

# Financial Risk Forecasting

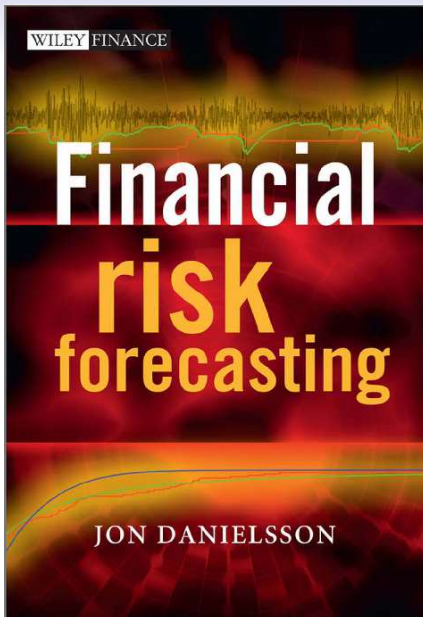
## Chapter 10

### Endogenous Risk

Jon Danielsson ©2025  
London School of Economics

To accompany  
*Financial Risk Forecasting*  
FinancialRiskForecasting.com  
Published by Wiley 2011

Version 10.0, August 2025



# Endogenous Risk (ER)

## What is Risk?

- Systemic risk, financial stability, and economic growth are directly dependent on risk
- The Goldilocks challenge
  - Not too much and not too little, just right
- But then we have to know what risk is



## Butterflies and Hurricanes

- Chaos theorists talk about how a butterfly in Hong Kong can cause a hurricane in the Caribbean
- What is important is the *mechanism* allowing this to happen
- The trigger (the butterfly) is incidental
- And the hurricane the unfortunate outcome
- Focus of study and policy should be the mechanism

## Keynesian Beauty Contest

“It is not a case of choosing those [faces] which, to the best of one's judgement, are really the prettiest, nor even those which average opinion genuinely thinks the prettiest. We have reached the third degree where we devote our intelligences to anticipating what average opinion expects the average opinion to be. And there are some, I believe, who practice the fourth, fifth and higher degrees.”

Keynes (1936)

# Endogenous Risk Versus Exogenous Risk

Danielsson and Shin (2002)

- *Endogenous risk*: the risk from shocks that are generated and amplified *within* the financial system
- *Exogenous risk*: shocks that arrive from *outside* the financial system
- Analogies
  - A financial hedge (futures contract) versus a weather hedge (umbrella)
  - Poker versus Roulette
- Essentially, situations where an agent affects outcomes  
vs.  
situations where the agent cannot



## Millennium Bridge

- First new Thames crossing for over a hundred years
  - New design, extensive tests, riskless
  - Opened by the Queen on 10 June 2000
- What happened?
  - Wobbled violently within moments of the bridge opening
  - Remained closed for the next 18 months



## What Went Wrong?

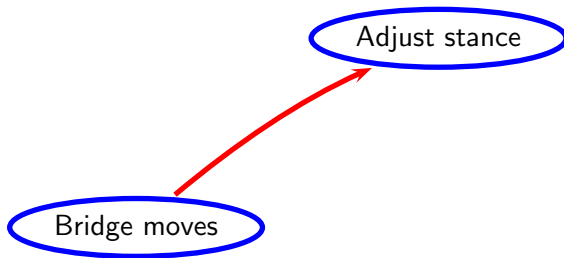
- An engineering answer
  - Cause: horizontal vibrations at 1 hertz
  - Walking pace: two steps per second, i.e. two hertz
  - Producing one-hertz horizontal force
- Why should it matter?
  - If the pedestrians sway randomly to the left and right, they cancel each other out
  - It is Only a problem when people walk in step like soldiers marching
  - Probability of a thousand people walking at random ending up walking exactly in step? — *close to zero*
  - If individual steps are independent events, but

## Given Feedback, Near Certainty!

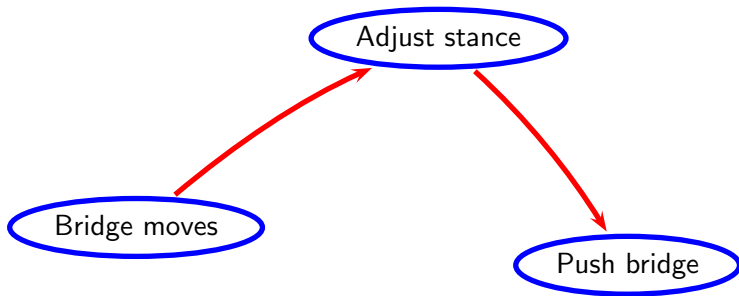
Bridge moves



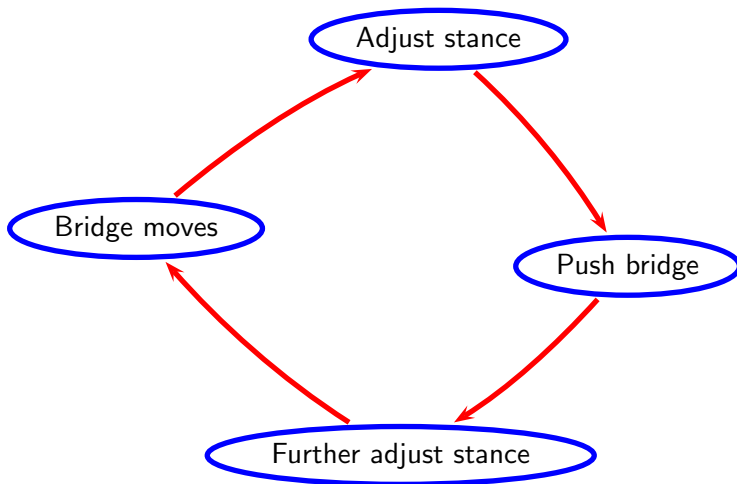
## Given Feedback, Near Certainty!



## Given Feedback, Near Certainty!



## Given Feedback, Near Certainty!



# Dual Role Of Prices

# Dual Role Of Prices

Danielsson, Shin, and Zigrand (2012)

- Prices of financial assets play two important roles. The first is quite familiar
  1. Prices reflect the underlying fundamentals
  2. Prices are also an imperative for action

# Endogenous Market Prices: Leverage Constraints and Upward Sloping Demand

- Leverage constraint  $L = 5$  (assets to equity)
- Initial (time 0) values
  - Prices,  $P_0 = \$10$
  - Number of assets,  $Q_0 = 100$
  - Assets,  $A_0 = \$1000$
  - Debt,  $D_0 = \$800$
  - Equity,  $E_0 = A_0 - D_0 = \$200$
- Leverage

$$L = \frac{A}{A - D = E} = 5 = \frac{1000}{200}$$

## Balance Sheets

Assets	Liabilities
1000	Equity \$200
	Debt \$800

Prices fall to  $P_1 = \$9$  at time 1

Assets	Liabilities
900	Equity \$100
	Debt \$800

Leverage to 9, bank needs to *sell assets and repay debt*

## Prices Are Exogenous

$$L_1 = \frac{A_1}{A_1 - D_1} = \frac{P_1 Q_1}{P_1 Q_1 - (D_0 - P_1 (Q_0 - Q_1))}$$

So

$$Q_1 = -L \frac{D_0 - P_1 Q_0}{P_1}$$

In our case,  $Q_1 = \frac{\$500}{9}$ , so the bank sells \$400 worth of assets, and its balance sheet becomes:

Assets	Liabilities
$A = 9 \frac{\$500}{9} = \$500$	$E = \$500 - \$400 = \$100$
	$D = \$800 - 9 \frac{\$400}{9} = \$400$



# Prices Are Endogenous: Bank Exerts Significant Price Impact

$\lambda$  is the *price impact factor*, and  $P_1 Q_1$  the amount the bank wants to sell, in our case \$400

