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Introduction

This is a book about the most important risk we face in finance. It's the risk that comes from learning about risk. I call it Pandora's risk in honor of legend's prime culprit. If she hadn't opened the box of wealth and woe, we'd have no hunger to learn.

Other fields involve learning too. Since the observer never fully understands the observed, there's always something to learn. Occasionally, learning overturns some core beliefs. That's how scientific revolutions occur.

Finance stands out in that the core objects of study are themselves observers. Market participants rarely know the true value of what they're trading. Markets grope for knowledge by aggregating individual beliefs. But beliefs are constantly shifting.

Twentieth-century finance theory treated learning as a sideshow. It assumed that the market consensus largely captured the true risks. Error was dirt around the edges. If the dirtballs got big enough, speculators should arbitrage the discrepancies and clean things up.

In reasoning this way, theorists missed something that every market practitioner knows. Most speculators don't trade on changes in risk. They trade on changes in *beliefs* about risk. Those aren't the same. Sometimes they're not even close.

This confusion pervades financial risk analysis. For example, the global banking regulations known as Basel sanctified nearly unlimited leverage for loans to top-rated credits. They brushed off as minor detail the difficulty in rating safety. The disregard helped stoke the greatest debt bubbles in world history.

Most financial analysts incline to downplay Pandora's risk. They want to impress their superiors with what they know. Their superiors in turn want to persuade investors and regulators that risks are under control. Few want to advertise their uncertainty.

Results betray them. Risk bounds have to be continually reset, even when the nominal investments don't change. Despite these adjustments, losses breach extremes far more frequently than standard models suggest. When stricken, most standard setters seek comfort in the crowd.

It doesn't have to be that way. Uncertainty is our friend as well as our enemy. It encourages us to agree with each other, or act as if we agree, even when there's no objective basis. The consensus encourages real trade and investment, which turns the fictions of belief into material facts.

Better appreciation of uncertainty can also help us think outside the box. As Mark Twain is alleged to have said, "It ain't what you don't know that gets you into trouble. It's what you know for sure that just ain't so." Every financial crisis brings reminders.

This book is dedicated to changing mindset. I want professional analysts to realize that uncertainty is core to finance, not peripheral. The market isn't some knowledge machine grinding out approximately ideal prices. It is a learning machine that continually errs, corrects itself, and makes new errors.

The scale of error makes us moan. Societies rend and nations lose their way over mania that later looks idiotic. Long-term inevitabilities get obscured by noise.

The scale of error correction makes us marvel. Capital markets forge consensus vision out of the dreams of millions of people, temper it in the fires of observation, and harness resources and will toward realizing it in practice. No one who has not witnessed huge capital markets would believe they exist.

Never has it been more important to keep both tendencies in mind. The world as a whole is the richest it's ever been, and growth is nearly the fastest. Yet debt imbalances are outpacing gross domestic product (GDP) and appear unsustainable. Financial analysts who can't draw the connections endanger those they serve.

On the practical side, this book offers some approximations to help track uncertainty. Mostly they're just stylizations of what traders already do. They aren't perfect. They can't be. The best model would require an infinite number of calculations every instant.

There is a broader lesson here. Every practical application makes do with error-correcting approximations. Sometimes these approximations work terribly and unleash a plague of market demons. Eventually the error correctors kick in and help rectify the mistakes.

From a learning perspective, both apostles and foes of free capital markets should curb their enthusiasm. On the one hand, markets deal in consensus beliefs rather than truth. Following like lemmings can lead us off the cliff. On the other hand, markets are awesome error-correcting mechanisms. Stifling what regulators don't want to see or hear often transforms downturn into disaster.

Confusion about the strengths and weaknesses of markets has fomented some rotten regulation. It lets some big excesses go unchecked, while exaggerating the importance of minor signals. It encourages statistical fraud. From a learning perspective, we need to simplify the regulatory framework and encourage more fiduciary responsibility.

Other overheated disputes pit orthodox finance against behavioral finance. Orthodox finance tells us how markets should operate, given well-informed participants acting in their own rational self-interest. Behavioral finance emphasizes the abundance of counterexamples and links them to human irrationality. Treating the market as a rational learning machine can help transcend the divide.

Last but not least, a learning perspective can improve portfolio management services for retail investors. Standard approaches expose them to far too much risk in crises. As we shall see, this is remarkably easy to mitigate. While it won't completely level the playing field with wealthy investors, it will reduce the "Dooh Nibor" (reverse Robin Hood) effects that prevail now.

