### A Theory of Model Sophistication and Operational Risk

SULEYMAN BASAK ANDREA M. BUFFA London Business School

Boston University

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#### • Advantages of sophistication:

technology-enabled innovation in financial services allows for faster and deeper analysis of financial markets, leading to investment decisions supported with more data and risk analytics (European Supervisory Authorities, 2016; International Organization of Securities Commissions, 2017)

improved credit risk assessments, investment returns, and pricing of insurance contracts (Financial Stability Board, 2017)

#### • Disadvantages of sophistication:

given complexity of information systems and procedures, potential for incorporating errors and biases at every implementation stage is higher, which could lead to inadequate output and operational losses (ESA, 2016; European Securities and Markets Authority, 2017)

implementation errors are more likely to occur when data analytics are developed and implemented by staff that is not sufficiently qualified, or yet trained, to work with complex and rapidly changing technologies (ESA, 2016)

greater use of technology and digital solutions increases the exposure to cybersecurity attacks (Bank of England, 2017; FSB, 2017; IMF, 2017; IOSCO, 2017) and system integration failures (FSB, 2017)

Enhancements and updates to systems, as well as the requisite training, entail significant costs and create risks associated with implementing new systems and integrating them with existing ones.

Goldman Sachs, 2017 Form 10-K

As the speed, frequency, volume and complexity of transactions increases, it becomes more challenging to effectively maintain the operational systems and infrastructure, especially due to the heightened risks that:

- errors cause widespread system disruption
- isolated or seemingly insignificant errors in operational systems compound, or migrate to other systems over time, to become larger issues

JPMorgan Chase, 2018 Form 10-K

• Basel Committee on Banking Supervision (2001) defines operational risk as: The risk of loss resulting from inadequate or failed internal processes, people, and systems or from external events

Operational risk is considered:

**internal** if due to controllable events: programming errors, system integration failures, execution errors, cyber attacks, business interruption due to third-party outsourcing

**external** if due to uncontrollable events: computer breakdowns, fat finger, natural disasters

- Increasing interest of financial institutions and regulators in operational risk Basel II sets requirements to manage this risk ever-increasing losses from operational risk events it is reaching same level as market and credit risk
- Although *large/infrequent* operational losses make it to the news (e.g., Salomon Brothers (\$303 million, 1993), Wells Fargo (\$150 million, 1996), Freddie Mac (\$207 million, 2001), Société Générale (€4.9 billion, 2008), UBS (\$2.3 billion, 2011), Knight Capital (\$460 million, 2012), JPMorgan (\$ billion, 2012)), operational risk is mostly induced by *small/frequent* operational errors (Jorion, 2007; Crouhy-Galai-Mark, 2014)
- Literature focuses on measurement and statistical properties of operational losses ⇒ little is known about economics behind operational risk

# **This Paper**

- Theoretical model to study decision making of financial institution subject to novel **implementation friction** that gives rise to (internal) operational risk First attempt to embed operational risk into asset allocation framework
- Friction ⇒ trade-off between model sophistication and operational risk: between investment that is more likely to be profitable and one that is less complex to implement (less exposed to operational errors)
- Microfoundation of operational losses

Level of sophistication (*how much to rely on advanced data analytics*) as endogenous response to operational risk

• Questions:

What drives sophistication of investment models that institutions use? How does operational risk interact with other risks that institutions face? How does operational risk affect their investment decisions? Are there notable cross-sectional predictions across financial institutions?