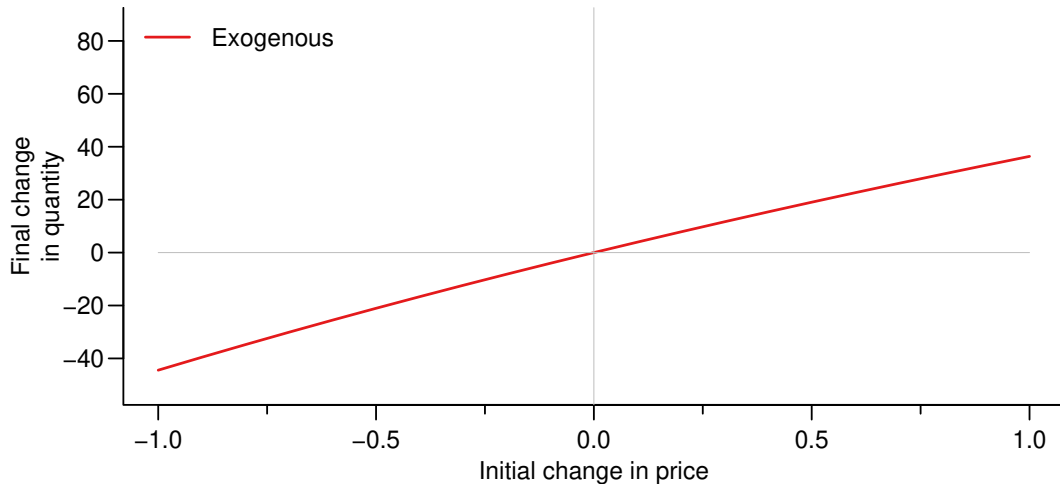
Make  $\lambda = 0.001$

1.  $p_n = p_{n-1} + \lambda p_{n-1} (Q_{n-1} - Q_{n-2})$
2.  $Q_n = L(Q_{n-1} - D_{n-1}/p_n)$
3.  $A_n = p_n Q_n$
4.  $E_n = A_n/L$
5.  $D_n = A_n - E_n$

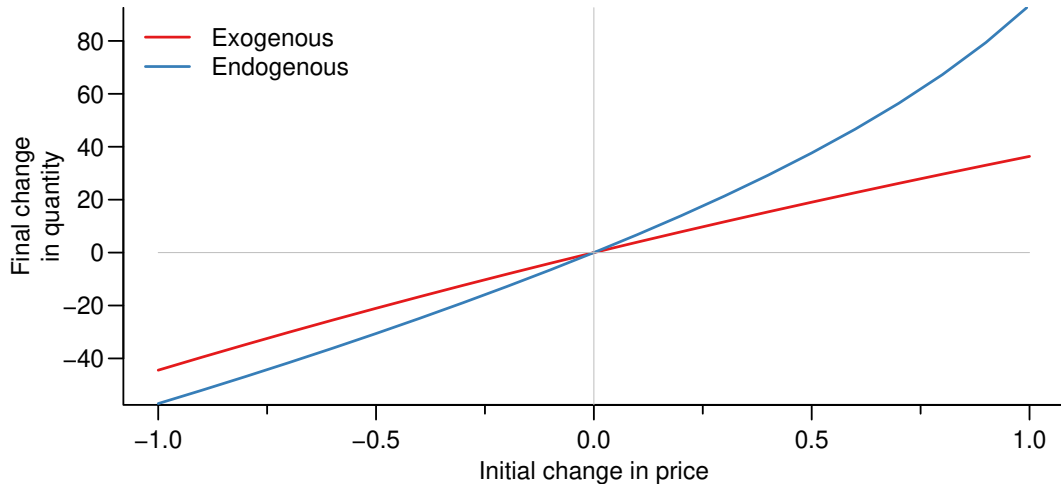
## Prices Are Endogenous: Iterate

Iteration	$Q$	$p$	$A$
1	100.000	\$10.000	\$1000.000
2	55.556	\$9.000	\$500.000
⋮	⋮	⋮	⋮
9	42.934	\$8.492	\$364.585
10	42.934	\$8.492	\$364.585

## Demand is Upward Sloping



## Demand is Upward Sloping



## Butterflies and Financial Crises

- Demonstrates how a small exogenous shock can trigger a large outcome
- The constraints dictate a “*sell cheap, buy dear*” strategy
- Precisely the kind of vicious feedback loops that destabilize markets
- This is the mechanism that allows the butterfly to create the hurricane

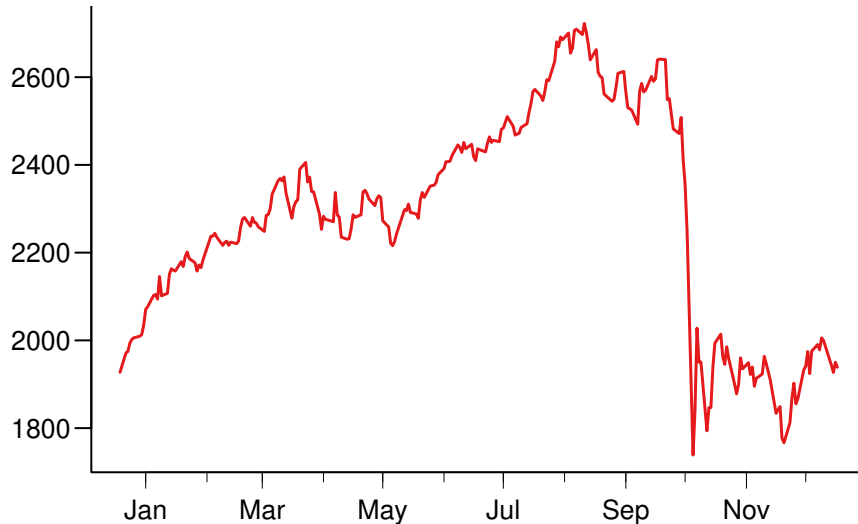
# Dynamic Strategies And The 1987 Crash

# Black Monday

## Gennotte and Leland (1990)

- 19 October 1987
- The biggest stock market crash in history
- Global stock markets crashed around 23%
- A key reason for the crash was *portfolio insurance*
- That is, the use of an automatic trading strategy

## 1987 Dow Jones Industrial Average





# Put Option and Delta

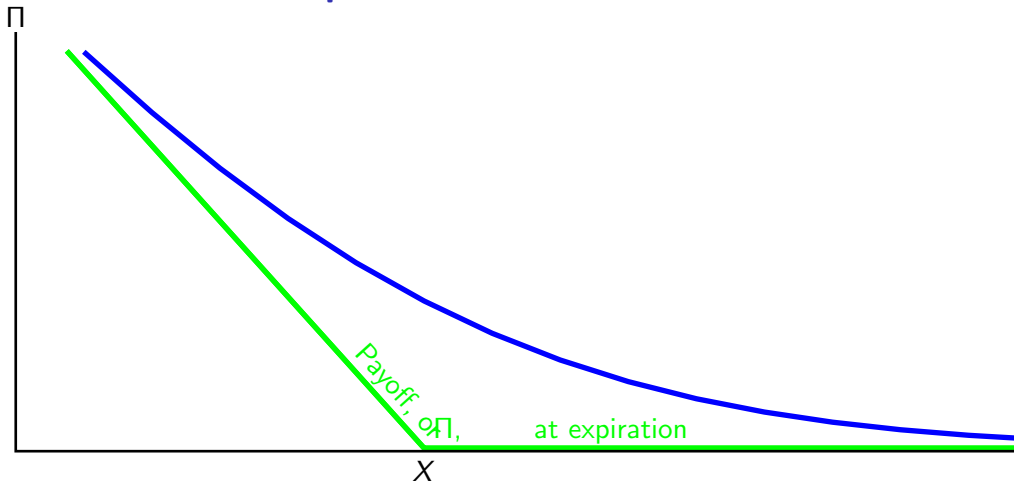
Danielsson, Shin, and Zigrand (2012)

- A *put option* gives the holder the right to sell an asset at an agreed *strike price* ( $X$ )
- *Delta* ( $\Delta$ ) of a put option is the rate of change of its price ( $\Pi$ ) with respect to the change in price of the underlying asset,  $p$

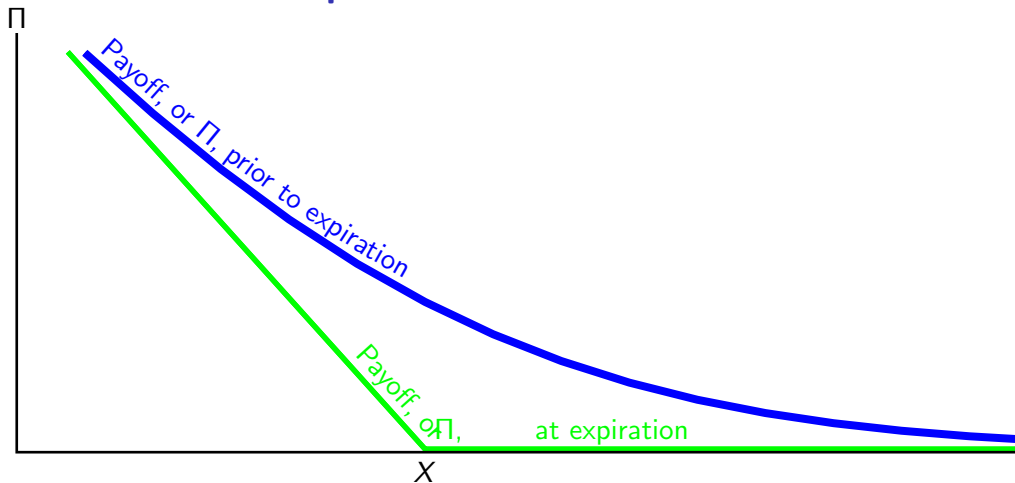
$$\Delta = \frac{d\Pi}{dp} < 0$$

- Graphically,  $\Delta$  is the slope of a curve – the option price against the price of the underlying