The Context of Finance

To appreciate the importance of learning in finance, let's go back to basics. Life forces a trade-off between risk and reward. By venturing out to eat, I expose myself to being eaten. Brains evolved in large part to raise

the munch-to-munched ratio. Risk analysis is what they do. Financial risk analysis is simply a special case, focused on investments.

Broadly speaking, financial risk analysis makes three kinds of assessments. The first kind rates the pleasure or pain of the possible outcomes. The second kind forecasts the relative likelihood of these outcomes. The third kind estimates the uncertainty fogging our projections.

In practice it is hard to say where valuation ends and risk or uncertainty estimation begins. Imagine, for example, a strawberry. What is eating it worth? On reflection, that depends on ripeness, flavor, and other qualities not evident on sight. Perhaps the strawberry is harboring a stomach bug. Or perhaps a stomach bug one already has will make the strawberry unpalatable. That happened once to my youngster, leaving a red stain on the carpet as memento.

We could, if we wanted, distinguish a host of specific strawberry-eating experiences, assign likelihoods to each, and gauge our uncertainty. Both brain and gut would soon tire of the effort. To simplify, we bundle choices and outcomes, define a bigger action like “buying a strawberry and eating it,” and compare that action to other actions in terms of rewards, risks, and uncertainty.

For more complex risk analysis, consider the joint action of planting a strawberry field, tilling it to harvest, and marketing the crop for profit. Here we have to guess both the strawberry yield and the future price per strawberry. Granted, we might lock in one or both with a futures contract, but that just transfers the risk analysis to someone else.

For still more complexity, consider the purchase of a strawberry farm. Now we must analyze a succession of strawberry fields, one year after another. The further we peer into the future, the more wobbly our estimates will be. We will not know what strawberry-growing innovation might appear, what pests might infest the area, or whether future customers will prefer blueberries. We will not know the future tax regime on strawberry fields or the option value of selling the farm to a real estate developer.

Next imagine a giant agribusiness. It operates many farms producing many different products, runs various processing plants, and engages in a host of trading operations. Diversification and vertical integration lower some product-specific risks but heighten exposure to macroeconomic risks.

Finance weighs risks against rewards in search of higher or more secure profit. When finance gets it right, it raises the average munch-to-munched ratio and encourages productive investment. Occasionally finance gets things

spectacularly wrong and wreaks havoc. Sometimes, too, it cannot resist munching on the people it is supposed to serve.

These contrasts between treasure and trouble, between promise and peril, naturally fascinate observers. They inspire envy and dread, admiration and contempt. Finance is awesome and awful.

One of the strangest features of finance is its self-absorption. Its most earthshaking decisions can seem divorced from studies of the earth. Most financiers are most concerned about what other financiers will think. This adds another layer of risk, but a strange, self-referential one. To invoke Keynes, a financial market is like a beauty contest aiming to pick not so much the greatest beauty as the one the judges will pick.

This makes financial markets terribly prone to herding. They can chase after bad ideas or run too far too fast after good ones. Those who resist can get trampled in a stampede.

However, there is a positive side to this. To appreciate it, let's transform our imaginary herd of cattle into a hive of bees. The bees go out looking for nectar. Not knowing where it is, each starts looking on its own. When one bee finds it, other bees find out. Perhaps they hear directly. Perhaps they notice telltale pollen on the discoverer's feet. Perhaps they just follow the buzz. Soon a swarm forms. The swarm becomes a better indicator of pollen than any individual bee. That is the wisdom of the hive.

As best we can tell, the wisdom of the hive generally outweighs the horrors of the herd. Economies with financial markets tend to be much more productive and innovative than those without. In the twentieth century, Communist states tried to prove the superiority of market-light planning. They failed miserably. The Soviet bloc collapsed. Only China thrived economically, and only after it reversed course and let markets guide planning.

Note that this is an empirical inference about financial markets, not a theoretical one. Note too that our confidence falls far below the standards of proof in natural science. We have observed a few dozen market-phobic industrializing societies, not a few trillion. We haven't rerun Soviet experience substituting different planners.

But that is the norm for financial risk analysis. Our inferences come from relatively few experiments, most of them poorly controlled. Consequently our conclusions are more tentative than in natural science and prone to more frequent and bigger readjustments.

Learning About Learning

Market learning is now a mainstream topic in economics. Pastor and Veronesi (2009) have recently surveyed the developments. I too have tried to popularize these themes in the narrower circle of finance practitioners interested in theory (Osband 2002–2005, 2008).

