# 1766-2016 RUTGERS 250

# Three Essays on Audit Innovation: Using Social Media Information and Disruptive Technologies to Enhance Audit Quality

*Dissertation Defense* Andrea M. Rozario

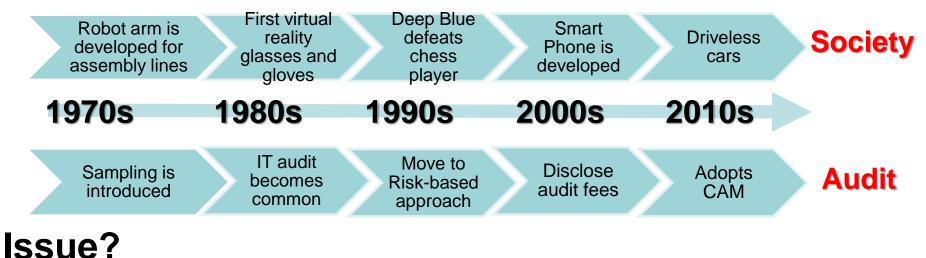
Dissertation Committee Chair: Dr. Miklos A. Vasarhelyi Dr. Alexander Kogan Dr. Helen Brown-Liburd Dr. David Wood

# Introduction (1)

## The Story

- The world is rapidly changing, technology enables a 365/24/7 economy
- How has the audit profession evolved?

Some major transformations...



# Auditing is at risk of losing its relevance

#### Introduction (2)

#### Motivation

- Technological advances are challenging the relevance of the current audit framework
- Audit community has proposed initiatives that are aimed at understanding the use and impact of technology in auditing
- Technology has the potential to enhance audit quality and transparency in the capital markets but its impact on auditing remains underexplored

### **Introduction (3)**

#### **Contribution:**

Fill the gap in the audit analytics literature by informing the audit community on the use of technological innovations to advance auditing and audit quality

# Essay One



# Enhancing Substantive Analytical Procedures with Third-Party Generated Information from Social Media

"Investors, and others, are accessing and analyzing massive amounts of information from sources, like social media, unimaginable just a few years ago. This new data may be empowering investors to make smarter investment decisions"

**Rutgers Business School** 

Kara Stein – SEC Commissioner 2015

#### **Objectives**

- Do Twitter proxies of consumer interest and consumer satisfaction enhance substantive analytical procedures for the revenue account?
- RQ 1A & RQ 1B: Do traditional and continuous substantive analytical models with Twitter experience improved prediction performance?
- RQ 2A & RQ1B: Do traditional and continuous substantive analytical models with Twitter experience improved error detection performance?

#### Motivation

- Social media postings contain incremental information about firms' stock market prices, and sales performance (e.g. Bollen, Mao, Zheng 2011; Tang 2017)
- Inspection findings indicate that accounting firms fail to develop precise expectations (PCAOB 2007; PCAOB 2016a)
- Social media consumer postings about firms' products and brands could be used as a source of audit evidence

#### **Prior Literature**

#### The Role of Nonfinancial Information in Analytical Models

- Macroeconomic information, customer satisfaction, and employee headcount improves the predictive ability of analytical models (Lev 1980; Ittner and Larcker 1998; Brazel et al. 2009)
- Yoon (2016) demonstrates that weather information is correlated with sales and that it enhances analytical models
- Advance research in analytical procedures by examining a different type of unorthodox audit evidence

#### **Research Design (1)**

#### Sample – 24 B2C industries

 Likefolio, <u>https://home.likefolio.com/</u>, BEA, <u>https://www.bea.gov/</u>, and Compustat

Sample Selection - Firm-Quarter Observations 2012-2017				
	Firms	Firm-Quarter Observations		
Firms that are publicly listed and have third-party generated Twitter information	194	4,656		
Less: Firms with missing financial information or zero values	(9)	(216)		
Less: Firms with missing information from Twitter for either Consumer Interest or Sentiment	(15)	(360)		
Less: Firms without four quarters of data	(73)	(1,752)		
Less: Firms in the Financial Services Industry	(9)	(216)		
Total	88	2,112		

• Quarterly economic and financial information is interpolated into monthly observations and matched with Twitter data

## **Research Design (2)**

#### <u>Twitter Measures</u>

- Likefolio, <u>https://home.likefolio.com/</u>, provided customer interest and satisfaction for products and brands
  - Mapping of products and brands to the company
  - Customer Interest to Buy



TCI: total count of tweets related to the firm's product or brand past/future interest to buy

#### Customer Sentiment



Mahesh Chand @mcbeniwal · 26 Dec 2017 #Apple needs to be punished for make me **buy** #iPhoneX. My #iPhone 6 started acting badly.

TCS: ratio of positive tweets to total (positive and negative) tweets

#### **Research Design (3)**

#### **Analytical Models with and without Twitter information**

$$\begin{aligned} Sales_{it} &= \beta_0 + \beta_1 Sales_{it-1} + \beta_2 TCS_{it} \\ Sales_{it} &= \beta_0 + \beta_1 Sales_{it-1} + \beta_2 GDP_{t-1} + \beta_3 TCS_{it} \\ Sales_{it} &= \beta_0 + \beta_1 Sales_{it-1} + \beta_2 AR_{it} + \beta_3 TCS_{it} \\ Sales_{it} &= \beta_0 + \beta_1 Sales_{it-1} + \beta_2 AR_{it} + \beta_3 GDP_{t-1} + \beta_4 TCS_{it} \end{aligned}$$

### Results (1)

#### RQ 1A & RQ 1B: Prediction Performance – 24 industries

Model	Lagged Sales + Lagged GDP + Twitter Consumer Interest	Lagged Sales + AR + Lagged GDP + Twitter Consumer Interest	Lagged Sales + Lagged GDP + Twitter Consumer Satisfaction	Lagged Sales + AR + Lagged GDP + Twitter Consumer Satisfaction
Traditional -	16 of 24	14 of 24	14 of 24	15 of 24
SAP	industries	industries	industries	industries
Continuous -	21 of 24	22 of 24	20 of 24	22 of 24
SAP	industries	industries	industries	industries

#### **Results (2)**

#### RQ 2A & RQ 2B: Error Detection Performance Cost Ratio -

#### 24 industries

Model	Lagged Sales GDP + <b>Twitter</b> Intere	Consumer	Lagged Sales + + Twitter C Satisfa	onsumer
Cost Ratio	1:1	1:2	1:1	1:2
Traditional - SAP	12 of 24 industries	12 of 24 industries	12 of 24 industries	12 of 24 industries
Continuous - SAP13 of 24 industries13 of 24 industries13 of 24 industries		13 of 24 13 of 24		13 of 24 industries

### **Results (3)**

#### The More Effective model:

Continuous - SAP	Lagged Sales + Lagged GDP + <b>Twitter Consumer</b> Interest	Lagged Sales + Lagged GDP + <b>Twitter Consumer</b> Satisfaction
Prediction	21 of 24	20 of 24
Performance	industries	industries
Error Detection	13 of 24	13 of 24
Performance	industries	industries

#### **Interesting finding:**

More effective model outperforms model with Advertising Expense

## Contributions

- Investigates the incremental contribution of social media information that is generated by third-parties to auditing
  - Prediction performance
  - Error detection performance

# **Limitations and Future Research**

- Monthly observations are estimated from quarterly information
- Only one source of Internet information is examined

# Essay Two

# Redesigning the Audit Process: Towards Robotic Audit Process Automation

"We are going through the process where software will automate software, automation will automate automation"

Mark Cuban

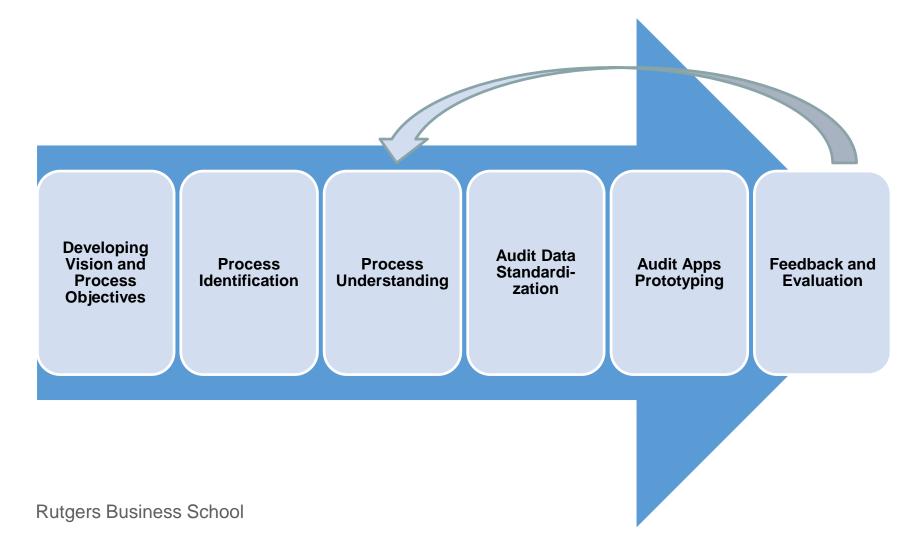
#### **Objectives**

- How can auditors redesign the audit process with RPA to achieve a systematic audit approach that could lead to enhanced audit quality?
- Propose a framework for redesigning the audit process using RPA
  - RPA for Audit
  - Process Redesign
- Validate feasibility of the framework by applying it to the loan testing audit sub-process of a public accounting firm

#### Motivation

- Technology-based audit techniques reflect the direct automation of manual audit tasks (e.g. Vasarhelyi and Halper 1991; Alles et al. 2006; Issa and Kogan 2014)
- Audit automation is not a new concept (e.g. Vasarhelyi 1984; Groomer and Murthy 1989), but the rethinking of the audit process to formalize it remains underexplored
- Public accounting firms are starting explore RPA (e.g. Cooper et al. 2018; Moffit et al. 2018; Huang 2018)

#### RAPA (Robotic Audit Process Automation) Framework



#### **Application of RAPA Framework (1)**

#### **Developing Vision and Process Objectives**

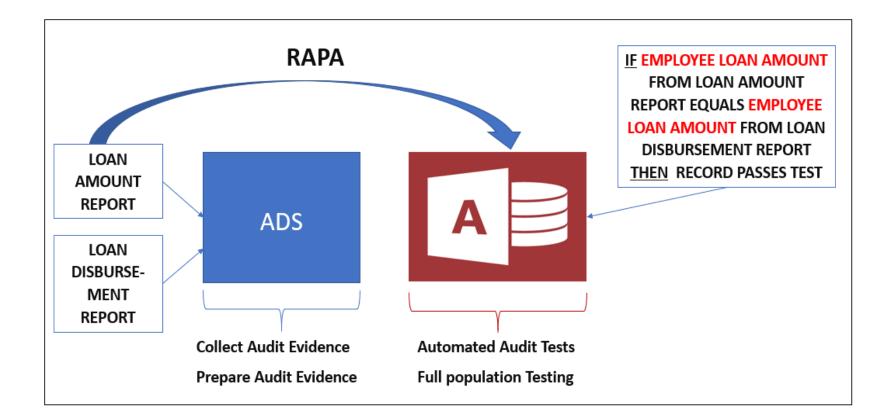
Apply a holistic approach to automation in audit:

- 1) Reduce the time spent
- 2) Improve audit effectiveness
- 3) Repurpose the work of auditors

#### **Process Identification**

Loan testing audit sub-process (part of EBP audit) consisted of repetitive, time consuming, and rules-based audit procedures

#### Application of RAPA Framework – Process Understanding and ADS (2)



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#### Application of RAPA Framework – Audit Apps (3)

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### Application of RAPA Framework – Feedback and Evaluation (4)

- Efficiency: RAPA spends 51 seconds executing tasks
  - Less time and scalable
- Effectiveness: Seeded errors were detected
  - More precise measure of RoMM and timelier detection on more audit engagements
  - Overall effectiveness: spend more time on riskier areas

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### Contributions

- Explores the potential for an audit production line with RPA
  - Proposing a framework for RAPA
  - Applying the framework to an audit sub-process

# **Limitations and Future Research**

- Framework was applied to a small audit sub-process
- Preliminary assessments were made for efficiency and effectiveness

# **Essay Three**

# Reengineering the Audit with Blockchain and Smart Contracts

Voter registration is

being facilitated via

a blockchain project

in Switzerland

spearheaded by

being used by

nsurer American

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endangered species

is being facilitated

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IBM is using the

Hyperledger Fabric

blockchain in China

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Microsoft Azure

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### Why blockchain for auditing?

Lower risk of management override than in an ERP system, no 'super user" role in blockchain and it is difficult to alter records using it for gain (Ibrahim 2017; Glaser 2017; Olsen et al. 2019) RAILWAYS

equation have strength Secure platform for third party monitoring, "guard the guards", and enhance trust in the capital markets (Alles et al. 2004)

Mitigate the risk of manipulation of audit workpapers

by Alphabet Inc. Proactive inspection process to detect deficiencies near real-time

fairer way to reward Optimize the use of blockchain for auditing given its increasing adoption

DIAMONDS	SUPPLY CHAINS
The De Beers Group	BM and Walmart have
is using blockchain	partnered in China to
to track the	create a blockchain
importation and	project that will
sale of diamonds.	monitor food safety.

offset trading.	🔆 нітелько
ENTERPRISE	0
Ethereunis blockchain can be accessed as a	•
cloud-based service courtesy of Microsoft Azure	Azun









TAXATION in China, a tax-hase

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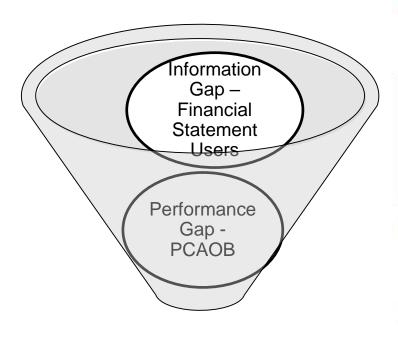
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arbit

blockchain to store

#### **Objectives**

- How can auditors leverage blockchain and smart contracts as audit data analytic tools to enhance audit quality?
- Map the characteristics of blockchain that can enhance audit evidence to PCAOB requirements
- Propose an external audit blockchain supported by a variety of smart audit procedures
- Propose novel functions for the PCAOB and a holistic audit framework
- Discuss the issues related to the application of these technologies
   Rutgers Business School



#### **Motivation**

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'Big Four' Giant Deloitte Completes Successful Blockchain Audit



Advertiseser: Set exclusive analysis and applocaments imagins on histoleaform for just 235 set month.