- Model sophistication is affected in opposite ways by different sources of risk: operational risk and market risk ↓ sophistication model risk ↑ sophistication
- Operational risk may reduce the endogenous exposure to operational errors
- Operational risk reduces investment volatility
- Operational risk may increase investment Sharpe ratio

# **Related Literature**

• Risk management textbooks:

Jorion (2007), Crouhy-Galai-Mark (2014), Hull (2015)

- Statistical properties of operational losses and regulatory capital: Extreme value theory: Chavez-Demoulin-Embrechts-Neslehova (2006), Coleman (2003), de Fontnouvelle-Rosengren-Jordan (2006), Ebnother-Vanini-McNeil-Antolinez-Fehr (2001), Moscadelli (2004) VaR and reg. capital: de Fontnouvelle-Jordan-DeJesus-Ureff-Rosengren (2006)
- Intensity-based (reduced form) models of operational losses: Jarrow (2008), Chernobai-Jorion-Yu (2011)

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# Model

• Three dates: 0,1,2

• Risky investment opportunity (e.g., portfolio of risky loans, CDO tranche) with (net) payoff X at date 2:

$$X = \kappa + w$$

where

 $\kappa$ : expected profitability  $w \sim \mathcal{N}(0, \sigma^2)$ : market uncertainty  $\sigma$ : market risk

• Incomplete information:  $\kappa$  is **unobservable** 

Financial institution's prior:  $\kappa \sim \mathcal{N}(\bar{\kappa}, \nu) \Rightarrow \nu$ : model risk

# **Model Sophistication**

• To improve forecast of  $\kappa$ , institution can rely on investment model generating **informative signal** 

$$s(\lambda) = \kappa + rac{1}{\sqrt{\lambda}} \zeta$$

where

 $\zeta \sim \mathcal{N}(0, 1)$ : pure noise,  $\perp (w, \kappa)$  $\lambda \in [0, \infty)$ : model sophistication (controls precision of signal)  $\lambda$  can be thought as number *n* of signals  $s_i = \kappa + \zeta_i$  generated  $\Rightarrow$  *Big Data* 

• Given model sophistication  $\lambda,$  distribution of  $\kappa$  conditional on signal s is

$$\kappa | s \sim \mathcal{N}(\hat{\kappa}, \hat{\nu}) \quad \text{where} \quad \left\{ \begin{array}{l} \hat{\kappa} = \bar{\kappa}(1 - \Lambda) + s\Lambda \\ \hat{\nu} = \nu(1 - \Lambda) \end{array} \right., \quad \Lambda = rac{\lambda 
u}{1 + \lambda 
u}$$

 $\Lambda \in [0, 1)$ : normalized model sophistication (more intuitive to work with)

higher sophistication  $\Rightarrow$  higher  $\Lambda \Rightarrow$  better info  $\Rightarrow$  better investment

# **Operational Risk**

- Friction: more sophisticated model is more complex to implement ⇒ investment strategy more likely to contain operational errors
- Given investment strategy  $\theta$ , implemented investment is

$$\theta_{\epsilon} = \theta + h(\lambda)\epsilon$$

where

$$\begin{split} \epsilon &\sim \mathcal{N}(\mathbf{0}, \sigma_{\epsilon}^2): \text{ operational errors, } \perp (w, \kappa, \zeta) \\ \sigma_{\epsilon}: \text{ operational risk (controls variability and likelihood of op. errors)} \\ h(\lambda): \text{ model complexity (controls sensitivity of investment to op. errors)} \\ \text{ function mapping model sophistication into complexity of model implementation} \\ \text{ internal operational risk: } h(\cdot) > 0, h'(\cdot) > 0, h(\cdot) \text{ hom. of degree } \alpha > 1/2 \\ \text{ external operational risk: } h(\cdot) > 0, h'(\cdot) = 0 \end{split}$$

 $h(\lambda)\sigma_{\epsilon}$ : operational exposure (overall exposure to op. errors)

lower sophistication  $\Rightarrow$  lower  $h(\lambda) \Rightarrow$  lower op. errors  $\Rightarrow$  better investment

### **Financial Institution**

- Timing of events and decision making: date 0: institution chooses model sophistication Λ date 1: institution receives signal, updates its forecast of κ, chooses θ date 2: investment θ<sub>ε</sub> gets implemented and asset payoff is realized
- CARA objective over investment payoff at date 2: − exp{−γ(θ<sub>ϵ</sub>X)}
- Date 1: given s(Λ), institution solves for optimal investment strategy θ\*(Λ)
   U<sub>1</sub>(Λ) = max E [-exp {-γ(θ<sub>ε</sub>X)} |s(Λ)]