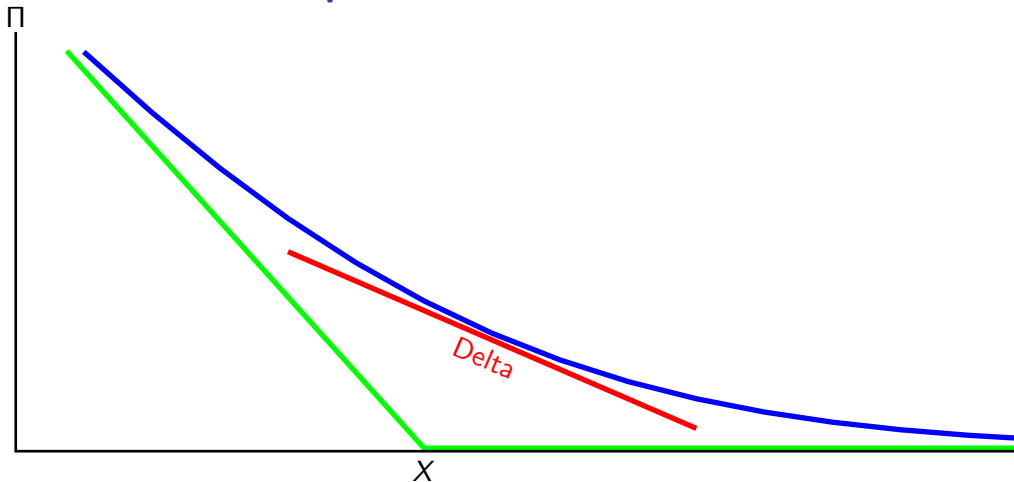
## Put Option and Delta



## Put Option and Delta



## Put Option and Delta



## Hedging Through Options

- Options are effective instruments to hedge
- Delta hedging
  - A portfolio that consists of 1 put option and  $\Delta$  stocks is riskless
  - Which must earn the risk-free rate
- Traded options don't always exist — long maturity, over-the-counter (OTC) markets

## Synthetic Options

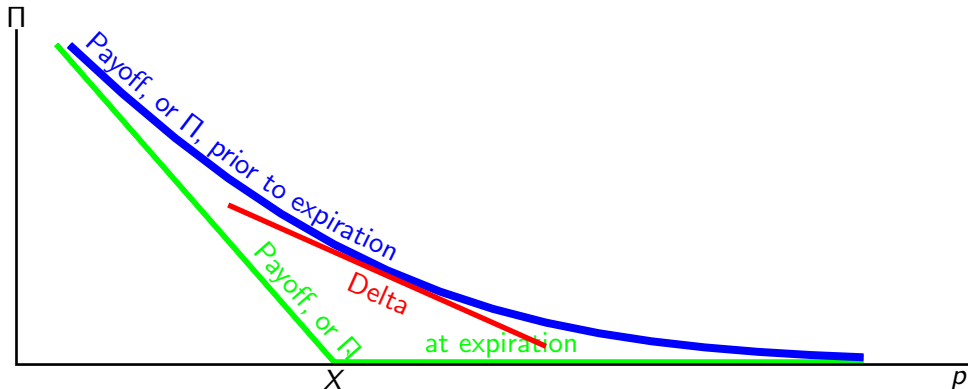
- Financial engineering: turn one asset into another
- *Synthetic replication*: create an option by a combination of cash and the underlying asset
- Dynamically replicating a put

$$\begin{Bmatrix} 1 & \text{Put} \\ 0 & \text{Cash} \end{Bmatrix} = \begin{Bmatrix} \Delta & \text{Underlying asset} \\ -p\Delta + \Pi & \text{Cash} \end{Bmatrix}$$

- $\Delta$  of a put option is always negative
- Replicating portfolio: short  $|\Delta|$  units of underlying asset at price  $p$  at all times

# Synthetic Put

- $\Delta$  of the option becomes more negative as the asset price falls
- *“Sell cheap, buy dear”* strategy



## Simulation

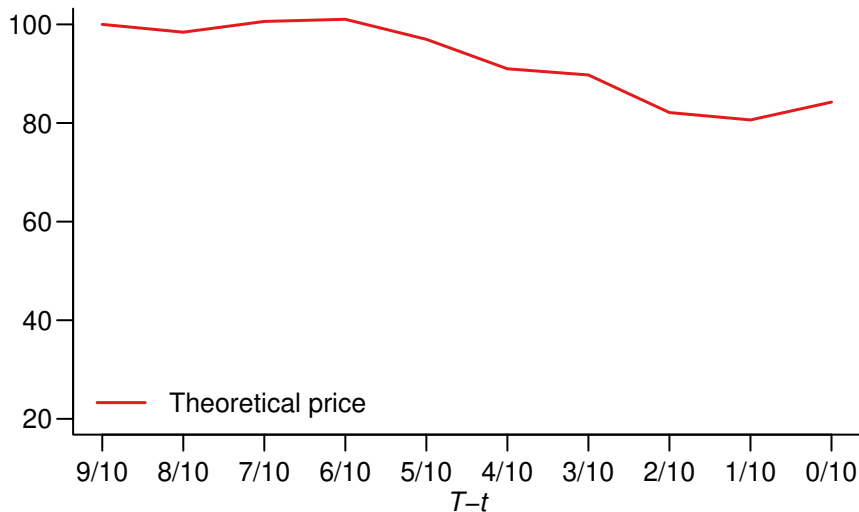
- Strike price at \$90
- The risk-free rate at 0%
- The annual volatility at 25%
- Time to maturity is 9 weeks
- Initial price \$100
- $\epsilon$  is shock
- Black-Sholes put is \$0.8012
- Use superscript  $*$  to denote the actual outcomes, so for example  $p$  refers to the theoretic price and  $p^*$  to the actual price



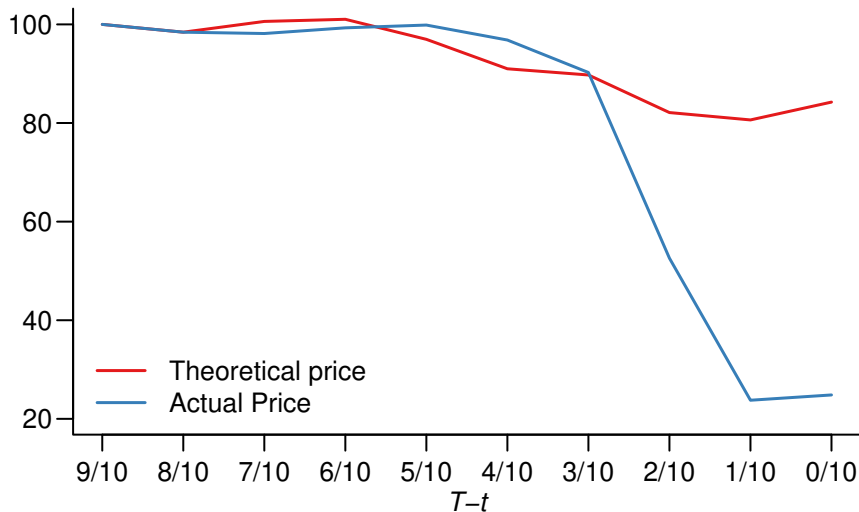
## Dynamic Replication Strategy

$T - t$	$\epsilon$	$p$	$p^*$	$\Delta$	$\Delta^*$	$C$	$C^*$
9/10		\$100.0	\$100.0	-0.14	-0.14	\$14.3	\$14.3
8/10	-0.016	\$98.4	\$98.4	-0.17	-0.17	\$16.8	\$16.8
7/10	0.022	\$100.6	\$98.1	-0.10	-0.16	\$10.3	\$16.1
6/10	0.004	\$101.0	\$99.3	-0.08	-0.12	\$7.9	\$11.5
5/10	-0.040	\$97.0	\$99.9	-0.16	-0.08	\$15.5	\$8.4
4/10	-0.062	\$91.0	\$96.8	-0.42	-0.14	\$39.6	\$13.6
3/10	-0.014	\$89.7	\$90.2	-0.51	-0.47	\$47.1	\$43.6
2/10	-0.085	\$82.1	\$52.6	-0.97	-1.00	\$84.9	\$71.5
1/10	-0.018	\$80.6	\$23.8	-1.00	-1.00	\$87.5	\$71.5
0/10	0.045	\$84.2	\$24.8	-1.00	-1.00	\$87.6	\$71.5