Multinational services firm and one of the so-called "Big Four" accounting firms De pitte has announced the completion of its latest blockchain endeavor. The firm scrutinized permissioned blockchain protocols and applications with professional aud ting standards.

The aim of the project, Defoitte see, was to "enhance the utility and trust of a permissioned blockchain system" by putting it through both professional audit and assurance standards.

#### PwC Has an Answer for the Blockchain: Audit It

Accounting firm unveils new service for clients' use of blockchain



Priorwite/houseCorpers LLP anys its new accurs will facilitate and encourage comparise' use of the Modelstam a still care technology flat faces a host of obstacles to adoption. PHOTO: MATT CARDY/NETT PMAGE3.

By Michael Rapoport Update Work 15, 2018 COS are D' <u>18</u> COHMENTS

If blockchain technology can validate transactions the way an auditor traditionally does, what's left for an auditor to do?

PricewaterhouseCoopers LLP's answer: Validate the validators.

**Expectations** gap

#### Increasing adoption of blockchain

Rutgers Business School Rutgers Business School Blockchain and smart contracts to narrow gap

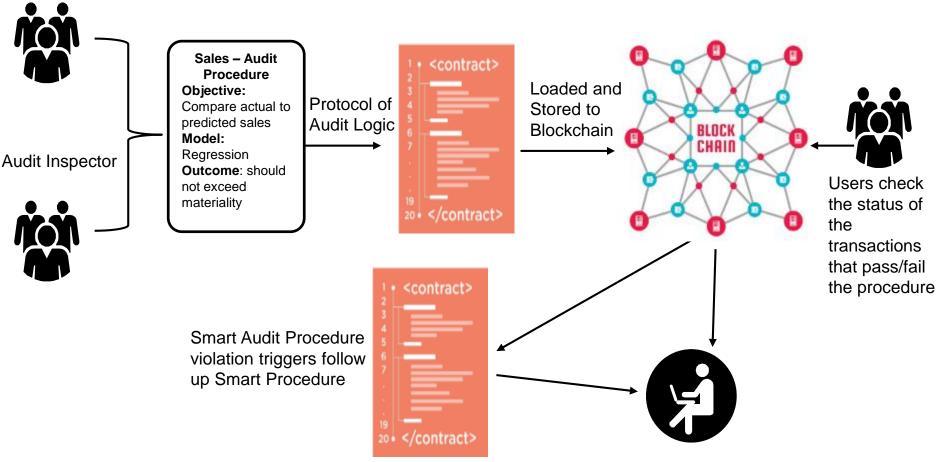
# Blockchain can Improve the Reliability of Internal and External Audit Evidence

 Requirements of audit evidence: sufficiency, relevance and reliability (PCAOB AS 1105 2010)

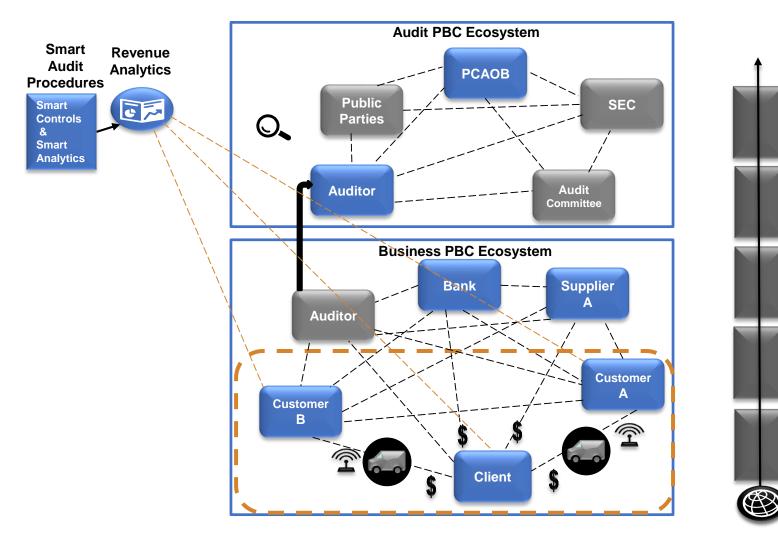
Challenges of Gathering Audit Evidence	Blockchain Attributes	Blockchain Benefits
Traceable origins of sources (veracity)	Decentralization Immutability Accountability	Data Integrity to improve the <b>reliability</b> of audit evidence
Disaggregated data sources (variety)	Decentralization	One distributed depository for financial and nonfinancial data to improve the accuracy and timeliness of audit procedures and obtain a deeper understanding of the client

#### Blockchain Audit Evidence and Smart Audit Procedures can Improve Audit Quality and Reporting

Audit Firm



#### **Interlinked Blockchain Ecosystems**



#### **Evolving the role of the PCAOB**

- The PCAOB oversees audit firms to ensure audits are conducted in accordance with GAAS
  - Seeks to improve their inspection process
  - Expected to enhance efficiency by relying on technology
- New role for PCAOB as an active node on the audit blockchain to validate smart audit procedures and review their results
- Issues such as the performance of inadequate audit procedures can be mitigated

### **Holistic Audit Approach for Revenue**

Risk	Assertions	Risk Assessment	Substan	itive Analytics	Tests of Controls	On BC?
Fictitious or erroneous revenue	Occurrence	Cognitive analytics is used to read a	and analyze terms of p	odf legal contracts, such as an	nount, approvals, contracting parties	No
transactions are entered into the system		Rules-based system is configured to automatically match the terms of legal contracts to the terms in legal smart contracts N				
System		Smart Control is configured to auto of current audit period	matically match legal	smart contract code from pre	evious audit period to legal smart contract code	Yes
		Smart Analytic is configured to prec revenue, locational, and temperatu			Smart Control is configured to automatically match location and temperature of goods that are being delivered to expected location and temperature of goods	Yes
		Smart Control is configured to auto	matically match rever	nue, invoice, and shipment ar	nount from the client's blockchain	Yes
		Not applicable		Not applicable	Smart Control is configured to automatically match the access level of customer node	Yes
		Not applicable		Not applicable	Smart Control is configured to automatically match customer name per legal smart contract to customer name on active digital wallets	Yes
Revenue Cut-off transactions are not		Not necessary, the record of the tra	ansaction and transact	tion event itself are triggered	at the same time	Yes
recorded in the correct period		Although not necessary to verify <b>cut-off</b> on BC, the following procedure, which is used to verify occurrence, can serve as a secondary test to verify the cut-off assertion:				
		Smart Control is configured to auto	matically match sales	order, sales invoice, and ship	ment amount from the client's blockchain	
Revenue is not recorded	Complete- ness	Not necessary, reconciliations occu	r as transactions are v	validated and then posted		Yes
		Although not necessary to verify co secondary test to verify the comple		e following procedure, which	is used to verify occurrence, can serve as a	Yes
		Smart Control is configured to auto	matically match sales	order, sales invoice, and ship	ment amount from the client's blockchain	
Revenue returns are not recognized	Occurrence	Inspect and evaluate revenue retur	n estimates			No

#### **Issues and Future Research**

Limitation	Future Research
Computational power	Why do users of private and permissioned blockchains opt out of using centralized databases?
Storage capabilities	Which methods can meet the demand to store big data on the blockchain?
Cybersecurity risk	How to design and implement a continuous monitoring system to reduce the risk of collusion on the blockchain network?
Litigation risk	How much transparency should be provided to financial statement users while maintaining an acceptable level of audit litigation risk?
Vulnerability of smart contracts	What are the quality processes that public accounting firms should have in place to ensure smart audit procedures are free of error?
Regulatory acceptance	How will the oversight model of financial statement audits be disrupted?
Economics	Would blockchain and smart contracts be developed in- house, or would it be outsourced?

## Contributions

- Explores the evolution of auditing in light of blockchain of smart contracts by:
  - Proposing an external audit blockchain supported by smart audit procedures
  - Discussing the issues related to the application of these technologies

# **Limitations and Future Research**

- Existing audit risks were considered, new audit risks may emerge
- Described purpose, usefulness, and challenges of the external audit blockchain

# Conclusion

#### Contributions

- Provides insights into the impact of technological innovations on auditing
- Explores the use of social media information and disruptive technologies to evolve auditing
- Describes the potential for such innovations to improve audit efficiency and effectiveness

#### Limitations and Future Research Directions

- Parallel comparison of proposed audit tools to traditional audit tools is not conducted
- Impact of these tools on audit judgment is not examined

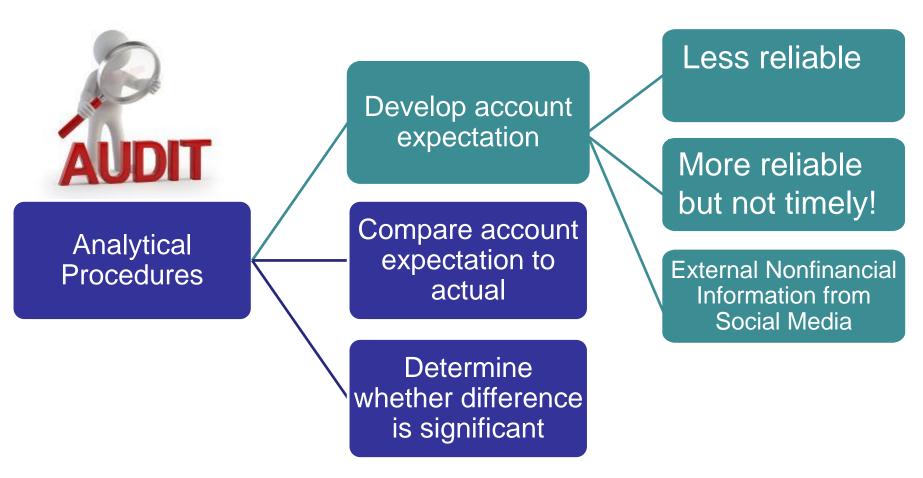
#### "For audit, innovation will drive quality"

KPMG Audit Partner Roger O'Donnell

# **THANK YOU!**

# **THANK YOU!**

### Introduction



**PCAOB AS 2110** 

### Prior Literature (1)

#### **Informativeness of Nonfinancial Information from the Internet**

- Google search queries related to influenza nowcasts influenza outbreaks 1 to 2 weeks before the CDC (Ginsberg et al. 2009)
- Da et al. (2011) demonstrate that the increase in google search queries of a firm's most popular product is a strong predictor of positive revenue surprises
- Tang (2017) investigates the predictive power of Twitter information generated by consumers and finds that it is predictive of future sales

### **Research Design (4)**

#### Model Comparison

- MAPE (Mean Absolute Percentage Error) is used to evaluate prediction performance of each model
- False positive and false negative error percentages are used to evaluate the **error detection performance** of each model
  - Seed errors into the dependent variable
  - Estimate prediction intervals
  - Apply statistical investigation rule
  - Procedure is repeated 10 times to reduce bias

### Results (1)

#### RQ 1A & RQ 1B: Prediction Performance – 24 industries

	Twit	ter Cons	umer Inte	rest	Twitter	Consun	ner Satis	faction
Model	(1) vs. (5)	(2) vs. (7)	(3) vs. (9)	(4) vs. (11)	(1) vs. (6)	(2) vs. (8)	(3) vs. (10)	(4) vs. (12)
Traditi onal - SAP	16 of 24	16 of 24	16 of 24	14 of 24	15 of 24	14 of 24	12 of 24	15 of 24
Contin uous - SAP	19 of 24	21 of 24	18 of 24	22 of 24	14 of 24	20 of 24	14 of 24	22 of 24

#### RQ 1B: Prediction Performance of Continuous Substantive Analytical Models with TCI and without TCI (Models 5, 7, 9 and 11 and 1, 2, 3, and 4)

