, engineering as a discipline is mainly concerned with the issues that arise when going from the scientist's theoretically perfect world to the real world that we inhabit. The next transition—from model bridge to real bridge—is smoother still. Except at transgalactic and subatomic scales, physical law applies consistently. The amoeba and the elephant dance to the same tune.

While Newton's laws and the everyday physical world form a near-perfect match, the same cannot be said for economic laws. Even the most zealous advocates of the market system are careful to distinguish between the abstract virtues of markets and their real-world manifestations. While engineers have been able to attribute apparent differences between theory and practice to ancillary forces, most notably friction, there appears to be no simple way to reconcile such discrepancies in the economic world. Given that the match between theory and reality is already tenuous, there would seem to be little to gain from interposing a model between them.

This book shows how creating markets in a laboratory setting not only serves as a useful way to model markets, but also helps to narrow the gap between economic theory and practice. Advances in technology are already narrowing this gap as electronic trading in real-world markets makes them more like the markets run in computerized economics labs. While there are many aspects of the global economy, including the actions of governments and central banks, that cannot be faithfully reproduced in a controlled setting, the basic mechanisms that underlie the market for all assets, not just financial ones, are ideally suited to the laboratory.

Physical scientists must be content with discovering the rules that nature presents to them; social scientists have the ability to make their own rules, or at a minimum to attempt to influence those who make the rules. Laboratories provide economists with the ability to test several alternative sets of market rules before they are unleashed on the economy.

Isolated from the noise of real-world markets—or *naturally occurring markets* as we will call them following the convention of experimental economics—the fundamental character of economic law is easily examined. In particular, within the laboratory we can adjust the parameters of the market mechanism, such as the mandated circuit breakers on U.S. stock markets, and determine their effect on market performance. By refusing to consider the market mechanism as merely the black-box abode of the invisible hand, but rather as a sophisticated computational device whose programming determines its performance, we take the first steps along the path to making markets fulfill their potential.

Our Road Map

The events of Blue Monday are not just an interesting story of regulatory folly; they provide a useful reference point for the contents of this book. Although the end-of-millennium bull market still had years to run, on December 5, 1996, Fed Chairman Alan Greenspan pondered: "How do we know when irrational exuberance has unduly escalated asset values, which then become subject to unexpected and prolonged contractions?" Translated into everyday English, Greenspan was signaling to the financial markets that he was concerned that the U.S. stock market was in a *speculative bubble* and that he might be forced to do something about it. Although Chairman Greenspan's remarks initially dampened spirits in the market, the effect was short-lived and the run-up in stock prices soon resumed. Nonetheless, many viewed the more than 1,000-point decline in the Dow during the following October as evidence of a market bubble that was beginning to deflate. Furthermore, the problems experienced by the U.S. market could be traced to a more obvious bubble in Asian securities markets. What no one could know then is that the real bubble in the U.S. had only begun to form. The bubble was not so much in the Dow as it was in the high-technology stocks on the Nasdaq (National Association of Security Dealers Automated Quote [System]).

A speculative bubble is said to occur when the price of an item, usually a financial asset, is driven *substantially* above its *intrinsic value*, which is its value determined by an objective procedure. In a bubble, buyers are willing to overpay for an item in hopes that a *greater fool* will emerge who is willing to pay an even higher price. When the supply of fools dries up, the price falls, often quite rapidly. The collapse of a bubble in one market can be contagious, precipitating declines in other markets, regardless of whether or not they are also in a bubble.

Bubbles are a controversial topic within the economics profession. Some economists, led by the late Merton Miller, a Nobel Prize–winning economist who taught at the University of Chicago, believe that the inherent efficiency of markets precludes the existence of speculative bubbles. Indeed, there are even articles that argue that the famous bubbles of history, such as the Dutch tulip mania, were not really bubbles. On the other hand, a growing group of economists, including Richard Thaler (also at Chicago) and Robert Shiller (at Yale), have conducted research on the behavioral aspects of economics and finance that provided the scholarly support for Chairman Greenspan's irrational exuberance remark.