However, financial risk analysis still treats learning risks as peripheral. It is stuck in a mindset akin to that of physics in the early twentieth century, which clung to classical mechanics despite the accumulating refutations. Arguably it's stuck worse. Whereas physicists never blamed dumb matter for messing up theory, finance theorists frequently blame dumb traders.

How can we best change mindset? I wish I knew. Rigorous treatments get dismissed as dry or incomprehensible. Popular treatments leave professionals unconvinced. This book will try something in between. It will lead a study tour.

Our tour will visit some of the biggest financial risks in the world and explore major uncertainties at their core. We will watch markets unite, stretch, and defy beliefs. We will witness the damage that comes from ignoring uncertainty. We will look for neat ways to rebuild.

As the tour guide, it's my responsibility to keep things lively and not too long. I will mix topics and approaches that don't normally get mixed and draw analogies that don't normally get drawn. I will ignore most caveats and keep intimidating terminology to a minimum. Where models scream out with policy advice, I will let them.

To those prizing neat results, I offer a few delights. We'll expose the statistical confusion implicit in conventional risk measures and discover superior alternatives. We'll decouple safety from certainty. We'll link market turbulence to learning.

In return, I'm going to ask a lot from participants. Readers ought to have a sound grounding in economic history, finance theory, and statistics. They should be interested in economic policy. They should enjoy mathematical modeling. They should love thinking outside the box.

If you're rusty in these areas, that's okay. I'll try to keep the exposition clear and provide references for deeper study. I will route most of the math to the Appendix so that it doesn't overwhelm the flow.

One thing I won't ask is complete agreement. Some of what I'm saying is surely wrong; I just don't know which some. For fairness, I will let two august critics weigh in at the end of every chapter.

If you're not sure it's worth investing the time, skip to the Conclusions in Chapter 12. If they all make perfect sense, you don't need to read the book. If none makes any sense, you won't want to read the book. I'm aiming for the persuadable middle.

Itinerary

Money (Chapter 2): Every day people sell real goods and services for ciphers simply because everyone else does. It's never certain that money will keep its magic, and sometimes it doesn't. Yet modern civilization is unimaginable without it. We'll uncover Mahserg's Law and watch it at work.

Wealth (Chapter 3): Financial wealth discounts future earnings in ways that have long puzzled theorists. We will see that the most plausible explanations invoke uncertainty. Forced to look backward into the future, people discount heavily for tiny fears of disasters and prize perceived safety.

Debt (Chapter 4): Debt trades current money for future money with interest. If wealth grows fast enough, debt can potentially be repaid indefinitely out of rollover. This tempts self-financing bubbles of debt. We'll examine a model in which patently worthless debt stays low-risk for long periods before blowing up. The model is too close to reality for comfort.

Banking (Chapter 5): Banks tend to be more interested in borrowing short to lend long than in facilitating payments. This makes the financial system more fragile and cycle prone. Regulators have inadvertently exacerbated the risks. To better appreciate the dynamics, we'll model credit spreads and debt stocks as a predator-prey game.

Safety (Chapter 6): Many credit markets behave as if they're inferring from only a few dozen years of relevant observations. We can best model their beliefs as highly dispersed distributions. The uncertainty calls for much larger contingent reserves on top-rated credits than standard regulations assign.

Regime Change (Chapter 7): Risks often change with little notice, rendering past observations obsolete. We can use dynamic mixtures of simple models to track change robustly. Still, tiny doubts can evolve into big differences. Using a cumulant expansion, we'll see that predictability is severely limited. That's why markets trade so much.

Credit Rating (Chapter 8): Credit rating is far more complex than the simple counting game at its core. Still, uncertainty pervades ratings and deserves more disclosure. This needn't make ratings gyrate wildly. In analogy to magnetism, a mild preference for agreement on relative safety can induce remarkable stability.

Portfolio Derivatives (Chapter 9): Large portfolios are commonly rated for risk as if losses are bound to fall close to the mean. This can be wildly inappropriate, especially for senior debt tranches. Ignorance, greed, and bad regulatory incentives have driven gross misuse verging on fraud. We'll examine some healthier alternatives.

Value at Risk (Chapter 10): Standard Value-at-Risk (VaR) methodology pretends to superior identification of the risks of large market losses. Instead, it indulges the common fallacy of extrapolating from small losses and needlessly sacrifices precision. We can do much better by tracking short-term volatility and allowing for uncertainty.