Salets:			(11)	(4)			(9)	(3)			(7)	(2)			(5)	(1)	
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Image: Problem         Image:				1+AR+G			1+AR+T				+TweetC				1+TweetC	Saletst-1	
SIC         MAPE1         MAPE5         Difference         B/W         P-value         MAPE3         MAPE3         MAPE3         MAPE4         MAPE1         Difference         B/W           20         0.1015         0.0921         0.0094 B         0.000         0.0855         0.0310 B         0.000         0.083         0.078         0.0056         0.001 B         0.017         0.040         0.039 B           21         0.0577         0.0565         0.0012 B         0.001         0.0576         0.0058         0.001 B         0.001         0.044         0.019         0.044         0.019         0.044         0.019         0.044         0.019         0.044         0.019         0.044         0.019         0.044         0.019         0.044         0.019         0.044         0.019         0.044         0.019         0.044         0.019         0.044         0.019         0.045         0.046         0.001 W         0.035         0.022         0.013 B         0.041         0.035         0.022         0.013 B         0.011         0.046         0.001 W         0.035         0.022         0.013 B         0.016         0.015         0.016         0.017         0.044         0.030         0.017         0.045         <			tCI+GDPt-	DPt-1			weetCI	I+AR			+GDPt-1	I+GDPt-I			I		
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20         0.1015         0.0921         0.0094 B         0.000         0.0855         0.0310 B         0.000         0.083         0.078         0.005 B         0.000         0.079         0.040         0.039 B           21         0.0577         0.0565         0.0012 B         0.001         0.0492         0.019         0.0222 B         0.001         0.056         0.001 B         0.001         0.0447         0.019         0.028 B           23         0.1439         0.1370         0.0069 B         0.000         0.0479         0.0446 B         0.046         0.001         0.0447         0.019         0.0455         0.046 B           28         0.0735         0.0733         0.0005 B         0.024         0.0547         0.034         0.0825         0.1403         -0.0578 W         0.000         0.055         0.055         0.055         0.055         0.055         0.055         0.055         0.055         0.056         0.001         0.035         0.022         0.013 B         0.040         0.035         0.022         0.016 B           29         0.0573         0.0005 B         0.034         0.1111         0.0137         0.024 B         0.000         0.025         0.035         0.025         0.0266	p-value	Vifforman D/W	MADE11 F		n voluo	Difference D/W	MADEO	MADE2	n voluo	Sifference D/W		MADE2 N	n valua	Difference D/W	MADES		0
21       0.0577       0.0565       0.0012 B       0.001       0.0492       0.019       0.0292 B       0.001       0.058       0.056       0.001 B       0.001       0.047       0.019       0.028 B         23       0.1439       0.1370       0.0069 B       0.001       0.057       0.0695 B       0.000       0.015 B       0.001       0.045       0.046       0.001 W       0.045       0.046       0.001 W       0.046       0.001 W       0.046       0.001 W       0.043       0.046       0.000 W       0.055       0.058       0.003 W       0.000 O       0.055       0.058       0.001 W       0.001 W       0.001 W       0.001 W       0.001 W       0.010 W       0.010 W       0.010 W       0.010 W       0.010 W       0.010 V       0.010 V<	<u>p-value</u> 0.000				1				1				1				-
23       0.1439       0.1370       0.0069 B       0.000       0.1271       0.0576       0.0695 B       0.000       0.015 B       0.000       0.091       0.045       0.046 B         28       0.0735       0.0733       0.0001 B       0.224       0.0577       0.0346       0.0200 B       0.000       0.045       0.046       -0.011 W       0.043       0.046       0.030       0.016 B         29       0.0578       0.0073       0.0005 B       0.034       0.0211       0.0178 W       0.000       0.055       0.003 W       0.000       0.035       0.022       0.013 B         31       0.1686       0.1680       0.0005 B       0.034       0.211       0.0177       0.057 B       0.000       0.072       -0.002 W       0.000       0.066       0.043       0.022 B       0.137       0.104       0.039       0.065 B         35       0.1120       0.0955       0.0064 B       0.000       0.1057       0.493       0.0564 B       0.000       0.072       -0.002 W       0.000       0.066       0.433       0.022 B       0.137       0.104       0.039       0.65 B         36       0.1020       0.0955       0.0064 B       0.000       0.311       0.075	0.000																
28       0.0735       0.0733       0.0001 B       0.224       0.0547       0.0346       0.020 B       0.000       0.045       0.046       -0.01 W       0.043       0.046       0.030       0.016 B         29       0.0578       0.0573       0.0005 B       0.034       0.0825       0.1403       -0.0578 W       0.000       0.055       0.037       0.000 B       0.001       0.035       0.022       0.013 B         31       0.1686       0.1681       0.0005 B       0.034       0.1211       0.0137 B       0.000       0.128       0.124       0.003 B       0.044       0.010       0.035       0.022       0.013 B         35       0.1193       0.1105       0.0088 B       0.000       0.1057       0.0493       0.0545 B       0.000       0.007       0.072       -0.002 W       0.006       0.043       0.022 B         36       0.1120       0.0054 B       0.000       0.1097       0.0493       0.071 B       0.017       0.040 B       0.071       0.009 B       0.033       0.021 B       0.037       0.014 B       0.033       0.021 B       0.037       0.014 B       0.033       0.020 B       0.001 B       0.031 B       0.031 B       0.031 B       0.031 B       <	0.001																
29       0.0578       0.0573       0.0005 B       0.034       0.0825       0.1403       -0.0578 W       0.000       0.055       0.038 W       0.000 B       0.001       0.035       0.022       0.013 B         31       0.1686       0.1681       0.0005 B       0.034       0.1411       0.0816       0.0955 B       0.000       0.128       0.124       0.003 B       0.034       0.107       0.064       0.042 B         35       0.1193       0.1105       0.0064 B       0.000       0.157       0.0493       0.0564 B       0.000       0.070       0.072       -0.002 W       0.000       0.066       0.043       0.022 B         36       0.1020       0.0955       0.0064 B       0.000       0.0705 B       0.000       0.095       0.094       0.02 B       0.137       0.104       0.039       0.065 B         37       0.1122       0.101B       0.254       0.0870 0.088 0       0.071 B       0.137       0.106       0.01 B       0.244       0.009 B       0.0378       0.000       0.213       0.209       0.004 B       0.077       0.180       0.075       0.105 B         39       0.3305       0.3007       0.298 B       0.000       0.0560       0.0182 </td <td>0.000</td> <td></td>	0.000																
30       0.0498       0.0508       -0.0010 W       0.0349       0.0211       0.0137 B       0.001       0.037       0.007       0.007       0.004 B       0.001       0.035       0.022       0.013 B         31       0.1686       0.1681       0.0005 B       0.034       0.1411       0.0816       0.0595 B       0.000       0.128       0.124       0.003 B       0.034       0.107       0.064       0.042 B         35       0.1193       0.1105       0.0088 B       0.000       0.1057       0.0493       0.0564 B       0.000       0.072       -0.002 W       0.000       0.066       0.043       0.022 B         36       0.1020       0.955       0.0064 B       0.000       0.0385       0.070 B       0.000       0.095       0.094       0.002 B       0.137       0.104       0.039       0.055 B         37       0.1122       0.1121       0.0010 B       0.254       0.0879       0.0808       0.071 B       0.137       0.106       0.105       0.001 B       0.841       0.080       0.071 O.099 B       0.305       0.203 B       0.001       0.055 O       0.144       0.016 B       0.001       0.53 O.020 O.033 B       0.001       0.056 O       0.018 O.137 B       0.0																	
31       0.1686       0.1681       0.0005 B       0.034       0.1411       0.0816       0.0595 B       0.000       0.128       0.124       0.003 B       0.034       0.107       0.064       0.042 B         35       0.1193       0.1105       0.0088 B       0.000       0.1057       0.0493       0.0564 B       0.000       0.070       0.072       -0.002 W       0.000       0.066       0.043       0.022 B         36       0.1020       0.0955       0.0064 B       0.000       0.1090       0.385       0.070 B       0.001       0.095       0.094       0.002 B       0.137       0.104       0.039       0.065 B         37       0.1122       0.1121       0.0001 B       0.254       0.0879       0.088       0.001       0.137       0.106       0.105       0.001 B       0.841       0.080       0.071       0.009 B         39       0.3305       0.3007       0.0298 B       0.000       0.3141       0.0723       0.2688 B       0.000       0.114       0.016 B       0.017       0.180       0.075       0.105 B         42       0.0745       0.0447       0.003 B       0.0101 B       0.037 B       0.0101 B       0.000       0.155       0.144	0.000																
35       0.1193       0.1105       0.0088 B       0.000       0.0157       0.0493       0.0564 B       0.000       0.072       -0.002 W       0.000       0.066       0.043       0.022 B         36       0.1020       0.0955       0.0064 B       0.000       0.0385       0.0705 B       0.000       0.095       0.094       0.002 B       0.137       0.104       0.039       0.065 B         37       0.1122       0.1121       0.0001 B       0.254       0.0879       0.0808       0.0071 B       0.137       0.106       0.105       0.001 B       0.841       0.080       0.071       0.009 B         39       0.3305       0.3007       0.0298 B       0.000       0.3411       0.0723       0.2688 B       0.000       0.213       0.209       0.004 B       0.077       0.180       0.075       0.105 B         42       0.0754       0.0415       0.0339 B       0.001       0.0560       0.182       0.0378 B       0.001       0.062       0.008 B       0.000       0.152       0.118       0.134 B         45       0.0745       0.0647       0.098 B       0.001       0.1318       0.0404       0.0914 B       0.001       0.126       0.002 B       0.001	0.001																
36       0.1020       0.0955       0.0064 B       0.009       0.0385       0.0705 B       0.000       0.095       0.094       0.002 B       0.137       0.104       0.039       0.065 B         37       0.1122       0.1121       0.0001 B       0.254       0.0879       0.0808       0.0071 B       0.137       0.106       0.105       0.001 B       0.841       0.080       0.071       0.009 B         39       0.3305       0.3007       0.0298 B       0.000       0.3411       0.0723       0.2688 B       0.000       0.213       0.209       0.004 B       0.077       0.180       0.075       0.105 B         42       0.0754       0.0415       0.033 B       0.034       0.1525       0.0184       0.134 B       0.000       0.155       0.144       0.011 B       0.000       0.152       0.018       0.134 B         44       0.1499       0.1396       0.0013 B       0.034       0.1525       0.0184       0.134 B       0.000       0.070       0.062       0.008 B       0.000       0.062       0.044       0.016 B         45       0.0745       0.0647       0.0098 B       0.000       0.0301       0.0200       0.0101 B       0.001       0.128	0.000																
370.11220.11210.0001 B0.2540.08790.08080.0071 B0.1370.1060.1050.001 B0.8410.0800.0710.009 B390.33050.30070.0298 B0.0000.34110.07230.2688 B0.0000.2130.2090.004 B0.0770.1800.0750.105 B420.07540.04150.0339 B0.0010.05600.01820.0378 B0.0010.0600.0440.016 B0.0010.0530.0200.033 B440.14990.13960.0103 B0.0340.15250.01840.1341 B0.0000.1550.1440.011 B0.0000.1520.0180.134 B450.07450.06470.0098 B0.0000.06460.05400.016 B0.0000.0700.0620.008 B0.0000.0620.0450.016 B470.17530.12940.0459 B0.0010.13180.04040.0914 B0.0010.1280.1260.002 B0.0010.1250.0400.084 B480.03050.02880.0018 B0.0010.18010.04180.1383 B0.0010.1900.1250.065 B0.0010.1810.0430.138 B550.10880.09780.0110 B0.0340.0240.0630.0550.031 B0.028 B0.0000.0550.0390.016 B570.12660.10420.163 B0.0340.02550.04160.139 B </td <td>0.000</td> <td></td>	0.000																
390.33050.30070.0298 B0.0000.34110.07230.2688 B0.0000.2130.2090.004 B0.0770.1800.0750.105 B420.07540.04150.0339 B0.0010.05600.01820.0378 B0.0010.0600.0440.016 B0.0010.0530.0200.033 B440.14990.13960.0103 B0.0340.15250.01840.1341 B0.0000.1550.1440.011 B0.0000.1520.0180.134 B450.07450.06470.0098 B0.0000.06460.05400.0106 B0.0000.0700.0620.008 B0.0000.0620.04450.016 B470.17530.12940.0459 B0.0010.13180.04040.0914 B0.0010.1280.1260.002 B0.0010.1250.0400.084 B480.03050.02880.0018 B0.0010.18010.04180.1383 B0.0010.1900.1250.065 B0.0010.1810.0430.138 B550.10880.09780.0110 B0.0340.0230.02730.0313 B0.0040.0930.0760.017 B0.0000.0680.038 B570.12060.10420.0163 B0.0340.02550.04160.139 B0.0000.0630.0580.005 B0.0000.0550.038 B580.6670.6690.0017 B0.0000.24510.07400.1710	0.000																
42       0.0754       0.0415       0.0339 B       0.001       0.0560       0.0182       0.0378 B       0.001       0.060       0.044       0.016 B       0.001       0.053       0.020       0.033 B         44       0.1499       0.1396       0.0103 B       0.034       0.1525       0.0184       0.1341 B       0.000       0.155       0.144       0.011 B       0.000       0.152       0.018       0.134 B         45       0.0745       0.0647       0.0098 B       0.000       0.0646       0.0540       0.0106 B       0.000       0.070       0.062       0.008 B       0.000       0.062       0.0445       0.016 B         47       0.1753       0.1294       0.0459 B       0.001       0.1318       0.0404       0.0914 B       0.001       0.128       0.126       0.002 B       0.001       0.125       0.040       0.084 B         48       0.0305       0.288       0.0018 B       0.001       0.1801       0.0418       0.1383 B       0.001       0.125       0.065 B       0.001       0.181       0.043       0.138 B         53       0.1947       0.1184       0.0764 B       0.031       0.0200       0.017 B       0.000       0.0659       0.011 B <td>0.841</td> <td></td>	0.841																
44       0.1499       0.1396       0.0103 B       0.034       0.1525       0.0184       0.1341 B       0.000       0.155       0.144       0.011 B       0.000       0.152       0.018       0.134 B         45       0.0745       0.0647       0.0098 B       0.000       0.0646       0.0540       0.0106 B       0.000       0.070       0.062       0.008 B       0.000       0.062       0.045       0.016 B         47       0.1753       0.1294       0.0459 B       0.001       0.1318       0.0404       0.0914 B       0.001       0.128       0.126       0.002 B       0.001       0.125       0.040       0.084 B         48       0.0305       0.0288       0.0018 B       0.000       0.0200       0.0101 B       0.000       0.030       0.029       0.002 B       0.001       0.181       0.043       0.138 B         53       0.1947       0.1184       0.0764 B       0.001       0.1801       0.0418       0.1383 B       0.001       0.190       0.125       0.065 B       0.001       0.181       0.043       0.138 B         55       0.1088       0.0978       0.0110 B       0.034       0.0273       0.0313 B       0.034       0.102       0.103	0.000																
450.07450.06470.0098 B0.0000.06460.05400.016 B0.0000.0700.0620.008 B0.0000.0620.0450.016 B470.17530.12940.0459 B0.0010.13180.04040.0914 B0.0010.1280.1260.002 B0.0010.1250.0400.084 B480.03050.02880.0018 B0.0000.03010.02000.0101 B0.0000.0300.0290.002 B0.0010.11810.0430.138 B530.19470.11840.0764 B0.0010.18010.04180.1383 B0.0010.1900.1250.065 B0.0010.1810.0430.138 B550.10880.09780.0110 B0.0340.12120.03360.0875 B0.0000.0930.0760.017 B0.0000.0690.0410.028 B570.12060.10420.0163 B0.0340.02550.04160.0139 B0.0000.0630.0580.005 B0.0000.0550.0390.016 B580.06870.06690.0017 B0.0000.24510.07400.1710 B0.0770.2530.2510.002 B0.0000.2430.0630.180 B590.25460.25150.0031 B0.0000.04980.639-0.0141 W0.0340.0530.0520.001 B0.0340.0490.0450.004 B700.05300.0543-0.013 W0.0000.0498	0.001																
47       0.1753       0.1294       0.0459 B       0.001       0.1318       0.0040       0.0914 B       0.001       0.128       0.126       0.002 B       0.001       0.125       0.040       0.084 B         48       0.0305       0.0288       0.0018 B       0.000       0.0301       0.0200       0.0101 B       0.000       0.030       0.029       0.002 B       0.000       0.030       0.020       0.010 B         53       0.1947       0.1184       0.0764 B       0.001       0.1801       0.0418       0.1383 B       0.001       0.125       0.065 B       0.001       0.181       0.043       0.138 B         55       0.1088       0.0978       0.0110 B       0.034       0.1212       0.0336       0.0875 B       0.000       0.093       0.076       0.017 B       0.000       0.028 B       0.038 B         57       0.126       0.1042       0.0163 B       0.034       0.0255       0.0416       0.0139 B       0.000       0.063       0.058       0.001 W       0.034       0.106       0.068       0.038 B         58       0.0669       0.017 B       0.000       0.2451       0.0740       0.1710 B       0.077       0.253       0.251       0.001 B <td>0.000</td> <td></td>	0.000																
48       0.0305       0.0288       0.0018 B       0.000       0.0301       0.0200       0.011 B       0.000       0.030       0.029       0.002 B       0.000       0.030       0.020       0.010 B         53       0.1947       0.1184       0.0764 B       0.001       0.1801       0.0418       0.1383 B       0.001       0.190       0.125       0.065 B       0.001       0.181       0.043 B       0.138 B         55       0.1088       0.0978       0.0110 B       0.034       0.1212       0.0336       0.0875 B       0.000       0.093       0.076       0.017 B       0.000       0.069       0.041       0.028 B         57       0.1206       0.1042       0.0163 B       0.034       0.0255       0.0416       0.0139 B       0.000       0.063       0.058       0.001 W       0.034       0.106       0.068       0.038 B         58       0.0687       0.0669       0.0017 B       0.000       0.2451       0.0740       0.1710 B       0.077       0.253       0.251       0.000       0.243       0.063       0.182       0.002 B       0.004       0.243       0.063       0.184       0.053       0.052       0.01 B       0.004 B       0.043       0.1710 B	0.000																
53       0.1947       0.1184       0.0764 B       0.001       0.1801       0.0418       0.1383 B       0.001       0.190       0.125       0.065 B       0.001       0.181       0.043       0.138 B         55       0.1088       0.0978       0.0110 B       0.034       0.1212       0.0336       0.0875 B       0.000       0.093       0.076       0.017 B       0.000       0.069       0.041       0.028 B         57       0.1206       0.1042       0.0163 B       0.034       0.0673       0.0313 B       0.034       0.102       0.103       -0.001 W       0.034       0.106       0.068       0.038 B         58       0.0687       0.0669       0.0017 B       0.000       0.0555       0.0416       0.0139 B       0.000       0.063       0.058       0.005 B       0.000       0.055       0.016 B         59       0.2546       0.2515       0.0031 B       0.000       0.2451       0.0740       0.1710 B       0.077       0.253       0.251       0.000       0.243       0.063       0.184       0.048       0.180 B         70       0.0530       0.0543       -0.013 W       0.000       0.0498       0.0639       -0.0141 W       0.034       0.053	0.001																
55       0.1088       0.0978       0.0110 B       0.034       0.1212       0.0336       0.0875 B       0.000       0.093       0.076       0.017 B       0.000       0.069       0.041       0.028 B         57       0.1206       0.1042       0.0163 B       0.034       0.0973       0.0313 B       0.034       0.102       0.103       -0.001 W       0.034       0.106       0.068       0.038 B         58       0.0687       0.0669       0.0017 B       0.000       0.0555       0.0416       0.0139 B       0.000       0.063       0.058       0.005 B       0.000       0.055       0.016 B         59       0.2546       0.2515       0.0031 B       0.000       0.2451       0.0740       0.1710 B       0.077       0.253       0.251       0.000       0.243       0.063       0.180 B         70       0.0530       0.0543       -0.013 W       0.000       0.0498       0.0639       -0.0141 W       0.034       0.053       0.052       0.001 B       0.049       0.045       0.004 B	0.000																48
57       0.1206       0.1042       0.0163 B       0.034       0.0986       0.0673       0.0313 B       0.034       0.102       0.103       -0.001 W       0.034       0.106       0.068       0.038 B         58       0.0687       0.0669       0.0017 B       0.000       0.0555       0.0416       0.0139 B       0.000       0.063       0.058       0.005 B       0.000       0.055       0.016 B         59       0.2546       0.2515       0.0031 B       0.000       0.2451       0.0740       0.1710 B       0.077       0.253       0.251       0.000       0.243       0.063       0.180 B         70       0.0530       0.0543       -0.013 W       0.000       0.0498       0.0639       -0.0141 W       0.034       0.053       0.052       0.001 B       0.049       0.045       0.004 B	0.001		0.043	0.181			0.125	0.190	0.001		0.0418						53
58       0.0687       0.0669       0.0017 B       0.000       0.0555       0.0416       0.0139 B       0.000       0.063       0.058       0.005 B       0.000       0.055       0.039       0.016 B         59       0.2546       0.2515       0.0031 B       0.000       0.2451       0.0740       0.1710 B       0.077       0.253       0.251       0.002 B       0.000       0.243       0.063       0.180 B         70       0.0530       0.0543       -0.013 W       0.000       0.0498       0.0639       -0.0141 W       0.034       0.052       0.001 B       0.049       0.045       0.004 B	0.000			0.069							0.0336						55
59         0.2546         0.2515         0.0031 B         0.000         0.2451         0.0740         0.1710 B         0.077         0.253         0.251         0.002 B         0.000         0.243         0.063         0.180 B           70         0.0530         0.0543         -0.0013 W         0.000         0.0498         0.0639         -0.0141 W         0.034         0.053         0.052         0.001 B         0.034         0.049         0.045         0.004 B	0.034	0.038 B	0.068	0.106	0.034	-0.001 W	0.103	0.102	0.034	0.0313 B	0.0673	0.0986	0.034	0.0163 B	0.1042	0.1206	57
70 0.0530 0.0543 -0.0013 W 0.000 0.0498 0.0639 -0.0141 W 0.034 0.053 0.052 0.001 B 0.034 0.049 0.045 0.004 B	0.000	0.016 B	0.039	0.055	0.000	0.005 B	0.058	0.063	0.000	0.0139 B	0.0416	0.0555	0.000	0.0017 B	0.0669	0.0687	58
	0.000	0.180 B	0.063	0.243	0.000	0.002 B	0.251	0.253	0.077	0.1710 B	0.0740	0.2451	0.000	0.0031 B	0.2515	0.2546	59
	0.034	0.004 B	0.045	0.049	0.034	0.001 B	0.052	0.053	0.034	-0.0141 W	0.0639	0.0498	0.000	-0.0013 W	0.0543	0.0530	70
/5 0.0049 0.0000 0.0049 D 0.457 0.0752 0.0500 0.0451 B 0.000 0.075 0.001 B 0.005 0.071 0.051 0.040 B	0.000	0.040 B	0.031	0.071	0.003	0.001 B	0.075	0.076	0.000	0.0431 B	0.0300	0.0732	0.437	0.0049 B	0.0800	0.0849	73
75 0.1525 0.0922 0.0602 B 0.001 0.1469 0.0143 0.1326 B 0.001 0.090 0.075 0.015 B 0.001 0.092 0.011 0.081 B	0.001	0.081 B	0.011	0.092	0.001	0.015 B	0.075	0.090	0.001	0.1326 B	0.0143	0.1469	0.001	0.0602 B	0.0922	0.1525	75