## Dynamic Replication Strategy (Cont.)



## Dynamic Replication Strategy (Cont.)



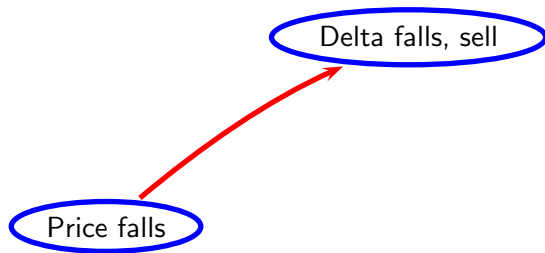
# The Crash

- \$60-\$90 billion in formal portfolio insurance (3% of pre-crash market capitalisation)
- 14 Oct (Wednesday) to 16 Oct (Friday)
  - Market decline of 10%
  - Sales dictated by dynamic hedging, \$12 billion
  - Actual sales (cash + futures), \$4 billion
  - Substantial pent-up selling pressure on Monday

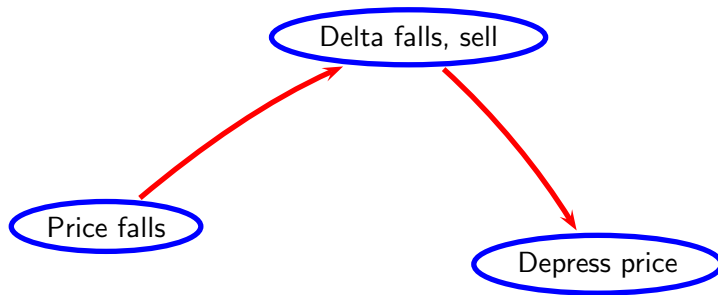
# Endogenous Market Dynamics; Portfolio Insurance

Price falls

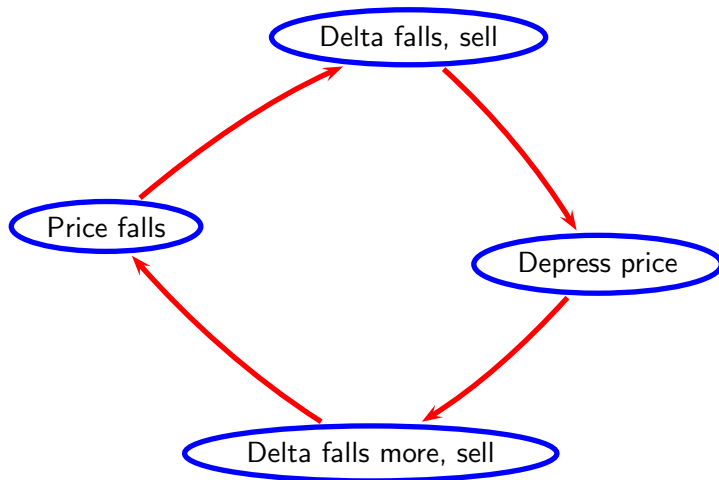
# Endogenous Market Dynamics; Portfolio Insurance



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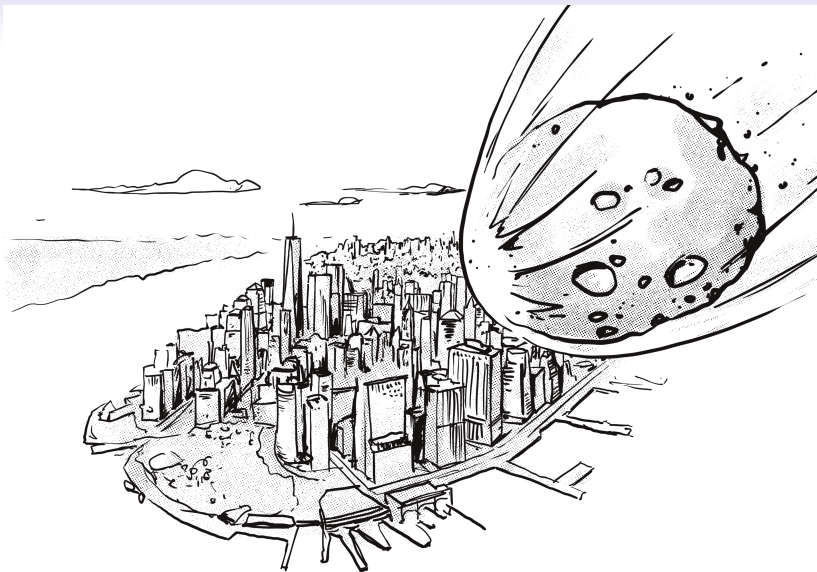




## Trading Rules

- Classic example of destabilising feedback effect on market dynamics of concerted selling pressures arising from certain mechanical *trading rules*
  - Like the *sell-on-loss* considered here.
- The underlying destabilising behaviour is completely invisible so long as trading activity remains below some critical but unknown threshold
- Only when this threshold is exceeded does the endogenous risk become apparent, causing a market crash
- Clearly demonstrates the difference between *perceived risk* and *actual risk*.

# Actual and Perceived Risk



## A Baby Risk Model

- Suppose returns are given by

$$y_t = \frac{P_t - P_{t-1}}{P_{t-1}}$$

- Suppose we measure exogenous risk by volatility

$$\text{volatility}_t^2 = \text{variance} = \frac{1}{N-1} \sum_{i=1}^N (y_{t-i} - \text{mean})^2$$

- Measured risk is a function of historical prices
- Recall the example of the dam bursting in Chapter 1

## Recall When Risk Is Created

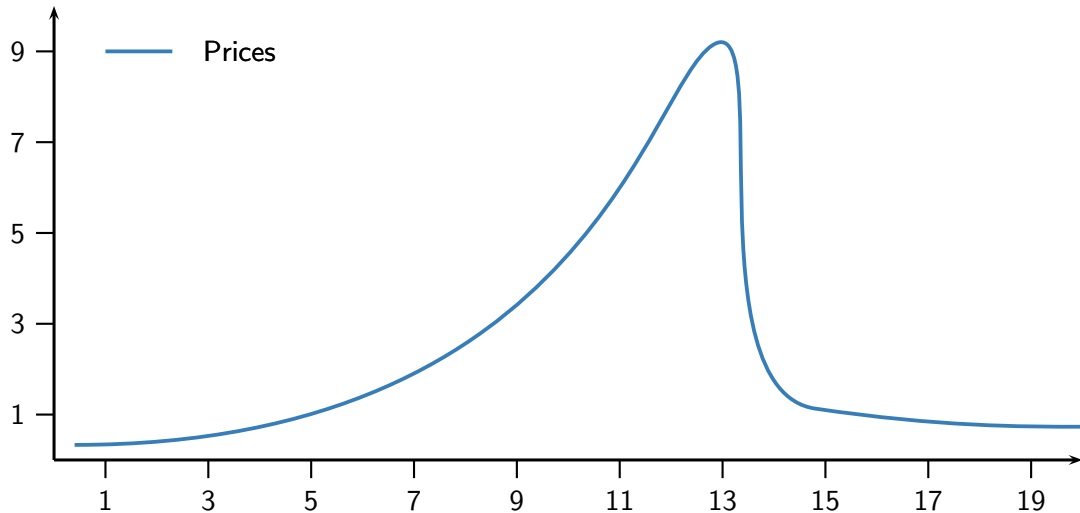
*“The received wisdom is that risk increases in recessions and falls in booms. In contrast, it may be more helpful to think of risk as increasing during upswings, as financial imbalances build up, and materialising in recessions.”*  
*Andrew Crockett, then head of the BIS, 2000*

- Consistent with Minsky’s financial instability hypothesis

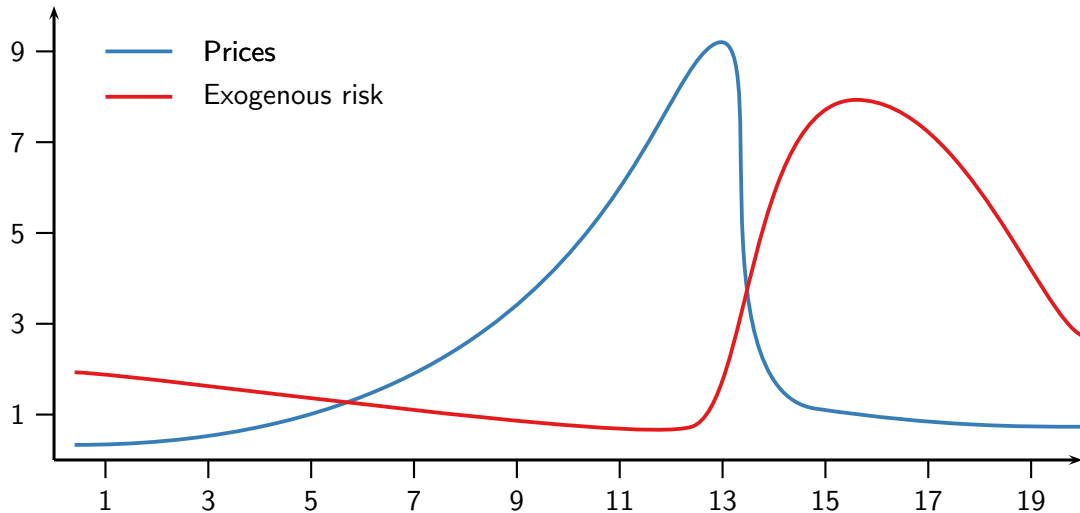
## Relevance of Endogenous Risk

- When individuals observe *and* react — affecting their operating environment
- Financial system is not invariant under observation
- We cycle between virtuous and vicious feedback
- Two faces of risk
  - Risk reported by most risk forecast models — exogenous (perceived) risk
  - Endogenous (actual) underlying risk that is hidden but ever-present