• <u>Date 0</u>: given  $\theta^*(\Lambda)$ , institution solves for optimal model sophistication  $\Lambda^*$ 

$$\mathcal{U}_0 = \max_{\Lambda} \mathbb{E}[\mathcal{U}_1(\Lambda)]$$

# **Optimal Behavior with Operational Risk**

# Model Sophistication $\Lambda^{\ast}$



- Model sophistication is decreasing in operational risk: ∂Λ\*/∂σ<sub>ε</sub> < 0 higher incentives to reduce model complexity
- Model sophistication is decreasing in market risk: ∂Λ\*/∂σ < 0 model sophistication is less desirable since market shocks are more likely to be large
- Model sophistication is increasing in **model risk**:  $\partial \Lambda^* / \partial \nu > 0$ model sophistication is more desirable since it can reduce the higher risk to rely on very inaccurate profitability forecast

## **Operational Exposure** $h^*\sigma_\epsilon$



• **External**: operational exposure is always increasing in  $\sigma_{\epsilon}$ 

- Internal: operational exposure becomes decreasing in  $\sigma_{\epsilon}$  if  $\sigma_{\epsilon}$  is high Endogenous model sophistication attenuates or even reverses sensitivity of implemented investment to operational errors
  - $CS \Rightarrow$  Low-operational-risk institutions (point B) may have higher operational exposure than high-operational-risk institutions (point C)

# Market Exposure $\theta_{\epsilon}^* \sigma$



- **External**: volatility of market exposure is always increasing in  $\sigma_{\epsilon}$
- Internal: volatility of market exposure is always decreasing in  $\sigma_{\epsilon}$ Endogenous model sophistication reduces sensitivity of implemented investment to both operational errors and market shocks
  - $\label{eq:CS} CS \Rightarrow \mbox{High-operational-risk institutions (point C) have less volatile investments than low-operational-risk institutions (point B)$

# Sharpe Ratio $SR(\theta_{\epsilon}^*X)$



- External: investment Sharpe ratio is always decreasing in  $\sigma_{\epsilon}$
- Internal: investment Sharpe ratio becomes increasing in σ<sub>ε</sub> if σ<sub>ε</sub> is high Endogenous model sophistication reduces both expected investment payoff and its volatility, but stronger effect on volatility
  - $CS \Rightarrow$  High-operational-risk institutions may appear as better performing than low-operational-risk institutions (or even no-operational-risk institutions)

Controlling for volatility of market (market risk), and for uncertainty around expected profitability of that market (model risk), on average:

- financial institutions with more intricate and inefficient organizational structure should adopt less sophisticated financial models, relying less heavily on data intense analytics and high performance computing
- financial institutions with either very lean and efficient organizational structure, or very intricate and inefficient one, should exhibit lower operational exposures (proxied by frequency and magnitude of operational losses)
- Intersection institutions with more intricate and inefficient organizational structure should have lower and less volatile market exposures (proxied by comovement of assets with market they operate in)
- In financial institutions with very intricate and inefficient organizational structure should exhibit higher Sharpe ratios and more light-tailed operational losses

# **Concluding Remarks**

- First attempt to study decision making of financial institutions subject to novel implementation friction giving rise to operational risk tractable setting as building block for future research on operational risk
- Contribution:

market risk: endogenous exposure through optimal asset allocation credit risk: endogenous exposure through optimal leverage operational risk: endogenous exposure through optimal model sophistication

• Novel results:

Choice of model sophistication is affected in opposite ways by different risks Exposure of investment model to op. errors may decrease in operational risk Operational risk reduces volatility of financial investments and may increase their Sharpe ratio

• Future work:

Implications of operational risk on equilibrium asset prices Normative analysis with emphasis on policy implications