#### **TCI** outperforms benchmark for:

19 industries

21 industries

18 industries

22 industries

## RQ 1B: Prediction Performance of Continuous Substantive Analytical Models with TCS and without TCS (Models 6, 8, 10 and 12 and 1, 2, 3, and 4)

	(1)	(6)			(2)	(8)			(3)	(10)			(4)	(12)		
	Saletst-1	Saletst- 1+TweetC S			Saletst- 1+GDPt-1	Saletst- 1+TweetC S+GDPt-1			Saletst- 1+AR	Saletst- 1+AR+T weetCS			Saletst- 1+AR+G DPt-1	Saletst- 1+AR+T weetCS+ GDPt-1		
2-Digit																
SIC	MAPE1	MAPE6	Difference B/W	1			Difference B/W	p-value	MAPE3		Difference B/W	1			Difference B/W	p-value
	0.101			0.000	0.0855			0.000			0.0031 B	0.000	0.0792			0.000
	0.057			0.001	0.0492			0.00			-0.0008 W	0.001	0.0472			0.001
	0.143			0.000	0.1271	0.0577		0.000			0.0036 B	0.000	0.0908			0.000
	28 0.073			0.224	0.0547			0.000			0.0001 B	0.398	0.0459			0.000
	0.057			0.000	0.0825			0.000			-0.0006 W	0.000	0.0553			0.000
	30 0.049			0.001	0.0349			0.00			0.0002 B	0.001	0.0351			0.001
	0.168			0.000	0.1411	0.0842		0.000			0.0031 B	0.034			0.0440 B	0.000
3	85 0.119			0.000	0.1057			0.000			-0.0036 W	0.000	0.0655			0.000
	36 0.102			0.003	0.1090		0.0619 B	0.022			-0.0126 W	0.000	0.1036			0.000
	.112			0.254	0.0879			0.398			0.0086 B	0.000	0.0798			0.883
3	39 0.330			0.000	0.3411	0.0625		0.000			-0.0025 W	0.077	0.1797		0.1176 B	0.000
4	12 0.075			0.001	0.0560			0.00			0.0083 B	0.001	0.0532			0.001
4	14 0.149	9 0.1486		0.034	0.1525	0.0192	0.1332 B	0.000	0.1548	0.1517	0.0030 B	0.034	0.1523	0.0195	0.1328 B	0.000
4	45 0.074	5 0.0642	2 0.0103 B	0.000	0.0646	0.0528	0.0118 B	0.000	0.0697	0.0627	0.0070 B	0.000	0.0616	0.0466	0.0149 B	0.000
2	0.175	3 0.1597	0.0156 B	0.001	0.1318	0.0439	0.0879 B	0.001	0.1278	0.1323	-0.0045 W	0.001	0.1249	0.0436	0.0813 B	0.001
4	48 0.030	5 0.0337	-0.0032 W	0.000	0.0301	0.0236	0.0065 B	0.000	0.0304	0.0306	-0.0002 W	0.034	0.0299	0.0237	0.0062 B	0.000
5	53 0.194	0.1740	0.0207 B	0.001	0.1801	0.0402	0.1399 B	0.001	0.1899	0.1523	0.0375 B	0.001	0.1810	0.0399	0.1411 B	0.001
4	55 0.108	8 0.1019	0.0070 B	0.000	0.1212	0.0333	0.0879 B	0.000	0.0931	0.0844	0.0087 B	0.034	0.0692	0.0375	0.0317 B	0.000
-	57 0.120	6 0.1025	5 0.0181 B	0.034	0.0986	0.0612	0.0374 B	0.034	4 0.1020	0.0988	0.0031 B	0.034	0.1063	0.0605	0.0458 B	0.034
5	58 0.068	0.0587	7 0.0100 B	0.000	0.0555	0.0410	0.0145 B	0.000	0.0626	6 0.0565	0.0062 B	0.000	0.0550	0.0395	0.0155 B	0.000
5	59 0.25 <sup>4</sup>	6 0.2558	3 -0.0012 W	0.077	0.2451	0.0691	0.1760 B	0.599	9 0.2532	0.2543	-0.0011 W	0.077	0.2430	0.0627	0.1803 B	0.000
7	0 0.053	0 0.0657	-0.0127 W	0.000	0.0498	0.0565	-0.0067 W	0.034	4 0.0532	2 0.0530	0.0003 B	0.034	0.0491	0.0455	0.0036 B	0.034
7	0.084	9 0.0822	2 0.0027 B	0.065	0.0732	0.0305	0.0427 B	0.000	0.0762	0.0755	0.0007 B	0.054	0.0714	0.0328	0.0387 B	0.000
7	0.152	5 0.1528	3 -0.0004 W	0.001	0.1469	0.0163	0.1306 B	0.00	1 0.0901	0.1006	-0.0105 W	0.001	0.0919	0.0146	0.0773 B	0.001

#### **TCS** outperforms benchmark for:

14 industries

18 industries

22 industries

#### RQ 2B: Error Detection Performance of Continuous Substantive Analytical Models with TCI and without TCI (Models 5 and 1)