Given that engineers can build defective model bridges and watch them twist inside a wind tunnel, might we also be able to create our own market bubbles and crashes in the laboratory? While such a laboratory bubble would not constitute proof that any specific naturally occurring market was experiencing a bubble, it would demonstrate that bubbles are possible in certain market settings. Indeed, part of the problem with determining whether any given market is in a bubble (aside from agreeing on the precise definition of a bubble) is that we cannot know an asset's intrinsic value with any degree of certainty. In the controlled laboratory setting, we can know its value because we are able to induce it.

In the preface, we noted that the first market experiments, which are described in Chapter 2, were conducted using index cards in a Harvard classroom in the 1940s. It was not until the 1980s that the first bubble experiments were run in a computer-based market laboratory at the University of Arizona. In Chapters 3 and 4, we will embark upon the 40-year voyage necessary to develop the techniques of experimental economics, apply them to a variety of market settings, and determine the parameters under which bubbles are formed, so that they can be replicated at will in laboratories around the world.

The beauty of being able to create market bubbles and crashes in the controlled environment of the laboratory is that we can then alter the environment in an effort to see what measures might prevent bubbles from forming in the first place. While there are several ways to avoid or reduce bubbles by educating the subjects in our experiments—something that may not be practical in naturally occurring markets—it turns out that bubbles can also be mitigated by allowing trade in securities whose value is derived from that of the assets that we wish to keep from entering into a bubble. Such securities, known as *derivative securities*, have sometimes been viewed more as a bane of the market than its salvation. Indeed, as we shall see in Chapter 5, the kind of derivative security that has shown some success at reducing bubbles in the laboratory was banned from U.S. exchanges in 1982 and only recently legalized.

The next part of this book explores the role of derivative securities in the proper functioning of the market mechanism. Chapter 6 explores Black Monday, the climactic day of the stock market crash of October 1987. Although stock prices were certainly high by historical standards and objective valuation measures coming into Black Monday, the crash appears to have been caused not so much by market excesses as by the widespread use of a certain kind of *portfolio insurance*. Although stock portfolios can be easily insured using stock index options, a type of derivative security that came into common use in the 1990s, these options, although legal in 1987, were not easy to trade—that is, the market for them was *illiquid*. Large institutional investors, concerned that stocks were in a speculative bubble but unable to use stock index options as insurance against a downturn, embarked on computer-driven trading strategies that became sufficiently widespread to exert a destabilizing influence on the stock market.

Black Monday can be viewed as an unintended consequence of a financial system that had temporarily become too sophisticated for its own good. The confluence of revolutionary financial theories, inexpensive computational power, and relaxed government regulation transported the markets from the white-shoe world of the gentleman banker to a high-tech universe of fast deals and programmed trades. The new sophistication was most apparent in the explosive growth in options and derivative securities that began in 1973 and continues to this day as options pervade the financial markets. Chapter 7 examines how options work and how to compute their value.

The pivotal chapter of this book is Chapter 8, where we see that the pervasiveness of options extends to the market mechanism itself by influencing *price discovery*, the process by which markets determine prices. While the price discovery process that takes place in most financial markets is too complicated to model satisfactorily, the behavior of auction markets, similar to those that have appeared on the Internet, has a large body of economic theory to help explain them. We examine how an auction's rules can affect its performance.

The second part of this book concludes with a general look at liquidity in markets. Chapter 9 examines those instances where inadequate information can seriously impair markets, sometimes leading to total market failure as buyers refuse to buy any item that a seller is willing to sell for fear that it is a "lemon." In contrast, Chapter 10 provides a brief examination of money, a derivative security that is liquidity in its purest form.