# Endogenous Bubble

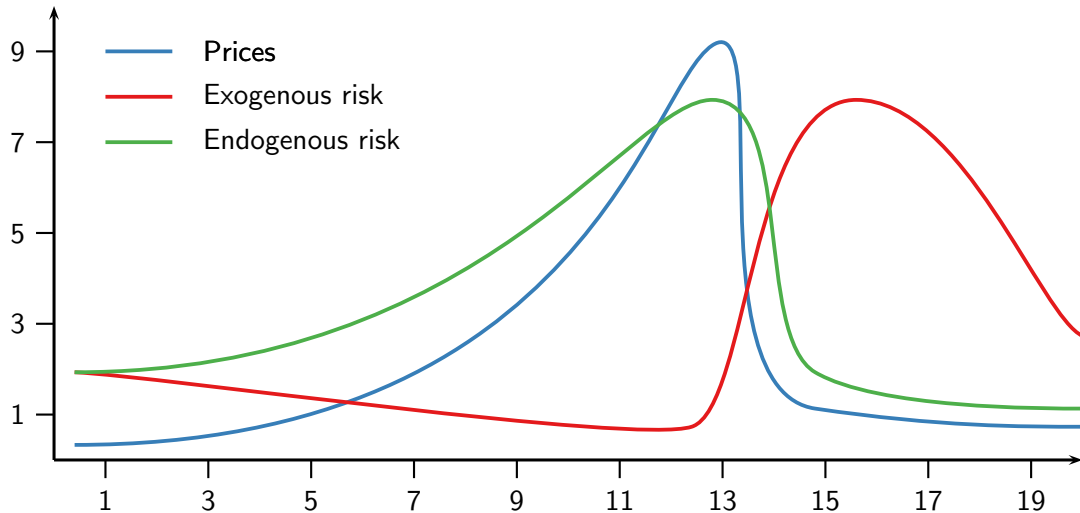


## Endogenous Bubble

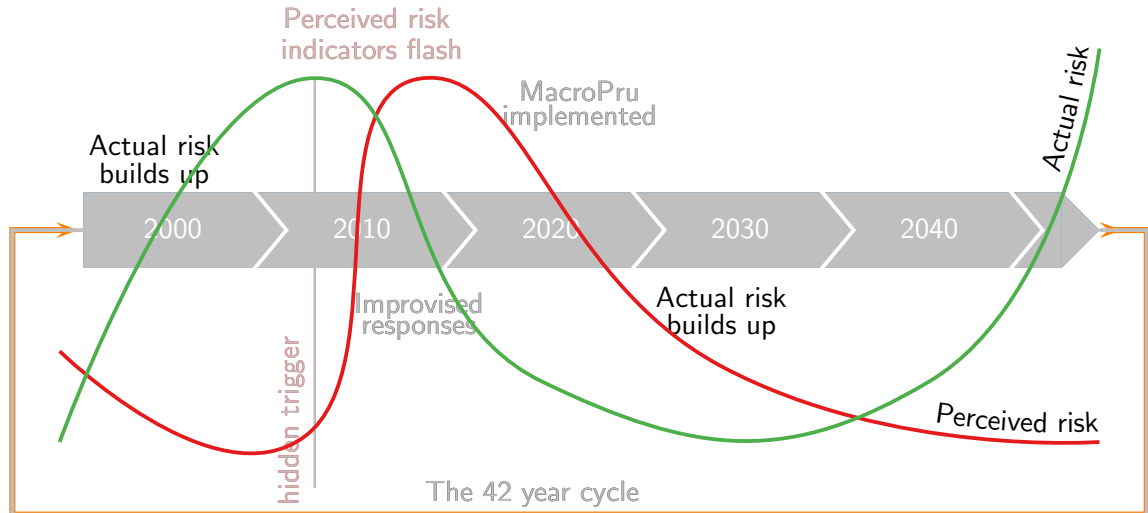




## Endogenous Bubble



# The 42 Year Cycle Of Systemic Risk



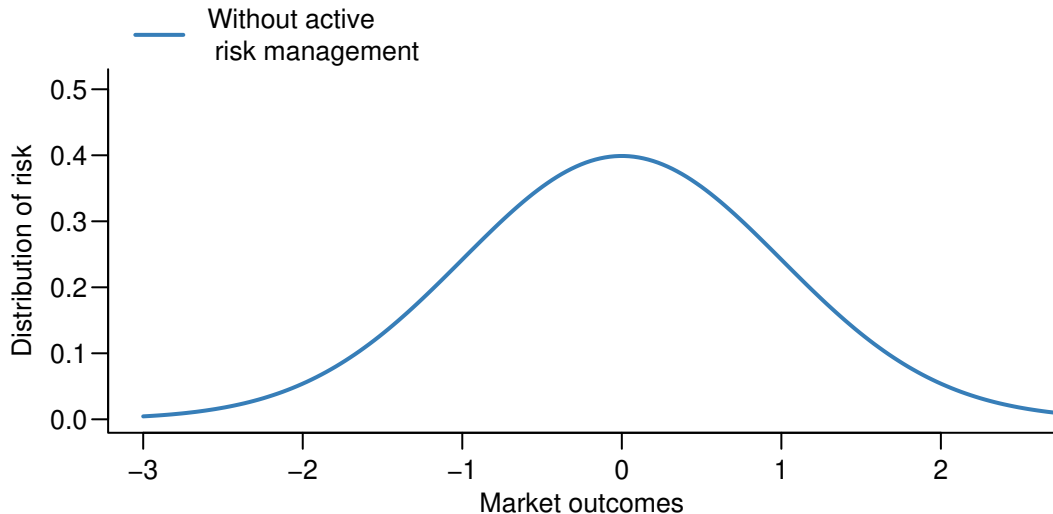
## Exam 2021

- Consider the day at the height of the Covid-19 market turmoil in the middle of March 2020. Would you expect perceived risk to increase over the subsequent few days? Would you expect actual risk to increase over the subsequent few days?

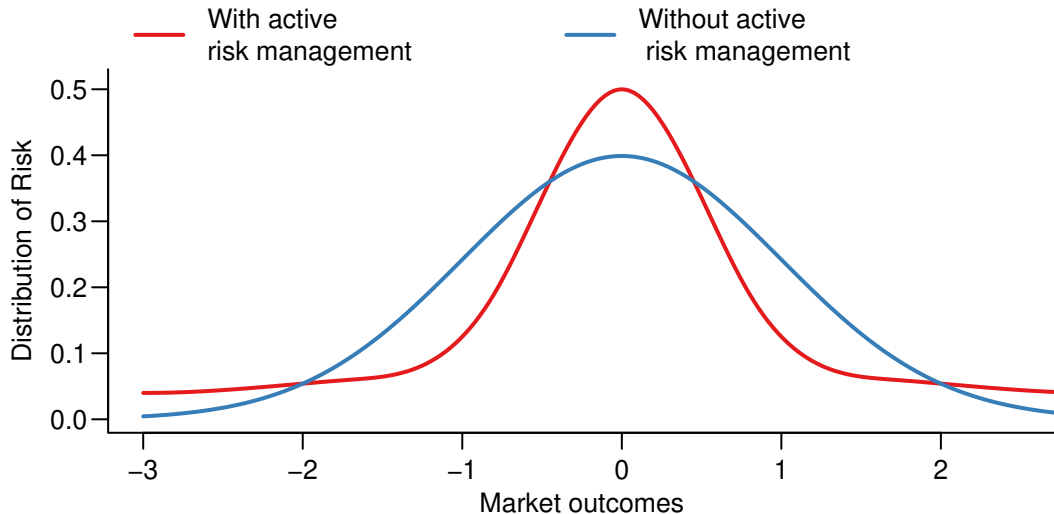
## The Impact Of Managing Risk

- Imagine two different worlds
  - A.** There are no regulations about risk, and banks are all doing their own thing
  - B.** We have harmonised regulations and stakeholders that demand state-of-the-art risk management
- Which world is more stable?
- It depends
- Because the management of risk controls only one part of the domain of risk