#### TCI outperforms benchmark for:

Error Detection Ability - Alpha = 0.33(1)(5)Benchmark - CI Benchmark - Salest-1 Twitter - CI (1:1)(1:2)(1:1)(1:2)Number of Better Better Benchmark Benchmark Better Difference - Difference Better Model Model -2-Digit SIC Observatio Model - FP Model - FN Total Cost Total Cost FP FN Cost Ratio /TCI Total /TCI Total Cost Ratio ns False False False False Cost Cost Positive Negative Positive Negative 43.99% 17.37% 0.64% TCI TCI 1.02 1.03 TCI TCI 20 144 44.72% 18.01% 0.73% 21 12 5.00% 0.00% 5.00% Benchmark TCI TCI\* TCI\* 47.86% 50.00% -2.14% 1.06 1.16 -7.50% Benchmark Benchmark 23 36 45.09% 2.50% 47.11% 10.00% -2.02% 0.83 0.75Benchmark Benchmark 28 72 13.21% -1.03% 0.95 0.93 43.97% 11.07% 45.00% -2.14% Benchmark Benchmark Benchmark Benchmark 29 24 45.67% 16.67% 41.94% 28.33% 3.73% -11.67% TCI Benchmark 0.89 0.80 Benchmark\* Benchmark\* 30 Benchmark\* Benchmark\* 12 50.00% 0.00% 47.86% 5.00% 2.14% -5.00% TCI Benchmark 0.95 0.86 31 24 42.40% 6.67% 43.87% 6.67% -1.47%0.00% Benchmark 0.97 0.97 Benchmark\* Benchmark\* 35 24 42.84% 15.00% 42.85% 16.67% -0.01% -1.67% Benchmark Benchmark 0.97 0.96 Benchmark Benchmark 36 48 43.58% 16.57% 42.39% 21.90% 1.18% -5.33% TCI Benchmark 0.94 0.89 Benchmark\* Benchmark\* 37 84 45.15% 15.44% 43.63% 17.94% 1.52% -2.50% TCI Benchmark 0.98 0.96 Benchmark\* Benchmark\* 7.50% Benchmark 39 36 44.35% 43.10% 23.00% 1.25% -15.50% TCI 0.78 0.67 Benchmark\* Benchmark\* 42 12 42.68% 10.00% 32.87% 20.00% 9.82% -10.00% TCI Benchmark 1.00 0.86 Benchmark\* Benchmark\* 44 24 40.03% 20.00% 40.51% 28.33% -0.49% -8.33% Benchmark Benchmark 0.87 0.82 Benchmark Benchmark 45 96 45.84% 14.67% 44.55% 16.12% 1.30% -1.45% TCI Benchmark 1.00 0.98 Benchmark\* Benchmark\* 47 12 0.00% 1.59 TCI\* 45.79% 15.00% 47.62% -1.83% 15.00% Benchmark TCI 1.28 TCI\* 48 24 1.29% 0.91 0.85 41.17% 13.33% 39.88% 20.00% -6.67% TCI Benchmark Benchmark\* Benchmark\* 53 12 34.08% 35.00% 39.53% 10.00% -5.45% 25.00% Benchmark TCI 1.39 1.75 TCI\* TCI\* 55 24 45.40% 8.33% 45.67% 16.67% -0.27% -8.33% Benchmark Benchmark 0.86 0.79 Benchmark Benchmark 57 24 8.33% -1.67% TCI 0.99 0.97 46.60% 6.67% 45.40% 1.20% Benchmark Benchmark\* Benchmark\* 58 180 13.83% 44.76% 14.81% 0.33% -0.97% TCI Benchmark 0.99 0.98 Benchmark\* Benchmark\* 45.09% 59 36 42.80% 16.50% 39.00% 25.50% 3.80% -9.00% TCI Benchmark 0.92 0.84 Benchmark\* Benchmark\* -5.00% TCI 70 24 45.54% 13.33% 42.99% 18.33% 2.55% Benchmark 0.96 0.91 Benchmark\* Benchmark\* 73 60 37.50% 27.68% 38.13% 27.08% -0.64% 0.60% Benchmark TCI 1.00 1.01 Benchmark\* TCI\* 75 12 48.10% 10.00% 33.68% 30.00% 14.42% -20.00% TCI Benchmark 0.91 0.73 Benchmark\* Benchmark\*

\*Better model determined based on the ratio of costs of FP and FN errors.

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4 5 indus- industries tries

#### RQ 2B: Error Detection Performance of Continuous Substantive Analytical Models with TCI and without TCI (Models 7 and 2)

#### **TCI** outperforms benchmark for:

Error Detect	tion Ability -	Alpha = 0.3	3										
	-	(2)		(7)									
		Benchmark GD	- Salest-1 & Pt-1	Twitter - C	I & GDPt-1	Benchm	ark - CI	-		(1:1)	(1:2)	(1:1)	(1:2)
0		Positive	False Negative	False Positive	False Negative	FP	Difference FN	Better Model - FP		/TCI Total Cost	Benchmark Total Cost /TCI Total Cost	Better Model - Cost Ratio	Better Model · Cost Ratio
20	144	43.27%	17.98%	41.72%		1.56%	-3.67%	-	Benchmark	0.97	0.93	Benchmark*	
21	12	39.53%	10.00%	45.00%	0.00%	-5.47%	10.00%	Benchmark	ICI	1.10	1.32	TCI*	TCI*
23		46.16%	6.50%	44.53%	11.50%	1.63%	-5.00%	TCI	Benchmark	0.94	0.88	Benchmark*	Benchmark*
28	72	43.68%	15.83%	40.86%	20.24%	2.83%	-4.40%	TCI	Benchmark	0.97	0.93	Benchmark*	Benchmark*
29		49.07%	6.67%	42.09%	30.00%	6.98%	-23.33%	TCI	Benchmark	0.77	0.61	Benchmark*	Benchmark*
30		36.73%	20.00%	39.53%	10.00%	-2.80%	10.00%	Benchmark	TCI	1.15	1.29	TCI*	TCI*
31	24	40.85%	6.67%	39.22%	6.67%	1.63%	0.00%	TCI		1.04	1.03	TCI*	TCI*
35	24	44.15%	13.33%	42.55%	10.00%	1.60%	3.33%	TCI	TCI	1.09	1.13	TCI	TCI
36	48	44.23%	16.00%	41.56%	22.95%	2.67%	-6.95%	TCI	Benchmark	0.93	0.87	Benchmark*	Benchmark*
37	84	42.88%	19.55%	43.96%	16.19%	-1.08%	3.36%	Benchmark	ГСІ	1.04	1.07	TCI*	TCI*
39	36	46.86%	2.50%	42.70%	14.00%	4.16%	-11.50%	TCI	Benchmark	0.87	0.73	Benchmark*	Benchmark*
42	12	40.18%	20.00%	32.87%	20.00%	7.31%	0.00%	TCI		1.14	1.10	TCI*	TCI*
44	24	44.29%	16.67%	45.54%	13.33%	-1.24%	3.33%	Benchmark	ICI	1.04	1.08	TCI*	TCI*
45	96	45.00%	19.02%	44.89%	16.73%	0.10%	2.29%	TCI	ГСІ	1.04	1.06	TCI	TCI
47	12	45.52%	10.00%	47.62%	0.00%	-2.10%	10.00%	Benchmark	TCI	1.17	1.38	TCI*	TCI*
48	24	42.70%	13.33%	39.87%	18.33%	2.83%	-5.00%	TCI	Benchmark	0.96	0.91	Benchmark*	Benchmark*
53	12	47.62%	0.00%	40.18%	20.00%	7.44%	-20.00%	TCI	Benchmark	0.79	0.59	Benchmark*	Benchmark*
55	24	48.11%	13.33%	46.72%	10.00%	1.38%	3.33%	TCI	TCI	1.08	1.12	TCI	TCI
57	24	43.87%	6.67%	46.47%	3.33%	-2.60%	3.33%	Benchmark	TCI	1.01	1.08	TCI*	TCI*
58	180	45.44%	18.19%	45.15%	19.76%	0.29%	-1.57%		Benchmark	0.98	0.97	Benchmark*	Benchmark*
59	36	42.40%	7.50%	44.35%	7.50%	-1.94%	0.00%	Benchmark		0.96	0.97	Benchmark*	Benchmark*
70	24	44.44%	20.00%	43.00%	20.00%	1.44%	0.00%	TCI		1.02	1.02	TCI*	TCI*
73	60	33.89%	29.76%	36.70%	26.79%	-2.82%	2.98%	Benchmark	TCI	1.00	1.03	TCI*	TCI*
75		46.05%	20.00%	34.08%	35.00%	11.97%	-15.00%		Benchmark	0.96	0.83	Benchmark*	Benchmark*
*Better mod	lel determine	d based on t	he ratio of co	sts of FP and	d FN errors.			16	10			13	13

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#### RQ 2B: Error Detection Performance of Continuous Substantive Analytical Models with TCI and without TCI (Models 9 and 3)

#### **TCI** outperforms benchmark for:

Error Detect	tion Ability -	Alpha $= 0.3$	3										
		(3)		(9)									
			- Salest-1 & R	Twitter -	CI & AR	Benchm	ark - CI			(1:1)	(1:2)	(1:1)	(1:2)
2-Digit SIC	ns	False Positive	False Negative	False Positive	False Negative	Difference - FP	Difference - FN		Better Model - FN	/TCI Total Cost	Benchmark Total Cost /TCI Total Cost	Better Model - Cost Ratio	Better Model - Cost Ratio
20	144	44.21%	17.00%	43.52%	17.66%	0.69%	-0.66%	TCI	Benchmark	1.00	0.99	TCI*	Benchmark*
21	12	47.86%	5.00%	50.00%	0.00%	-2.14%	5.00%	Benchmark	TCI	1.06	1.16	TCI*	TCI*
23	36	44.53%	12.50%	40.75%	17.50%	3.78%	-5.00%	TCI	Benchmark	0.98	0.92	Benchmark*	Benchmark*
28	72	37.85%	25.86%	37.73%	23.36%	0.12%	2.50%	TCI	TCI	1.04	1.06	TCI	TCI
29	24	42.55%	10.00%	45.40%	10.00%	-2.85%	0.00%	Benchmark	-	0.95	0.96	Benchmark*	Benchmark*
30	12	42.97%	15.00%	42.97%	15.00%	0.00%	0.00%	-	-	1.00	1.00	Benchmark*	Benchmark*
31	24	39.71%	15.00%	39.71%	15.00%	0.00%	0.00%	-	-	1.00	1.00	Benchmark*	Benchmark*
35	24	38.36%	21.67%	39.88%	20.00%	-1.52%	1.67%	Benchmark	TCI	1.00	1.02	TCI*	TCI*
36	48	43.58%	18.00%	44.30%	18.00%	-0.71%	0.00%	Benchmark	-	0.99	0.99	Benchmark*	Benchmark*
37	84	43.59%	16.69%	43.50%	14.19%	0.08%	2.50%	TCI	TCI	1.04	1.07	TCI	TCI
39	36	42.90%	19.00%	38.77%	20.50%	4.14%	-1.50%	TCI	Benchmark	1.04	1.01	TCI*	TCI*
42	12	32.87%	20.00%	36.37%	15.00%	-3.50%	5.00%	Benchmark	TCI	1.03	1.10	TCI*	TCI*
44	24	42.69%	11.67%	43.14%	21.67%	-0.45%	-10.00%	Benchmark	Benchmark	0.84	0.76	Benchmark	Benchmark
45	96	45.00%	19.13%	44.44%	13.62%	0.56%	5.52%	TCI	TCI	1.10	1.16	TCI	TCI
47	12	42.97%	15.00%	47.62%	0.00%	-4.65%	15.00%	Benchmark	TCI	1.22	1.53	TCI*	TCI*
48	24	39.71%	16.67%	39.88%	20.00%	-0.17%	-3.33%	Benchmark	Benchmark	0.94	0.91	Benchmark	Benchmark
53	12	47.86%	5.00%	40.18%	20.00%	7.68%	-15.00%	TCI	Benchmark	0.88	0.72	Benchmark*	Benchmark*
55	24	46.72%	10.00%	47.86%	6.67%	-1.14%	3.33%	Benchmark	TCI	1.04	1.09	TCI*	TCI*
57	24	46.60%	6.67%	45.40%	8.33%	1.20%	-1.67%	TCI	Benchmark	0.99	0.97	Benchmark*	Benchmark*
58	180	46.24%	10.96%	45.34%	15.42%	0.89%	-4.46%	TCI	Benchmark	0.94	0.89	Benchmark*	Benchmark*
59	36	43.00%	20.50%	43.87%	18.00%	-0.87%	2.50%	Benchmark	TCI	1.03	1.05	TCI*	TCI*
70	24	47.98%	10.00%	44.29%	15.00%	3.70%	-5.00%	TCI	Benchmark	0.98	0.92	Benchmark*	Benchmark*
73	60	40.54%	21.85%	40.60%	23.51%	-0.07%	-1.67%	Benchmark	Benchmark	0.97	0.96	Benchmark	Benchmark
75	12	40.82%	30.00%	29.42%	30.00%	11.40%	0.00%	TCI	-	1.19	1.13	TCI*	TCI*

\*Better model determined based on the ratio of costs of FP and FN errors.