Resizing Risks (Chapter 11): Most discretionary traders scan price charts for channels. Orthodox finance theory regards this as voodoo. In fact, the practice provides substantial insight into uncertainty. The extra information can warn of crisis and help investors dynamically resize their portfolios. However, it can never completely tame market risk.

Risk Versus Uncertainty

Before we embark, let me clarify some basic concepts and alert readers to relevant scholarship. For more analytic discussion, see the Appendix. I will start with the distinction between risk and uncertainty.

Financial risk means different things in different contexts. Counterposed to reward, it refers to exposure to possible loss. Counterposed to determinacy, it refers to a spectrum of potential outcomes. Counterposed to uncertainty, it refers to an objective probability distribution independent of the observer.

The juxtaposition of uncertainty to risk harks back to Frank Knight's *Risk, Uncertainty and Profit* (1921), which defined uncertainty as unquantifiable risk and treated it as one of the cornerstones of economics:

Uncertainty must be taken in a sense radically distinct from the familiar notion of Risk, from which it has never been properly separated. . . .

There are far-reaching and crucial differences in the bearings of the phenomenon depending on which of the two is really present and operating. . . . A measurable uncertainty, or “risk” proper, as we shall use the term, is so far different from an unmeasurable one that it is not in effect an uncertainty at all. It is this “true” uncertainty, and not risk, as has been argued, which forms the basis of a valid theory of profit and accounts for the divergence between actual and theoretical competition. (Knight 1921: chap. 1)

John Maynard Keynes (1937) echoed Knight’s concern:

By “uncertain” knowledge, let me explain, I do not mean merely to distinguish what is known for certain from what is only probable. The game of roulette is not subject, in this sense, to uncertainty. . . . The sense in which I am using the term is that in which the prospect of a European war is uncertain, or the price of copper and the rate of interest twenty years hence. . . . About these matters there is no scientific basis on which to form any calculable probability whatever. We simply do not know.

The influence of so-called Knightian uncertainty waned for two main reasons. The first was Knight’s aversion to quantification, embedded in the very definition he used. The second was the rational expectations revolution, launched in hindsight by Muth (1961) and gaining influence through the work of Lucas (1972), Sargent and Wallace (1973), Sargent (1979), Stokey and Lucas (1989), and others. Rational expectations tended to presume that people correctly anticipate risks.

In my opinion, both Knight and the reaction against Knight went overboard. Knight confused mathematical formalization with precise measurement. Knight’s critics confused ignorance with stupidity.

I say that as someone who easily gets confused too. Suppose someone hands me a coin and ask me to check it for fairness. Seeing no obvious blemish, I toss it 100 times and count 52 heads. That’s reasonably close to 50 (less than 0.5 standard deviation for a fair coin), and I don’t expect perfection in every sample, so I start to say it’s fair. Then I wonder. If there’s no suspicion of bias, why am I asked to check? Come to think of it, how sure am I that other coins are perfectly fair?

Real life rarely poses questions as crisply as we would like. At one extreme we can stress our inability to know. At the other we can assume a

competitive market has zoomed in on the correct odds. This book will focus on the learning process that goes on in between.

Quantification of Uncertainty

Reconciling uncertainty with probability theory is a challenge. A measure should be something we can agree on. If we're uncertain enough, we likely can't. According to game theory, two people who disagree can never fully agree on what they disagree about.

The simplest resolution, which dates back to the Reverend Thomas Bayes (1764), treats beliefs as subjective probabilities. Its main tool is a rule for updating beliefs given new evidence. Known as Bayes' Rule, it is embedded in the concept of conditional probability itself. In effect it operates the laws of probability in reverse. Bernardo and Smith (2000) provide an excellent overview of Bayesian theory.

Probabilistic beliefs are closely related to ideal market prices, as Bruno de Finetti (1931b, 1937) emphasized. Bayesian probability represents the maximum willingness to pay for a claim paying one if the event occurs and zero if it doesn't. Given a complete set of option prices, we can potentially infer an entire spectrum of beliefs. From this perspective, any rational bettor behaves as a Bayesian.

Nevertheless, the application of Bayes' Rule is fraught with controversy. In mingling distorted beliefs with sound ones, it muddies the notion of statistical truth. For generations the statistics profession split into rival camps, with a majority opposed to so-called subjective probability and a minority favoring it.