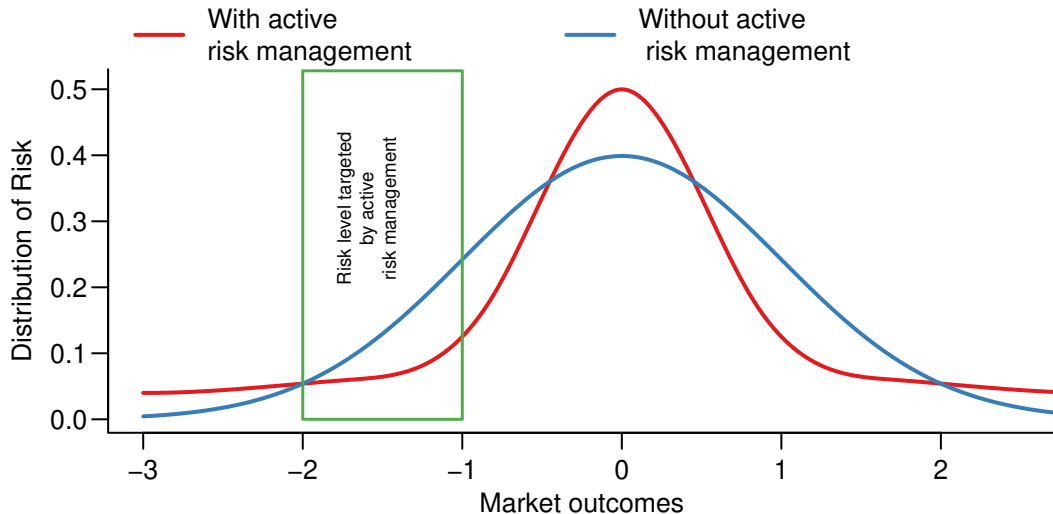
## Impact of Active Risk Management



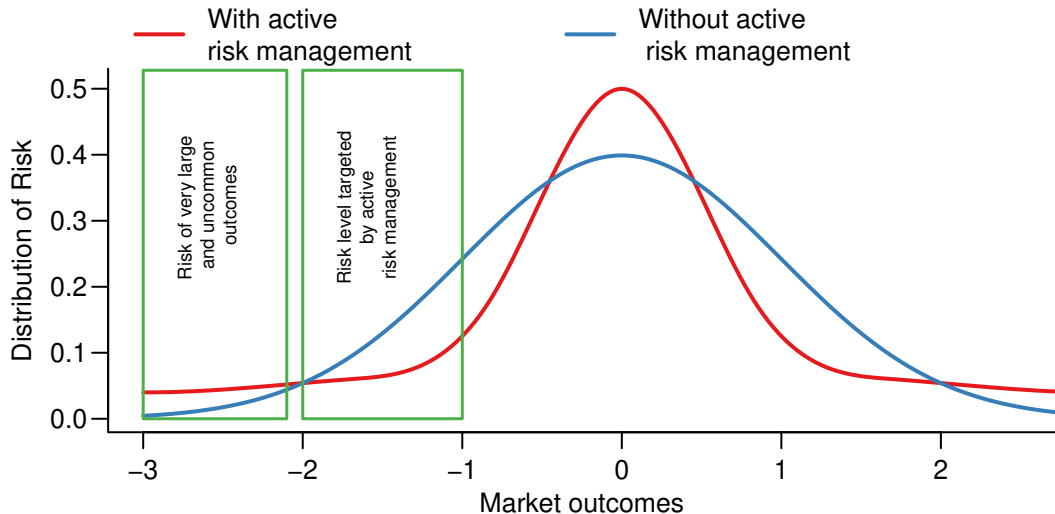
## Impact of Active Risk Management



## Impact of Active Risk Management



## Impact of Active Risk Management





# The Long Term Capital Management (LTCM) Crisis

# Long-Term Capital Management

Lowenstein (2000), Lewis (1989)

- Founded by John Meriwether, experts include Robert Merton and Myron Scholes
- Minimum investment \$10 million, charge 2 and 25, three-year lock-in
- \$1.01 billion in capital to start with
- Performance
  - First two years: 43%, and 41%, after fees
  - Net capital in September 1997 was \$6.7 billion
  - Leveraged to \$126.4 billion (19 times)

# LongShort–Term Capital Management

Lowenstein (2000), Lewis (1989)

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- Minimum investment \$10 million, charge 2 and 25, three-year lock-in
- \$1.01 billion in capital to start with
- Performance
  - First two years: 43%, and 41%, after fees
  - Net capital in September 1997 was \$6.7 billion
  - Leveraged to \$126.4 billion (19 times)
- *Failed spectacularly in 1998*

## Leverage

- “*LTCM would make money by being a vacuum sucking up nickels that no one else could see.*”
  - Myron Scholes
- Drove very hard bargains on financing

## Trading Strategies

- Convergence or relative value trades
- Examples:
  - Fixed rate residential mortgages in the US
  - Japanese and European government bonds
  - Interest rate swaps
  - Italy

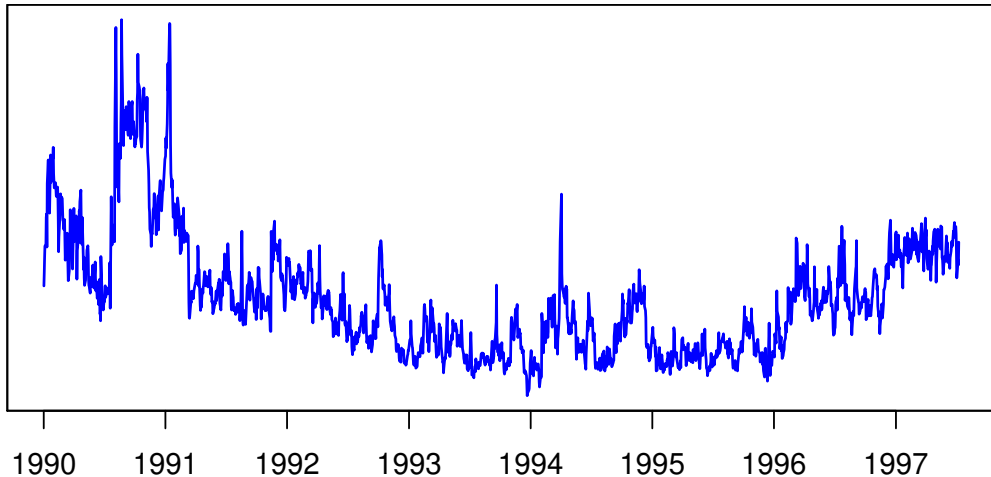
## The Bigger Picture

- VaR in 1998 indicated that it would take a *10 $\sigma$  event* for it to lose all capital in a single year ( $p = 10^{-24}$ )
  - Probability of default of  $7.6 \times 10^{-23}$
  - The earth is  $4.5 \times 10^9$  years old and the universe is  $1.3 \times 10^{10}$  years old
- Returned \$2.7 billion to investors in December 1997 (focus on investing own money)
- (And we worry about incentives in bonuses!)
- Copycat funds, proprietary trading desks of creditor banks  
→ Narrowing of spreads
- Venturing into uncharted territory in search of profitable trades

## “Central Bank Of Volatility”

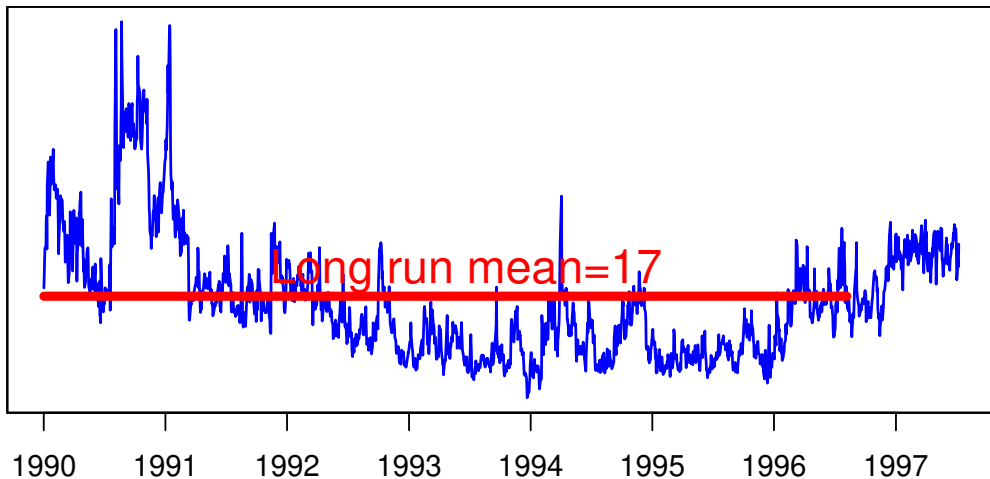
- The biggest trade in 1998 was to sell/write long-dated options
- Expect volatility to go to long-run level
- LTCM became a major supplier of S&P 500 vega
- High leverage to profit from minute differences in value