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11 9 indus- industries tries 12 11 indus- industries tries

#### RQ 2B: Error Detection Performance of Continuous Substantive Analytical Models with TCI and without TCI (Models 11 and 4)

#### **TCI** outperforms benchmark for:

Error Detect	tion Ability -	Alpha $= 0.3$	3										
		(4)		(11)									
		Benchmark			CI & AR &	Benchm	ark - CI			(1:1)	(1:2)	(1:1)	(1:2)
		AR &	GDPt-1	GD	Pt-1					(1.1)	(1.2)	(1.1)	(1.2)
2-Digit SIC	Number of Observatio					Difference - FP	Difference - FN	Better Model - FP	Better Model - FN		Benchmark Total Cost	Better Model -	Better Mode - Cost Ratio
	ns	False	False	False	False					/TCI Total	/TCI Total	Cost Ratio	
		Positive	Negative	Positive	Negative					Cost	Cost		
20	144	43.80%	18.80%	42.68%	20.90%	1.12%	-2.10%	TCI	Benchmark	0.98	0.96	Benchmark <sup>3</sup>	<sup>k</sup> Benchmark
21	12	42.39%	5.00%	36.01%	10.00%	6.38%	-5.00%	TCI	Benchmark	1.03	0.94	TCI*	Benchmark <sup>3</sup>
23	36	45.27%	7.50%	45.27%	7.50%	0.00%	0.00%	-	-	1.00	1.00	Benchmark <sup>3</sup>	* Benchmark <sup>*</sup>
28	72	40.64%	26.19%	39.50%	24.76%	1.14%	1.43%	TCI	TCI	1.04	1.04	TCI	TCI
29	24	41.47%	18.33%	43.87%	6.67%	-2.40%	11.67%	Benchmark	TCI	1.18	1.37	TCI*	TCI*
30	12	36.73%	20.00%	36.73%	20.00%	0.00%	0.00%	-	-	1.00	1.00	Benchmark <sup>3</sup>	<sup>*</sup> Benchmark <sup>*</sup>
31	24	42.40%	6.67%	40.85%	6.67%	1.55%	0.00%	TCI	-	1.03	1.03	TCI*	TCI*
35	24	38.19%	20.00%	36.95%	28.33%	1.24%	-8.33%	TCI	Benchmark	0.89	0.84	Benchmark <sup>3</sup>	<sup>*</sup> Benchmark <sup>*</sup>
36	48	42.33%	23.33%	40.78%	23.33%	1.55%	0.00%	TCI	-	1.02	1.02	TCI*	TCI*
37	84	43.46%	13.89%	44.56%	10.97%	-1.10%	2.92%	Benchmark	TCI	1.03	1.07	TCI*	TCI*
39	36	33.33%	32.50%	35.67%	29.50%	-2.34%	3.00%	Benchmark	TCI	1.01	1.04	TCI*	TCI*
42	12	32.87%	20.00%	32.87%	20.00%	0.00%	0.00%	-	-	1.00	1.00	Benchmark <sup>3</sup>	* Benchmark*
44	24	45.67%	16.67%	46.85%	13.33%	-1.18%	3.33%	Benchmark	TCI	1.04	1.07	TCI*	TCI*
45	96	44.62%	18.28%	43.55%	18.34%	1.07%	-0.06%	TCI	Benchmark	1.02	1.01	TCI*	TCI*
47	12	45.52%	10.00%	47.62%	0.00%	-2.10%	10.00%	Benchmark	TCI	1.17	1.38	TCI*	TCI*
48	24	41.31%	15.00%	39.87%	18.33%	1.44%	-3.33%	TCI	Benchmark	0.97	0.93	Benchmark <sup>3</sup>	* Benchmark*
53	12	47.62%	0.00%	39.85%	15.00%	7.77%	-15.00%	TCI	Benchmark	0.87	0.68	Benchmark <sup>3</sup>	* Benchmark*
55	24	42.99%	18.33%	41.47%	18.33%	1.52%	0.00%	TCI	-	1.03	1.02	TCI*	TCI*
57	24	46.34%	0.00%	45.13%	3.33%	1.21%	-3.33%	TCI	Benchmark	0.96	0.89	Benchmark <sup>3</sup>	* Benchmark*
58	180	45.16%	15.92%	45.02%	17.00%	0.15%	-1.09%	TCI	Benchmark	0.98	0.97	Benchmark <sup>3</sup>	<sup>*</sup> Benchmark <sup>*</sup>
59	36	41.06%	22.00%	40.95%	19.50%	0.11%	2.50%	TCI	TCI	1.04	1.06	TCI	TCI
70	24	46.98%	16.67%	44.44%	20.00%	2.54%	-3.33%	TCI	Benchmark	0.99	0.95	Benchmark <sup>3</sup>	* Benchmark*
73	60	38.13%	27.08%	41.17%	22.14%	-3.04%	4.94%	Benchmark	TCI	1.03	1.08	TCI*	TCI*
75	12	43.55%	25.00%	25.10%	35.00%	18.46%	-10.00%	TCI	Benchmark	1.14	0.98	TCI*	Benchmark*

\*Better model determined based on the ratio of costs of FP and FN errors.

#### **Rutgers Business School**

158indus-indus-triestries

1412indus-indus-triestries

#### RQ 2A: Error Detection Performance for Continuous Substantive Analytical Models with TCS and without TCS (Models 6 and 1)

#### TCS outperforms benchmark for:

		(1)		(6)									
			k - Salest-1		er - CS	Benchm	ark - CS			(1:1)	(1:2)	(1:1)	(1:2)
2-Digit SIC		False	False Negative	False Positive	False Negative	Difference - FP	FN		Better Model - FN	Benchmark Total Cost /TCS Total Cost	Benchmark Total Cost /TCS Total Cost	Better Model - Cost Ratio	Better Mode - Cost Ratio
20	) 144	44.72%	18.01%	44.00%	17.85%	0.73%	0.16%	TCS	TCS	1.01	1.01	TCS	TCS
21	12	47.86%	5.00%	41.14%	35.00%	6.72%	-30.00%	TCS	Benchmark	0.69	0.52	Benchmark*	Benchmark*
23	36	45.09%	2.50%	45.99%	2.50%	-0.90%	0.00%	Benchmark	-	0.98	0.98	Benchmark*	<sup>4</sup> Benchmark <sup>2</sup>
28	5 72	43.97%	11.07%	43.63%	13.69%	0.34%	-2.62%	TCS	Benchmark	0.96	0.93	Benchmark*	<sup>6</sup> Benchmark <sup>2</sup>
29	24	45.67%	16.67%	45.67%	16.67%	0.00%	0.00%	-	-	1.00	1.00	Benchmark*	Benchmark <sup>3</sup>
30	12	50.00%	0.00%	48.10%	10.00%	1.90%	-10.00%	TCS	Benchmark	0.86	0.73	Benchmark*	Benchmark
31	24	42.40%	6.67%	39.22%	6.67%	3.18%	0.00%	TCS	-	1.07	1.06	TCS*	TCS*
35	24	42.84%	15.00%	42.84%	15.00%	0.00%	0.00%	-	-	1.00	1.00	Benchmark*	Benchmark <sup>3</sup>
36	i 48	43.58%	16.57%	44.22%	14.95%	-0.64%	1.62%	Benchmark	TCS	1.02	1.03	TCS*	TCS*
37	84	45.15%	15.44%	45.04%	12.44%	0.12%	3.00%	TCS	TCS	1.05	1.09	TCS	TCS
39	36	44.35%	7.50%	42.60%	11.50%	1.75%	-4.00%	TCS	Benchmark	0.96	0.90	Benchmark*	Benchmark
42	. 12	42.68%	10.00%	32.87%	20.00%	9.82%	-10.00%	TCS	Benchmark	1.00	0.86	Benchmark*	Benchmark
44	- 24	40.03%	20.00%	41.31%	15.00%	-1.29%	5.00%	Benchmark	TCS	1.07	1.12	TCS*	TCS*
45	96	45.84%	14.67%	43.91%	17.46%	1.94%	-2.80%	TCS	Benchmark	0.99	0.95	Benchmark*	<sup>6</sup> Benchmark <sup>2</sup>
47	12	45.79%	15.00%	48.33%	15.00%	-2.55%	0.00%	Benchmark	-	0.96	0.97	Benchmark*	<sup>6</sup> Benchmark <sup>2</sup>
48	3 24	41.17%	13.33%	39.54%	11.67%	1.63%	1.67%	TCS	TCS	1.06	1.08	TCS	TCS
53	12	34.08%	35.00%	42.97%	15.00%	-8.89%	20.00%	Benchmark	TCS	1.19	1.43	TCS*	TCS*
55	24	45.40%	8.33%	44.01%	8.33%	1.39%	0.00%	TCS	-	1.03	1.02	TCS*	TCS*
57	24	46.60%	6.67%	41.32%	16.67%	5.27%	-10.00%	TCS	Benchmark	0.92	0.80	Benchmark*	Benchmark
58	180	45.09%	13.83%	44.41%	15.14%	0.68%	-1.30%	TCS	Benchmark	0.99	0.97	Benchmark*	Benchmark
59	36	42.80%	16.50%	42.80%	15.50%	0.00%	1.00%	TCS	TCS	1.02	1.03	TCS	TCS
70	24	45.54%	13.33%	44.29%	16.67%	1.24%	-3.33%	TCS	Benchmark	0.97	0.93	Benchmark*	Benchmark
73	60	37.50%	27.68%	39.29%	23.04%	-1.79%	4.64%	Benchmark	TCS	1.05	1.09	TCS*	TCS*
75	12	48.10%	10.00%	48.10%	10.00%	0.00%	0.00%	-	-	1.00	1.00	Benchmark*	Benchmark <sup>a</sup>

\*Better model determined based on the ratio of costs of FP and FN errors.

#### Rutgers Business School

158indus-indus-triestries

10 10 indus- industries tries

#### RQ 2B: Error Detection Performance of Continuous Substantive Analytical Models with TCS and without TCS (Models 8 and 2)

#### TCS outperforms benchmark for:

Error Detect	tion Ability -												
		(2)		(8)				<u>.</u>		•	1	-	
			- Salest-1 & Pt-1	Twitter - CS	5 & GDPt-1	Benchm	ark - CS			(1:1)	(1:2)	(1:1)	(1:2)
2-Digit SIC		False	False		False Negative	Difference - FP	Difference - FN	Better Model - FP	Better Model - FN	Benchmark Total Cost TCS Total Cost	Benchmark Total Cost /TCS Total Cost	Better Model - Cost Ratio	Better Mode - Cost Ratio
20	144	43.27%	17.98%	43.88%	15.18%	-0.60%	2.80%	Benchmark	TCS	1.04	1.07	TCS*	TCS*
21	12	39.53%	10.00%	39.21%	5.00%	0.32%	5.00%	TCS	TCS	1.12	1.21	TCS	TCS
23	36	46.16%	6.50%	44.25%	5.00%	1.91%	1.50%	TCS	TCS	1.07	1.09	TCS	TCS
28	72	43.68%	15.83%	41.90%	20.07%	1.79%	-4.24%	TCS	Benchmark	0.96	0.92	Benchmark*	Benchmark <sup>3</sup>
29	24	49.07%	6.67%	49.07%	6.67%	0.00%	0.00%	-	-	1.00	1.00	Benchmark*	Benchmark*
30	12	36.73%	20.00%	40.50%	25.00%	-3.77%	-5.00%	Benchmark	Benchmark	0.87	0.85	Benchmark	Benchmark
31	24	40.85%	6.67%	40.85%	6.67%	0.00%	0.00%	-	-	1.00	1.00	Benchmark*	Benchmark <sup>3</sup>
35	24	44.15%	13.33%	41.17%	13.33%	2.99%	0.00%	TCS	-	1.05	1.04	TCS*	TCS*
36	48	44.23%	16.00%	44.86%	14.67%	-0.63%	1.33%	Benchmark	TCS	1.01	1.03	TCS*	TCS*
37	84	42.88%	19.55%	44.40%	16.97%	-1.53%	2.58%	Benchmark	TCS	1.02	1.05	TCS*	TCS*
39	36	46.86%	2.50%	47.78%	5.00%	-0.92%	-2.50%	Benchmark	Benchmark	0.94	0.90	Benchmark	Benchmark
42	12	40.18%	20.00%	37.45%	30.00%	2.72%	-10.00%	TCS	Benchmark	0.89	0.82	Benchmark*	Benchmark <sup>3</sup>
44	24	44.29%	16.67%	44.44%	20.00%	-0.14%	-3.33%	Benchmark	Benchmark	0.95	0.92	Benchmark	Benchmark
45	96	45.00%	19.02%	44.30%	18.86%	0.70%	0.16%	TCS	TCS	1.01	1.01	TCS	TCS
47	12	45.52%	10.00%	45.52%	10.00%	0.00%	0.00%	-	-	1.00	1.00	Benchmark*	Benchmark*
48	24	42.70%	13.33%	41.01%	10.00%	1.69%	3.33%	TCS	TCS	1.10	1.14	TCS	TCS
53		47.62%	0.00%	45.26%	5.00%	2.36%	-5.00%	TCS	Benchmark	0.95	0.86	Benchmark*	Benchmark <sup>3</sup>
55		48.11%	13.33%	46.85%	13.33%	1.25%	0.00%	TCS	-	1.02	1.02	TCS*	TCS*
57	24	43.87%	6.67%	42.40%	6.67%	1.47%	0.00%	TCS	-	1.03	1.03	TCS*	TCS*
58		45.44%	18.19%	44.24%	15.14%	1.20%	3.05%	TCS	TCS	1.07	1.10	TCS	TCS
59		42.40%	7.50%	45.36%	10.00%	-2.96%			Benchmark	0.90	0.88	Benchmark	Benchmark
70	24	44.44%	20.00%	43.14%	21.67%	1.30%	-1.67%	TCS	Benchmark	0.99	0.98	Benchmark*	Benchmark <sup>3</sup>
73		33.89%	29.76%	37.35%	24.82%	-3.46%		Benchmark		1.02	1.07	TCS*	TCS*
75		46.05%		50.00%	0.00%	-3.95%	20.00%	Benchmark	TCS	1.32	1.72	TCS*	TCS*
Better mod	lel determine	d based on tl	he ratio of co	sts of FP and	I FN errors.			12	10			13	13
								indus	- indus	-		indus-	indus

Rutgers Business School

tries tries

tries

tries

#### RQ 2B: Error Detection Performance of Continuous Substantive Analytical Models with TCS and without TCS (Models 10 and 3)