Mark Twain solved the mystery over who wrote the plays credited to Shakespeare by declaring that it wasn't Shakespeare but someone else by the same name. In that spirit, I declare that beliefs are not probabilities but something else that behaves the same. Only now I have to immediately undercut myself by noting that beliefs about probabilities fly around a lot more than the probabilities themselves. That's why credit spreads oscillate so much more than default risk.

Markets mix objective risk with subjective uncertainty and sometimes mix them up. So do the planners who oversee markets or intercede. Everyday speech adds confusion by referring to both hypotheses and degrees of conviction as beliefs. However, for mental clarity let us try to keep the following division in mind:

Concept	Objective Risk	Subjective Uncertainty
Applies to	observed outcome	imagined cause
Described by	probability	conviction (belief)
Core difference	same for all observers	in each observer's head
Characteristic behavior	relatively persistent but may change	wanders noisily around objective risk
How to measure	actual payoff	maximum willingness to pay
Observations needed for 100% accuracy	infinite	one
Example	credit risk	default perception implied by credit spread

Straightaway, this division creates a problem. Objective risk is usually deduced from principles of symmetry, making certain kinds of events equally likely. If not, we should have enough same-but-different samples (the technical name is “independent, identically distributed,” or i.i.d.) to estimate the probabilities to high precision—e.g., a billion trillion sub-atomic collisions of identical type. How can we obtain that kind of clarity in finance?

The short answer is we can't. While we may liken default or other outlier event to the roll of a die, its measure can't be pinned down nearly as well. Finance deals, in effect, with dice that are not fair, might get switched between rolls, and are subject to freak interference. The objectively measurable risk, if there is one, gets shrouded with subjective uncertainty.

In personal interactions, we can see that others' uncertainty adds to our risk and vice-versa. In financial markets, beliefs reverberate even more strongly on real investment and growth. George Soros (1988) dubbed the feedback loop “reflexivity”.

Hence, the division is largely heuristic. However, it does embody one core truth. All knowledge derives ultimately from observation.

What happens if the events of interest are so rare, or our vision so restricted, that even years of observation provide little genuine news? Then we won't know very much. That's far more common in finance than we care to admit. Still, it doesn't change the core updating rules associated with rational learning.

In fairness, let me acknowledge that one can embrace uncertainty without accepting the definition or relevance of rational learning. Nassim Taleb's best-seller, *The Black Swan: The Impact of the Highly Improbable* (2010), falls into this camp. Taleb provides numerous reasons for doubting the rationality of ordinary mortals. He also is skeptical of Bayesian inference, particularly where rare events are concerned (Douady and Taleb 2010).

Instead of debating these points, this book conducts an extended thought experiment. It treats market prices as assessments of subjective probability while portraying objective risk as heavily veiled. It assumes that market participants make rational or near-rational probabilistic inferences based on inherently limited information. It then works out the consequences. I find it remarkable how much weird financial behavior this can explain. Keep reading and I think you'll agree.



"Did you hear?" asked Pandora. "Osband agreed to write the book."

"I heard," said Prometheus. "Only the outline seems incomplete. Where's your equation? Where are all the puzzles it solves?"

"Be patient. First he has to motivate the questions. We've had millennia to think about them. And people don't like to think about uncertainty. It makes them anxious. They'd rather fight or flee open risk than have it lurk in the shadows."

"I don't see why. They've done a good job embedding uncertainty into quantum theory."

"That took generations. Even Einstein resisted. And physics doesn't have to grapple with stupidity the way finance does. When atoms don't do what theory predicts, no one says, 'Oh, the theory's fine, that's just atoms being foolish.' In finance it's the gut reaction."

"So how does theory make progress?"

"It splits in two. Finance theorists can win Nobel prizes either for explaining how investors ought to behave or for explaining how they don't. No evidence need refute anything, just get categorized right."

"That doesn't sound healthy."

"It isn't. I hope this book will help mend the rift."

"Then why hive off the math from the intuition?"

"To some people, even in finance, higher math is torture."

“That’s ridiculous! Math is relief from torture. I once spent a decade pondering Euclid before I noticed the eagle eating my guts.”

“You’re super-human. They’re not. Look, all he’s asking you math types to do is page to the end and come back. It’s a minor annoyance, I know, and it’s not fair. But the nonmath types can’t jump over the math; they look down, get scared, and run away.”

“If they can’t stand the heat they shouldn’t be in the kitchen.”

“They are in the kitchen, like it or not. Or they run kitchens. They need to know what’s brewing.”