Before we discuss the final part of the book, it is worth remarking on what happened to financial markets in the year that followed Blue Monday. Although the U.S. stock market recovered nicely, going on to make higher highs in the months that followed, the inability of Russia to make the interest payments on its outstanding bonds the following August led to a financial crisis unlike any that had preceded it. At the center of the storm was Long-Term Capital Management (LTCM), a hedge fund with more than 60,000 positions that controlled over $100 billion of assets with an investment of $2.3 billion. LTCM made its money by doing some of the invisible hand's work; when the prices in related markets would get out of line, LTCM would profit by buying the underpriced assets and selling the overpriced assets and would then wait until the prices got back in line so that it could exit the position, a procedure known as *arbitrage*.

LTCM was the acknowledged master of its universe and its partners were the dream team of the financial world. The most visible partners were Nobel laureates Robert Merton and Myron Scholes, who first appear in this book in Chapter 7 as the inventors (with the late Fischer Black) of a revolutionary new method for pricing options. But LTCM's bench was just as impressive, if not as well known. Many of them had already been stars on Wall Street working for the legendary John Meriwether, LTCM's chairman, at Salomon Brothers.

With vast computer power at its disposal, LTCM could quickly scour the global markets to catch arbitrage opportunities as they arose. Over time, LTCM (and the Wall Street firms that emulated it) exhausted the easy opportunities for arbitrage, and so computers became even more critical to finding ever-more-convoluted ways in which it could squeeze arbitrage profits from the market. After superlative performances in 1996 and 1997, LTCM started to lose its touch in 1998.

By September 1998, it became clear to the financial markets that Meriwether and LTCM had been dealt a losing hand that it could not fold. In the wake of Russia's financial difficulties, financial markets no longer snapped back in line as LTCM had counted on, but drifted farther out of whack. LTCM had found itself at the center of what could best be described as financial gridlock. Because of the way in which the financial markets were interlinked, LTCM lacked the resources (capital) necessary to exit its positions. Its over 60,000 positions alone appeared to exhaust the available liquidity of the market. As with an automobile stuck in traffic gridlock, outside intervention was necessary to extricate LTCM.

Portfolio insurance, which destabilized financial markets on Black

Monday, and the LTCM's arbitrage activities, which shook them nearly 11 years later, are examples of *program trading*, the implementation of trading strategies with computer programs. In both instances, these strategies were initially profitable because they served to fill holes in the market system. With portfolio insurance, the holes came from the absence of critical markets for stock index options; for LTCM, missing links between markets created the holes that facilitated arbitrage.

The alternative to leaving the task of perfecting the market to private parties who fly the flag of the invisible hand but may unwittingly destabilize markets is to program the market mechanism itself. Markets that are programmable in this way are known as *smart markets* or *intelligent markets*. (Of course, programming alone does not make a market smart. Circuit breakers constitute a simple market program, and as we saw on Blue Monday, they were anything but intelligent.)

The third part of this book examines the linkages between markets and how to create more of them and keep them in better shape using smart markets. Building on the lessons introduced in Chapter 11 from the example of LTCM, Chapter 12 explores some smart market mechanisms, how they can help stabilize markets and prevent gridlock, as well as some of their limitations. Then, in Chapter 13, we look beyond financial markets to examine how specialized smart markets are starting to be deployed in other places in the economy as smart versions of the auction markets introduced in Chapter 8. One of the first institutions to experiment with smart markets was a government facility with several wind tunnels of its own, the Jet Propulsion Laboratory (JPL), which is jointly run by NASA and Caltech. Another government entity, the Federal Communications Commission (FCC), has not only tested smart markets for use in its auctions of the electromagnetic spectrum; it is working to deploy them. To both JPL and the FCC, institutions steeped in physics and engineering, the process of designing and testing a market in the laboratory before putting it into service is just common sense, and not a radical new approach to economics and markets. In Chapter 14, we go behind the perfection of the market mechanism itself and examine the challenges posed by the imperfections of the political processes by which markets are implemented.