#### TCS outperforms benchmark for:

Error Detec	tion Ability -	Alpha = 0.3	3										
		(3)		(10)									
			- Salest-1 & R	Twitter -	CS & AR	Benchm	ark - CS	-		(1:1)	(1:2)	(1:1)	(1:2)
		Positive	False Negative	Positive	False Negative	Difference - FP	FN		Better Model - FN	/TCS Total Cost	Benchmark Total Cost /TCS Total Cost	Better Model - Cost Ratio	Better Model - Cost Ratio
20			17.00%		13.40%	-0.56%		Benchmark		1.05	1.09	TCS*	TCS*
21		47.86%	5.00%		25.00%	1.55%	-20.00%		Benchmark		0.60		Benchmark*
23			12.50%		12.50%	0.95%	0.00%		-	1.02	1.01	TCS*	TCS*
28		37.85%	25.86%		24.79%	-0.52%		Benchmark	TCS	1.01	1.02	TCS*	TCS*
29		42.55%	10.00%		10.00%	1.54%	0.00%	TCS	-	1.03	1.03	TCS*	TCS*
30		42.97%	15.00%		20.00%	-3.07%	-5.00%	Benchmark	Benchmark		0.85	Benchmark	Benchmark
31		39.71%	15.00%	42.70%	13.33%	-2.99%	1.67%	Benchmark	TCS	0.98	1.00	Benchmark*	TCS*
35	5 24	38.36%	21.67%	38.36%	21.67%	0.00%	0.00%	-	-	1.00	1.00	Benchmark*	Benchmark*
36		43.58%	18.00%	44.44%	22.00%	-0.86%	-4.00%	Benchmark	Benchmark	0.93	0.90	Benchmark	Benchmark
37		43.59%	16.69%	42.79%	17.53%	0.80%	-0.83%	TCS	Benchmark	1.00	0.99		Benchmark*
39	36	42.90%	19.00%	41.89%	19.00%	1.01%	0.00%	TCS	-	1.02	1.01	TCS*	TCS*
42	2 12	32.87%	20.00%	32.87%	20.00%	0.00%	0.00%	-	-	1.00	1.00	Benchmark*	Benchmark*
44	4 24	42.69%	11.67%	42.55%	10.00%	0.14%	1.67%	TCS	TCS	1.03	1.06	TCS	TCS
45	5 96	45.00%	19.13%	43.07%	22.76%	1.93%	-3.63%	TCS	Benchmark	0.97	0.94	Benchmark*	Benchmark*
47	12	42.97%	15.00%	45.52%	10.00%	-2.55%	5.00%	Benchmark	TCS	1.04	1.11	TCS*	TCS*
48	3 24	39.71%	16.67%	37.83%	11.67%	1.88%	5.00%	TCS	TCS	1.14	1.19	TCS	TCS
53	3 12	47.86%	5.00%	40.18%	20.00%	7.68%	-15.00%	TCS	Benchmark	0.88	0.72	Benchmark*	Benchmark*
55	5 24	46.72%	10.00%	45.54%	13.33%	1.19%	-3.33%	TCS	Benchmark	0.96	0.92	Benchmark*	Benchmark*
57	24	46.60%	6.67%	42.40%	6.67%	4.19%	0.00%	TCS	-	1.09	1.08	TCS*	TCS*
58	3 180	46.24%	10.96%	44.41%	15.41%	1.83%	-4.45%	TCS	Benchmark	0.96	0.91	Benchmark*	Benchmark*
59	36	43.00%	20.50%	42.30%	27.00%	0.70%	-6.50%	TCS	Benchmark	0.92	0.87	Benchmark*	Benchmark*
70	) 24	47.98%	10.00%	45.54%	13.33%	2.45%	-3.33%	TCS	Benchmark	0.98	0.94	Benchmark*	Benchmark*
73	60	40.54%	21.85%	42.29%	20.24%	-1.75%	1.61%	Benchmark	TCS	1.00	1.02	Benchmark*	TCS*
75	5 12	40.82%	30.00%	45.79%	15.00%	-4.97%	15.00%	Benchmark	TCS	1.17	1.33	TCS*	TCS*

\*Better model determined based on the ratio of costs of FP and FN errors.

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148indus-indus-triestries

10 12 indus-industries tries

#### RQ 2B: Error Detection Performance of Continuous Substantive Analytical Models with TCS and without TCS (Models 12 and 4)

-5.00% TCS

-3.33% TCS

0.89% Benchmark TCS

15.00% Benchmark TCS

#### Error Detection Ability - Alpha = 0.33(4)(12)Benchmark - Salest-1 & Twitter - CS & AR & Benchmark - CS (1:1)(1:2)AR & GDPt-1 GDPt-1 Number of Benchmark Benchmark Better Better Difference - Difference Total Cost 2-Digit SIC Observatio Total Cost Model - FP Model - FN FN FP ns TCS Total /TCS Total False False False False Cost Cost Positive Negative Positive Negative 44.42% 20 144 43.80% 18.80% 16.58% -0.62%2.21% Benchmark TCS 1.03 1.05 21 12 42.39% 5.00% 39.21% 5.00% 3.18% 0.00% TCS 1.07 1.06 23 36 7.50% 2.47% -9.00% TCS 0.89 0.80 45.27% 42.80% 16.50% Benchmark 40.64% 28 72 26.19% 40.43% 22.62% 0.21% 3.57% TCS TCS 1.06 1.09 29 0.00% 24 41.47% 18.33% 41.47% 18.33% 0.00% -1.00 1.00 30 12 36.73% 20.00% 40.50% 25.00% -3.77% -5.00% Benchmark Benchmark 0.87 0.85 31 24 42.40% 6.67% 41.00% 8.33% 1.40% -1.67% TCS Benchmark 0.99 0.97 24 35 38.19% 20.00% 38.19% 20.00% 0.00% 0.00% -1.00 1.00 48 42.33% -2.29% TCS 0.97 36 23.33% 40.13% 25.62% 2.20% Benchmark 1.00 37 1.02 84 43.46% 13.89% 43.04% 13.42% 0.42% 0.47% TCS TCS 1.02 39 36 33.33% 32.50% 31.95% 32.50% 1.38% 0.00% TCS 1.02 1.01 \_ 42 12 32.87% 20.00% 32.87% 20.00% 0.00% 0.00% -1.00 1.00 44 24 45.67% 16.67% 45.67% 16.67% 0.00% 0.00% -1.00 1.0096 Benchmark 45 44.62% 18.28% 42.93% 21.01% 1.69% -2.73% TCS 0.98 0.96 47 12 0.00% -45.52% 10.00% 45.52% 10.00% 0.00% 1.00 1.00 48 24 41.31% 15.00% 41.01% 10.00% 0.30% 5.00% TCS TCS 1.10 1.17 -5.00% TCS 53 12 47.62% 0.00% 45.26% 5.00% 2.36% Benchmark 0.95 0.86 55 24 0.00% -42.99% 18.33% 42.99% 18.33% 0.00% 1.00 1.0057 24 46.34% 0.00% 42.40% 6.67% 3.94% -6.67% TCS Benchmark 0.94 0.83 58 180 45.16% 15.92% 43.88% 16.22% 1.29% -0.31% TCS Benchmark 1.02 1.01

27.00%

20.00%

26.19%

10.00%

1.95%

2.54%

-0.62%

-1.97%

39.11%

44.44%

38.75%

45.52%

#### TCS outperforms benchmark for:

\*Better model determined based on the ratio of costs of FP and FN errors.

41.06%

46.98%

38.13%

43.55%

22.00%

16.67%

27.08%

25.00%

#### **Rutgers Business School**

36

24

60

12

59

70

73

75

14 6 indus- industries tries

Benchmark

Benchmark

0.95

0.99

1.00

1.23

9 9 indus- industries tries

(1:1)

Better

Model -

Cost Ratio

TCS\*

TCS\*

TCS

TCS

TCS\*

TCS

TCS\*

TCS\*

TCS\*

0.91

0.95

1.01

1.43

Benchmark\* Benchmark\*

Benchmark\* Benchmark\*

Benchmark Benchmark

Benchmark\* Benchmark\*

(1:2)

Better Model

Cost Ratio

TCS\*

TCS\*

TCS

TCS

TCS\*

TCS

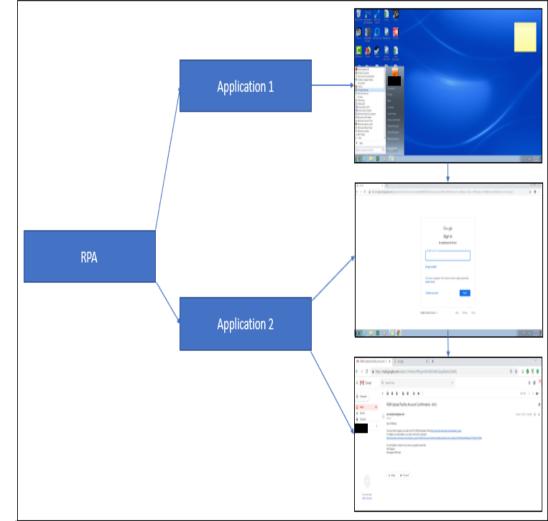
TCS\*

TCS\*

TCS\*

### Introduction

 RPA is "a type of software that mimics the activity of a human being in carrying out a task within a process. It can do repetitive stuff more quickly, accurately, and tirelessly than humans, freeing them to do other tasks" (McKinsey 2016)



### **Background on RPA & Process Redesign**

### RPA

 RPA has been applied to various industries including telecommunications, financial services, retail, and manufacturing (Lacity et al. 2015; Seasongood 2016)

#### **Process Redesign**

- Process redesign refers to changing old rules in a process to new rules (Davenport and Short 1990; Hammer 1990)
- Most cases of process redesign focused on "evolutionary" implementations (Davenport and Stoddard 1994; Jarvenpaa and Stoddard 1998)

### Hammer 1990

- 1) organizing outcomes around tasks: have one person perform all the tasks in the process
- 2) have those who use the output of a process, perform the process: have individuals who need the result of the process do it themselves
- 3) subsume information processing work into the real work that produces the information: move work from one person/department to another
- 4) treat geographically dispersed resources as though they were centralized: use databases, telecommunications networks and standardized processing systems to get the benefits of coordination while maintaining flexibility
- 5) put the decision point where the work is performed, and build control into the process: people who do the work should make decisions
- 6) capture information once and at the source: eliminate data Rutgers Business School redundancy

### **Davenport and Short 1990**

- Developing the business vision and process objective: automate process to reduce costs, reduce time in performing the task, improve output quality, and quality of work life
- 2) Identifying process to be redesigned: identify business process to automate
- 3) Understanding and measuring existing processes: understand and measure to target areas that need to be improved
- 4) Identifying IT levers: understand the role and capabilities of IT
- 5) Designing and building a prototype of the new process: apply automation vision

### **Application of APA Framework (3)**

#### **Audit Data Standardization**

	А	В	С	D	
1	Standard Name	Column Name Per Report	Data Type	Report	
2	Employee_ID	SSN	NUMERICA	Annual Loan Balance	
3	Name	Participant Name	TEXT	Annual Loan Balance	
4	Loan_Number	Loan ID	NUMERICA	Annual Loan Balance	
5	Loan_Amount	Loan Amount	NUMERICA	Annual Loan Balance	
6	Interest_Rate	Int Rate	Percentage	Annual Loan Balance	
7	Date_Opened	Date Opened	DATE	Annual Loan Balance	
8	Year_Opened	Date Opened2	DATE	Annual Loan Balance	
9	Employee_ID	SSN	NUMERICA	Check Register	
10	Name	PAYEE	TEXT	Check Register	
11	Loan_Amount_R2	NET AMT	NUMERICA	Check Register	

1) Link to Standard Field

	А	В	C D	E	F	1	( A	В	с	D	E	F	
1	SSN	Participant Name	Loan ID Int Rate	Date Oper	Loan Amo	1	SSN	PAYEE	AMOUNT				
2	XXX-XX-1234	Farrah Stambaugh	LOAN 11 5	6132016	9199	2	XXX-XX-1234	Farrah St	a 9199				
3	XXX-XX-1235	Cecelia Kendra	LOAN 04 5	3302016	3739	3	XXX-XX-1235	Cecelia Ke	3739				
4	XXX-XX-1236	Alba Moseley	LOAN 02 5	8182016	5160	4	XXX-XX-1236	Alba Mos	< 5160				
5	XXX-XX-1237	Emil Stlouis	LOAN 03 5	1222016	8030	5	XXX-XX-1237	Emil Stlou	9999				
6	XXX-XX-1238	Taren Farrelly	LOAN 02 5	8082016	13202	6	XXX-XX-1238	Taren Far	13202				
7	XXX-XX-1239	Tiana Harstad	LOAN 03 5	8302016	8793	7	XXX-XX-1239	Tiana Har	8793				
8	XXX-XX-1240	Bette Wildt	LOAN 02 5	12232016	10462	8	XXX-XX-1240	Bette Wil	d 10462				
9	XXX-XX-1241	Gustavo Kocher	LOAN 03 5	5102016	10572	9	XXX-XX-1241	Gustavo I	( 10572				
10	XXX-XX-1242	Latrina Pickel	LOAN 02 5	7202016	1412	10	XXX-XX-1242	Latrina Pi	c 1412			2) Com Rep	ipany
11	XXX-XX-1243	Irena Wease	LOAN 03 5	6272016	14191	11	XXX-XX-1243	Irena We	a 14191				
12	XXX-XX-1244	Aide Nuckles	LOAN 11 5	9062016	179	12	XXX-XX-1244	Aide Nucl	c 179			Kep	orts
13	XXX-XX-1245	Ester Mullings	LOAN 04 5	4252016	1761	13	XXX-XX-1245	Ester Mu	1761				
14	XXX-XX-1246	Russ Cushman	LOAN 02 5	2222016	14938	14	XXX-XX-1246	Russ Cush	14938				
15	XXX-XX-1247	Allena Aldridge	LOAN 03 5	7192016	5426	15	XXX-XX-1247	Allena Ale	5426				
16	XXX-XX-1248	Hermila Faw	LOAN 02 5	6272016	1579	16	XXX-XX-1248	Hermila F	1579				
17	XXX-XX-1249	Gerry Osby	LOAN 03 5	12292016	9025	17	XXX-XX-1249	Gerry Osl	9025				
18	XXX-XX-1250	Fernande Fuhr	LOAN 02 5	10102016	635	18	XXX-XX-1250	Fernande	6350				
19	XXX-XX-1251	Maris Vicente	LOAN 03 5	12232016	13225	19	XXX-XX-1251	Maris Vic	e 13225				
20	XXX-XX-1252	Natashia Maag	LOAN 02 5	2022016	14613	20	XXX-XX-1252	Natashia	14613				
21	XXX-XX-1253	Odis Douglass	LOAN 03 5	12052016	7663	21	XXX-XX-1253	Odis Dou	g 7663				
22	XXX-XX-1254	Letitia Gambrel	LOAN 11 5	6022016	7063	22	XXX-XX-1254						
-	→ Linl	k to Standard Field	Annual Loan Balance	Check Reg	ister Lc		C E Lir	nk to Stand	lard Field	Annual Los	an Balance	Check	