## VIX

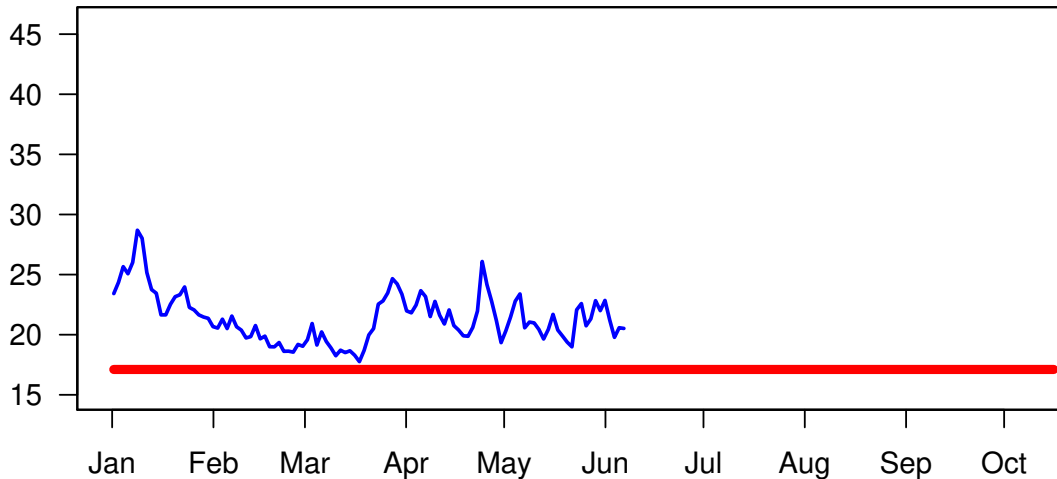




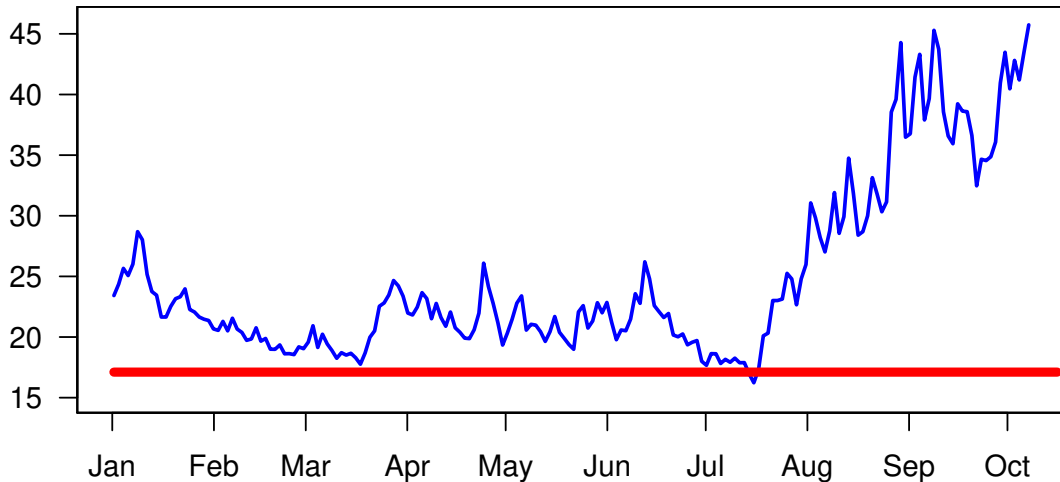
## VIX



## VIX – Close to The Crisis – 1998



## VIX – Close to The Crisis – 1998



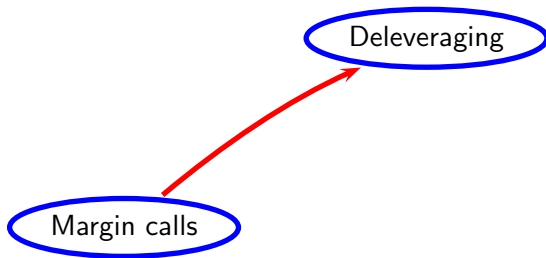
## A Perfect Storm

- Returns: -6.7% in May, -10.1% in June
- Leverage became 31/1 (capital drops relatively more than assets)
- Salomon Smith Barney closed US bond arbitrage group
- Russia default 17 August, triggered a panic
- Credit spreads widened, volatility shot up to 45% (the unthinkable happened)
- All correlations tended to one (as happens in crises)

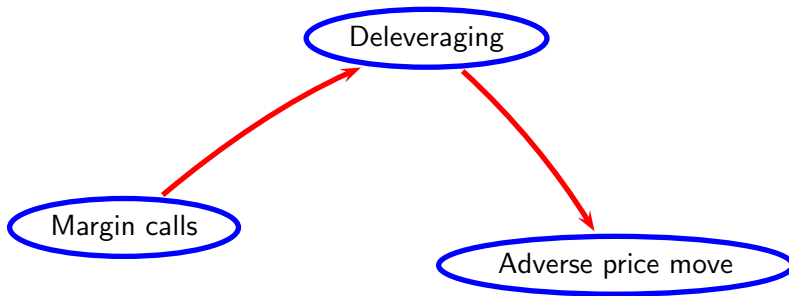
# Endogenous Collapse

Margin calls

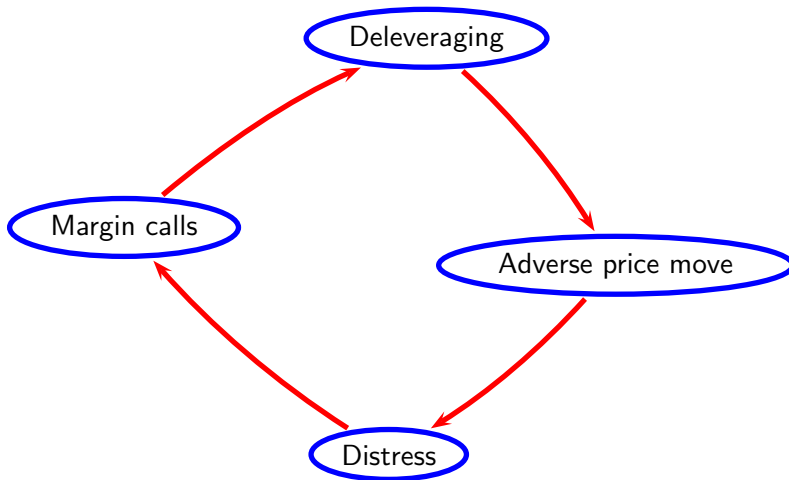
# Endogenous Collapse



# Endogenous Collapse



## Endogenous Collapse





## Deleveraging

- Mutually reinforcing effect of deleveraging
- Distress and margin calls entail short-horizon trading
- Lost more than \$45 million per day
- Equity tumbled from \$2.3 billion to \$600 million in the first three weeks of September
- Fed organised a \$3.625 billion rescue

## Preconditions For Endogenous Risk

- Individual economic agents react to outcomes
- Individual actions affect outcomes
- To believe that LTCM was just hugely unlucky is to commit the same mistake as the engineers of the Millennium Bridge
- Far from a probability close to zero, the collapse was near certain given the right conditions

## Irrationality of Markets?

- LTCM invested in a mean-reverting asset, expecting VIX to fall eventually, bringing significant profits
- Profits were made, but only by those who bailed LTCM out
- The explanation is provided by an observation often attributed incorrectly to Keynes

“The market can stay irrational longer than you can stay solvent.”

- The very high levels of VIX were explicitly caused by the uncertainty created by the presence of LTCM
- *A necessary condition* for the VIX to return to its long-run mean was the failure of LTCM

# How data lies

## The Problem with Data

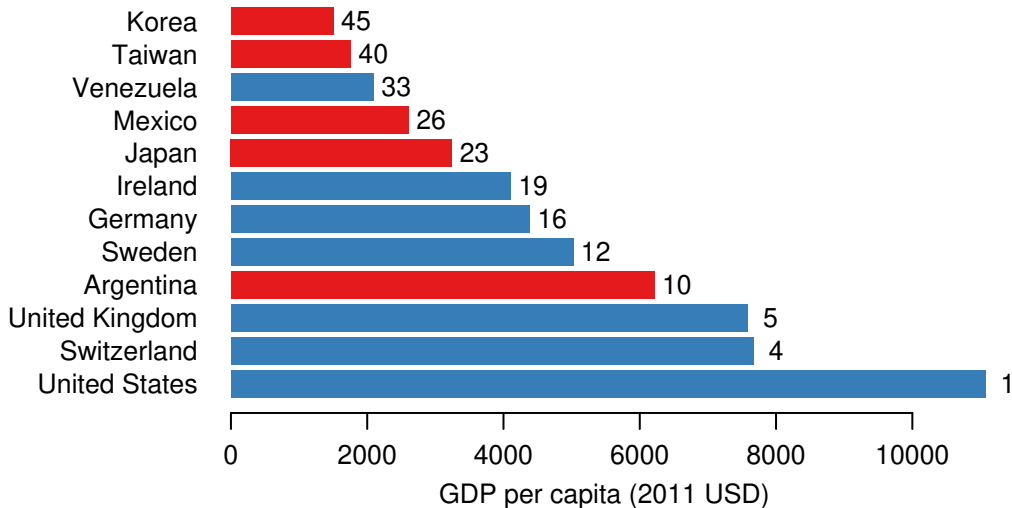
- We have an almost infinite amount of data
- And very sophisticated technology for processing it
- In the context of the stability of the financial system
- Does this mean we can analyse all important problems?
- And design optimal responses to them?