### Application of APA Framework (3) cont'd

#### **Audit Data Standardization**

1		_	D	E	_	G			-		
2 1	Source Annual Loan B Standard Field Employee ID			Annual Coan Bat Date Opened			n Bali Annual Loan Ba an 🔹 Interest Rate 🗢		Check Register Name	Check Reg Loan_Amo	
	1284	Foresche Stande 1400	NUT	6/18/2010	2016		90.99 26.00	1240	Both wildt		10/16/2.08
0	1235	Cecelia Kendr LOAI Alba Moseley LOAI		3302016 8182016				1241 1242	Gustovo Kocher Larrina Pickel		10572.00
2	1246	Emil Stlemis 1004		1222016				1248	Frenci Wease		14191.00
2	1208	Taren Farrelly LOA		8052016	2016			1244	Alde Nuckles		179.00
1	1239	Tiana Harstar LOA Bette Wildt – LOA		8302016 12232016				1245	Ester Mullings Russ Cushmum		1761.00
e	1241	Gustavo Koch LOAI		5102016				1247	Allena Aldridge		5426.00
1	1242	Catrina Pickel 1000		7202030				1.248	Hermila Faw		100204-00
8	1243	Aide Nuckles, LOAI		6272016 9062016	2016	1		1240	Gerry Osby Fernande Fubr		9025.00 6350.00
415	1245	Ester Mulling 1000	NUM	4252036	2016		1261 5.00	1251	Maris Vicente		18225-00
21	1246	Russ Cushma: LOA Allena Aldridg LOA			2016			1252 1253	Noteshia Maag Odis Douglass		14613.00
9	1248	Hermila Faw LOA		6272016				1254	Letitia Gambrel		7063.00
24	1249	Gerry Osby LOA		12292016				1255	Diana Zager		10892.00
11	1250	Fernande Foli LOA Mans Vicente LOA		10102016 12232016				1255	Violeta Reen Asuncion Peskin		25716.00
26	1252	Natashia MazLOA	N 02	2022016	2016	1	4613 5.00	1258	Versie Daniel		12269.00
494	1258	Odis Danglass LOA Letitia Gambr LOA		12052016				1959	Vella Coopp		1749.00
22	1254	Diana Zager 10A		6022016 8292016				1260	Margery Rain Caridad Finnie		13917.00
1	1256	Violeta Been, LOA	N 02	11252016			8516 5.00	1262	Hailey Lainez		4508.00
	Annual Loan Balance	Awardon Parll OA Check Register		4252016 g - ADS_Data	Prep Loar		ADS Copy Paste	(1265) (±)	Dovie Cercuitte		2000.00
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l c	Company Employee ID			an Number			Year Opened <u>*</u>			Loan Amount	
Ļ.	1 123	4 Farrah Stambaugh	LC LC	DAN 11	6	132016	2016	5 9199	5	• • • • • • • • • • • • • • • • • • •	9199
Ļ.		5 Cecelia Kendra		DAN 04		302016	2016		5		3739
	1 123	6 Alba Moseley	LC	OAN 02	8	182016	2016	5 5160	5		3739 5160
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) 1 2 3	1 123 1 123 1 123 1 123 1 124 1 124 1 124 1 124 1 124 1 124 1 124 1 124	6 Alba Moseley 7 Emil Stlouis 8 Taren Farrelly 9 Tiana Harstad 0 Bette Wildt 1 Gustavo Kocher 2 Latrina Pickel 3 Irena Wease 4 Aide Nuckles 5 Ester Mullings		0AN 02 0AN 03 0AN 02 0AN 02 0AN 02 0AN 03 0AN 02 0AN 03 0AN 03 0AN 03 0AN 04	8 11 88 12 5 7 6 9 9 4 2	182016 222016 082016 232016 2232016 102016 202016 272016 062016 252016	2016 2016 2016 2016 2016 2016 2016 2016	5 5160 5 8030 5 13202 5 8793 5 10462 5 10572 5 1412 5 14191 5 179 5 1761 5 14938	5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5		5160 9999 13202 8793 10462 10572 1412 14191 179 1761
	1 123 1 123 1 123 1 123 1 124 1 124 1 124 1 124 1 124 1 124 1 124 1 124 1 124	6 Alba Moseley 7 Emil Stlouis 8 Taren Farrelly 9 Tiana Harstad 0 Bette Wildt 1 Gustavo Kocher 2 Latrina Pickel 3 Irena Wease 4 Aide Nuckles 5 Ester Mullings 6 Russ Cushman		0AN 02 0AN 03 0AN 02 0AN 03 0AN 03 0AN 03 0AN 03 0AN 03 0AN 03 0AN 11 0AN 04	8 12 5 7 6 9 4 2 7	182016 222016 082016 232016 2232016 102016 202016 222016 062016 252016 222016	2016 2016 2016 2016 2016 2016 2016 2016	5 5160 5 8030 5 13202 5 8793 5 10462 5 10572 5 1412 5 14191 5 1491 5 1761 5 14938 5 5426	5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5		5160 9999 13202 8793 10462 10572 1412 14191 179 1761 14938
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3) Loan Testing – ADS Data Prep

4) Loan Testing – ADS Copy Paste

#### <u>Audit Apps Prototyping – Microsoft Access App</u>

<b>□</b> 5-2- <b>\$</b> ++	Query Tools Loan Testi	ting1_dummy : Database- C:\Users\ochoa\One	Drive\Desktop\CR\Loan Testing1_dummy	accdb Andrea Rozario ? - @ ×
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SeorchP AS [Match_Interest Rate], ADS.[Loan_Amount] Tables & Iff[[ADS].[Loan_Amount]>=[PlanDoc].[Minimu Loans].[CountOfLoans]<=[PlanDoc].[Maximu	(), ADS.[Loan_Amount_R25], un Loan Requirement], "PASS m Number of Loans Allowed	e, IDJ, ADS.Name, PlanDoc.Company AS PlanDoc, Cor , Ilf([Loan_Amount]=[Loan_Amount_R25];"PASS";"FAI S";"FAIL") AS [Match_Min Loan], [Count Number of L d];"PASS";"FAIL") AS [Match_Mac Number Loan] any[) INNER JOIN [Count Number of Loans] ON ADS.	IL <sup>*</sup> ) AS [Match _Loan Amount], PlanDoc.[Minim oans].CountOfLoans, PlanDoc.[Maximum Num]	

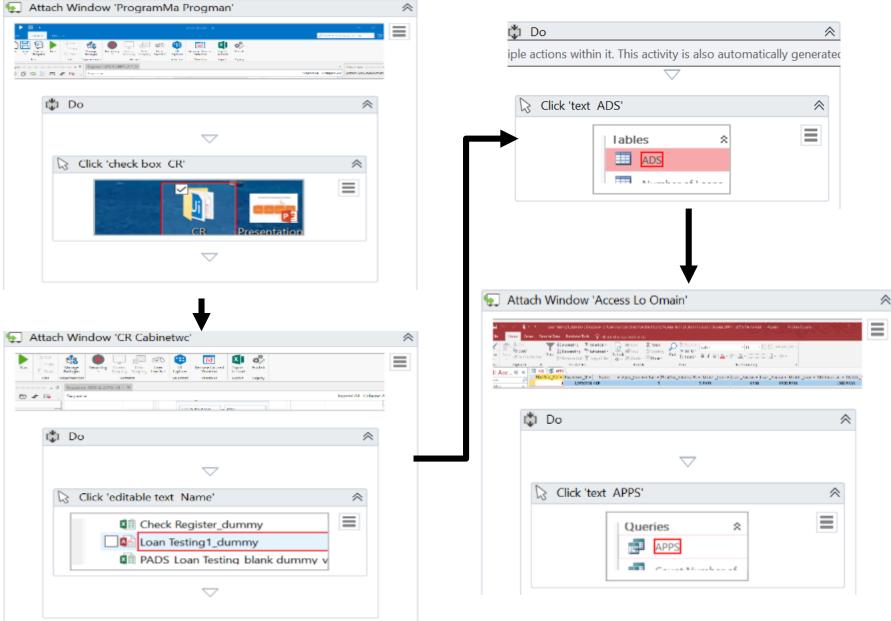
#### Audit Apps Prototyping – UiPath Workflow

Excel application scope	*	Excel application scop	)e	1
"C:\Users\ochoa\OneDrive\Desktop\CR\Annual Loan Balance de	ummv.xlsx"	"C:\Users\ochoa\OneDr	ive\Desktop\CR\PADS Loan Te	estina blank dummv v5.xlsx"
Do  Read Range  "Database"  ""  Output data table	*		Range	
Excel application scope "C:\Users\ochoa\OneDrive\Desktop\CR\Check Register due	mmv.xlsx"	Excel application scope "C:\Users\ochoa\OneDriv	e ve\Desktop\CR\PADS Loan Te	estina blank dummv v5.xlsx"
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#### Audit Apps Prototyping – UiPath Workflow

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"Loan Testing - ADS Data Preo"	"Loan Testing - ADS Copy Paste" "A1:H11"
	$\bigtriangledown$
"Table2" "Year Opened"	E Output data table
application scope	For each row
s\ochoa\OneDrive\Desktop\CR\PADS_Loan_Testing_blank_dummv_v5.xlsx"	ForEach row in ADS
s\ochoa\OneDrive\Desktop\CR\PADS_Loan_Testing_blank_dummv_v5.xlsx"	ForEach row in ADS
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#### Audit Apps Prototyping – UiPath Workflow



### **Results**

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PlanDoc	1	1258 Versie Daniel	5	5 PASS	12269	12269 PASS	30 PASS	1	3 PASS
Queries *	1	1259 Yetta Cropp	5	5 PASS	1739	1739 PASS	30 PASS	1	3 PASS
APPS	1	1260 Margery Rain	5	5 PASS	13917	13917 PASS	30 PASS	1	3 PASS
_	1	1261 Caridad Finnie	5	5 PASS	14678	14678 PASS	30 PASS	1	3 PASS
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	1	1264 Ursula Hirshma	5	5 PASS	2426	2426 PASS	30 PASS	1	3 PASS
	1	1265 Rubi Eslinger	5	5 PASS	878	878 PASS	30 PASS	1	3 PASS
	1	1266 Shirlene Saavec	5	5 PASS	3164	3164 PASS	30 PASS	1	3 PASS
	1	1267 Austin Victor	5	5 PASS	1666	1666 PASS	30 PASS	1	3 PASS
	1	1268 Judi Stoute	5	5 PASS	9028	9028 PASS	30 PASS	1	3 PASS
	1	1269 Andera Wolter	5	5 PASS	9371	9371 PASS	30 PASS	1	3 PASS
	1	1270 Nicolasa Hickle	5	5 PASS	14541	14541 PASS	30 PASS	1	3 PASS
	1	1271 Carlena Paulett	5	5 PASS	5476	5476 PASS	30 PASS	1	3 PASS
	1	1272 Arlyne Bodnar	5	5 PASS	5845	5845 PASS	30 PASS	1	3 PASS
	1	1273 Sanora Windle	5	5 PASS	10415	10415 PASS	30 PASS	1	3 PASS
	1	1274 Isela Tubb	5	5 PASS	2646	2646 PASS	30 PASS	1	3 PASS
	1	1275 Malcom Arviso	5	5 PASS	8567	8567 PASS	30 PASS	1	3 PASS
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### Introduction

Blockchain is a decentralized, distributed, and secure

ledger originally developed for Bitcoin transactions



DENTIFICATION

Voter registration is

being facilitated via

a blockchain project

in Switzerland

Types of blockchain databases: public (permissionless), blockshain private (permissioned) pertaining to repair requests and rolling stock



CARBON OFFSET

IBM is using the

offset tracking

ENTERPRIS Ethereumis

accessed as a

Microsoft Azure

coursesy of

DIAMONDS

to track the

importation and

sale of diamonds.

cloud-based service

The De Beers Group

is using blockchain

Atize

De Beers

IBM and Walmart have

partnered in China to

create a blockchain

monitor food safety.

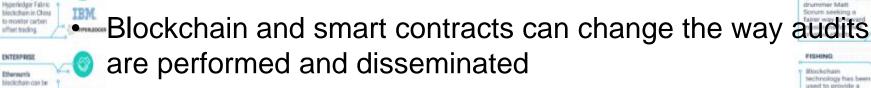
Walmart 💥

project that will

line as a means of

saving costs and intrasting transparence

> Smart contracts autonomously execute the tasks for terms of contracts but can be useful in an auditing context









ENERGY
Food importation is another industry where blockchain is
proving its worth, with Loois Drivyfus Co trialing a
soybean importation operation using this and



TAXATION

in China, a tax-hase-

initiative is using

tax records and

led by Miaocai

Chile's National Energy Commission

blockshain

has started using

of certifying data

pertaining to the

country's energy Upage as it seeks to

infrastructure

ENTERPRIS Google is building it own blockchair

which will be

own white later

by Alphabet Inc.

MERSEC

retaion developed

Arbit is a blockchair based project led by

ransparent record

of where fish was

caught as a means of ensuring it was

DC.

ormer Gans N Rosen

tegrated into its

update its electrical

technology as a way

CNE

CONISIÓ

ACIDHD:

HOBOTPAHC

Google

arbit

Network

ENERGY

blockchain to store

electronic involces

### Exploring an External Audit Blockchain Ecosystem for Revenue