Does data lie? Or more precisely do we lie to ourselves with data?

## The Driver of Extreme Risk is Politics

- Key events: 2008, Italy, Trump, Ukraine, Taiwan, Venezuela, Middle East, real estate, inflation
- Politics allows risks to emerge and prevents timely solutions
- Inability to address environmental risks is entirely political
- The demographic challenge follows a similar pattern
- Political systems often work against those seeking to prevent undesirable outcomes
- Short-term tangible benefits are prioritized over long-term stability
- Few are willing to invest now to mitigate potential future problems

## GDP and Rank in 1923 (again)



## Risk vs Uncertainty Knight (1921)

- *Risk*: Situations where outcomes are unknown but probabilities can be estimated
  - Examples include rolling a die, pricing insurance, and portfolio theory
- *Uncertainty*: Situations where outcomes are unknown and probabilities are not well-defined
  - Examples include future technological shifts and geopolitical events
- Knight argued that only risk can be effectively addressed by statistical methods
- Uncertainty requires nuanced judgment, robust institutions, and precautionary approaches



# Rumsfeld on unknown unknowns

Donald Rumsfeld (2002) was US Secretary of Defense in 2002

- There are known-knowns
  - These are things we know that we know
- There are known-unknowns
  - These are things that we know we don't know
- But there are also unknown-unknowns
  - These are things we don't know we don't know
- Rumsfeld's unknown unknowns correspond to Knight's deepest form of uncertainty

Is it all about risk?

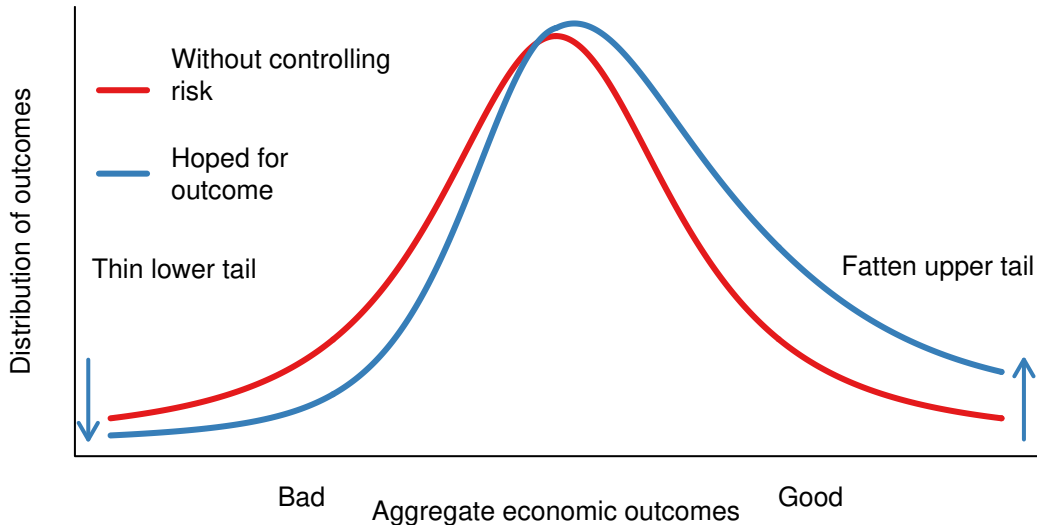
or perhaps uncertainty or  
unknown-unknowns?

What do we want?

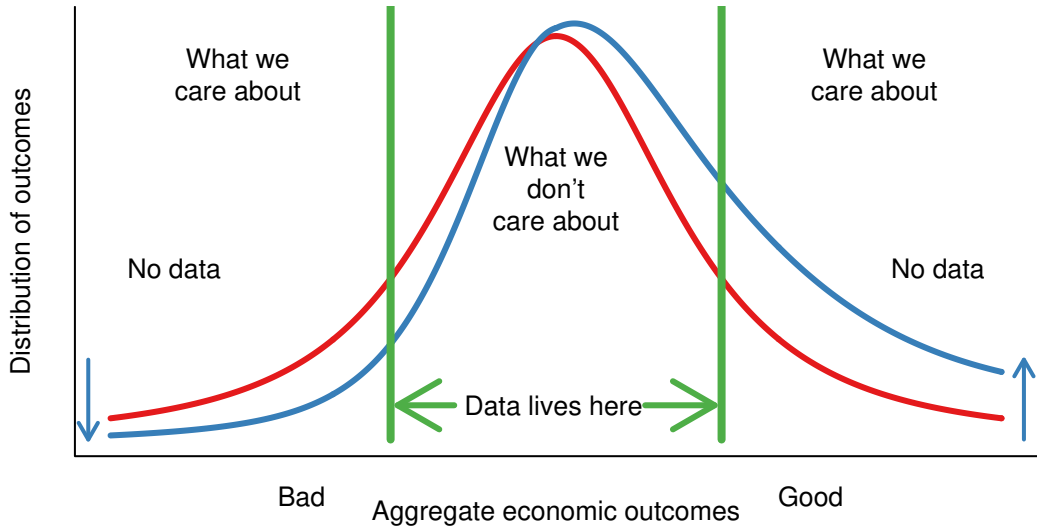
## McNamara 1967

- “It is true enough that not every conceivable complex human situation can be fully reduced to the lines on a graph, or to percentage points on a chart, or to figures on a balance sheet, but all reality can be reasoned about. And not to quantify what can be quantified is only to be content with something less than the full range of reason.”
- Yankelovich (1972)
- “The first step is to measure whatever can be easily measured. This is OK as far as it goes. The second step is to disregard that which can't be easily measured or to give it an arbitrary quantitative value. This is artificial and misleading. The third step is to presume that what can't be measured easily really isn't important. This is blindness. The fourth step is to say that what can't be easily measured really doesn't exist. This is suicide.”

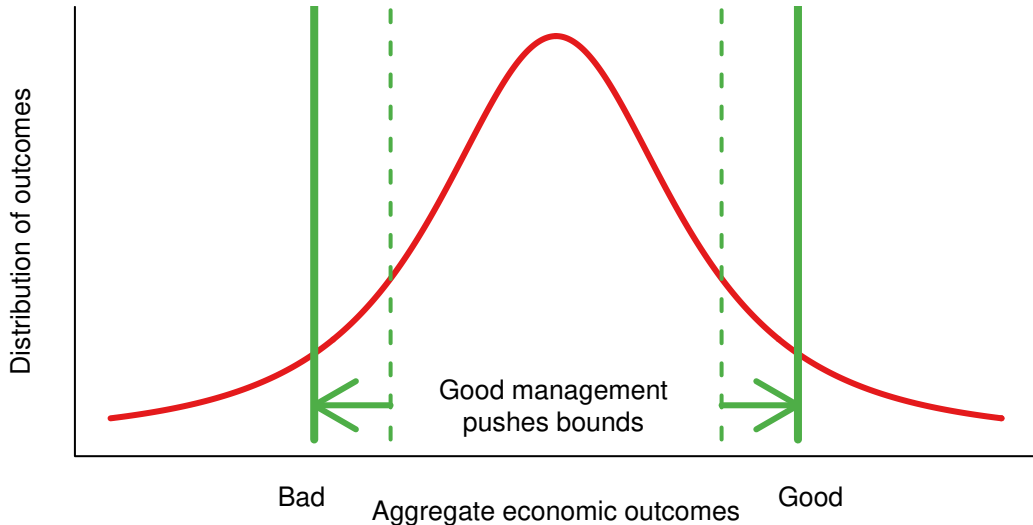
## What We Want



## What We Get



## And If We Are Good at Our Jobs



## The Danger

- We form our worldview using only existing data
- Neglecting the potential for future extreme outcomes shaped by new human objectives
- Such outcomes are fundamentally unpredictable
- We consequently focus on the least significant aspects of the decision space
- Ignoring the critical underlying factors
- Resulting in profound surprise when significant events occur

Do we really understand the risks we model?

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