# Labor-Technology Substitution: Implications for Asset Pricing

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# Background

Routine-task labor: workers performing procedural and rule-based tasks.

- Tax preparers $\rightarrow$ Tax preparation software
- Automobile assemblers $\rightarrow$ Robotic arms

# Motivation

Labor economics: secular trend of routine-task labor being replaced by automation Autor, Levy, and Murnane (2003); ...

Macroeconomics: disappearance of routine-task jobs is concentrated in recessions and explains 90% of all job losses Jaimovich and Siu (2014)

This research: **Is a firm's ability to replace its labor with machines a determinant of its systematic risk?**

# This paper

1. Develop a new model
   - Replacement (restructuring) interrupts production
   - Replace when profitability is low — minimizing opportunity cost
   - Firms with routine-task labor have hedging options $\rightarrow$ low risk

2. Construct first measure of firms' share of routine-task labor
   - Administrative data from BLS

3. Present novel empirical findings
   - **Asset pricing:** Firms' betas and stock returns monotonically decrease in their share of routine-task labor within industry. Return spread: 3.9% within industry.

   - **Mechanism:** In bad times, high-share firms cut investment in machines less and increase routine-task layoffs more than their industry peers.

# Contributions to the literature

1. Theoretical Asset Pricing: separate investment opportunities by purpose
   - Growth options — increase output

     Berk, Green, and Naik (1999); Carlson, Fisher, and Giammarino (2004); Kogan and Papanikolaou (2014); etc.

   - Technology switching options — increase efficiency

2. Empirical Asset Pricing: share of routine-task labor and systematic risk
   - Labor heterogeneity and stock returns

     Eisfeldt and Papanikolaou (2013); Donangelo (2014); Belo, Lin, and Bazdresch (2014); Kuehn, Simutin, and Wang (2014); Tuzel and Zhang (2017); etc.

   - Highlight labor composition within firm

3. Macroeconomics: labor-technology substitution and the business cycle
   - Firm-level data on routine labor hiring and machinery investment.

     Autor, Levy, and Murnane (2003); Autor, Katz, and Kearney (2006); Goos and Manning (2007); Autor and Dorn (2013); etc.

   - Substitution is more pervasive during economic downturns

     Hershbein and Kahn (2016); Jaimovich and Siu (2014)

# A “Technology-Switching” Model

# Setup

Basic setup:

- A firm is a single project.
- Project generates revenues subject to productivity shocks

$$A_{j,t} = e^{x_t + \epsilon_{j,t}}$$

New ingredient:

- There are two types of projects (based on task performers)
  - ⋆ **Unautomated project**: production by routine-task labor
  - ⋆ **Automated project**: production by machines
- The firm has technology switching options: Switch types

# Optimal exercise of switching options

Trade-off for switching technology

- Automated project is less costly than unautomated project:

$$\pi_u = A_t - f - f_R$$
$$\pi_a = A_t - f$$

- Switching technology interrupt the production of the project
  - * Project shuts down for $T$ periods

$$\text{Payoff} = \underbrace{\frac{f_R}{r}}_{\text{Cost Saving}} - \underbrace{I_M}_{\text{Direct Cost}} - \underbrace{\int_0^T A_t e^{g(s)} ds}_{\text{Production Loss}}$$

**Proposition 1:** The optimal strategy to switch is when $A_t < A^*$.

# Empirical prediction

**Empirical Prediction 1:** *If the economy experiences a negative shock, firms with a high share of routine-task labor reduce investment in machines less and increase layoffs of routine-task labor more than firms with a low share of routine-task labor, ceteris paribus.*

# Comparison of firm risk

Comparing $\beta_a = 1 + \frac{V_a^f}{V_a}$ and $\beta_u = 1 + \frac{V_u^f}{V_u} + \frac{V_u^{so}}{V_u}\beta_u^{so}$...

**Proposition 2**: The comparison depends on two channels:

$$\beta_u - \beta_a = \underbrace{\frac{V_u^f}{V_u} - \frac{V_a^f}{V_a}}_{\text{Operating leverage channel}} + \underbrace{\frac{V_u^{so}}{V_u}\beta_u^{so}}_{\text{Switching options channel}}$$

- ⋆ $\beta_u^{so} < 0$: switching options are hedging options.
- ⋆ Unclear which firms have higher operating leverage.

**Proposition 3**: Assume that all firms start as unautomated. Define $\beta_U$ and $\beta_A$ as the portfolio-level betas for unautomated and automated firms. After sufficiently long time periods, we have

$$\beta_U < \beta_A$$

# Empirical prediction

**Empirical Prediction 2:** *Portfolio of firms with a higher share of routine-task labor have lower equity betas.*

- ⋆ *They also have higher operating costs and higher cash flows.*

# Measuring Routine-Task Labor

# Main Data

- Occupational composition of firms:

  Microdata of Occupational Employment Statistics 1988-2014

  - Employment and wages at occupation-establishment level
  - 1.2 million establishments; 62% total employment
  - Matched to 3,857 publicly-traded firms per year

- Characteristics of occupations:

  Dictionary of Occupational Titles (DOT)

- Financial and returns:

  Firm investment in machinery and equipment: Compustat

  Stock returns: CRSP

- Computer investment of establishments:

  Computer Intelligence Technology Database (CiTDB)

  - Number of computers and servers for establishments
  - 0.5 million establishments before 2010 and 3.2 million after.

# Classifying routine-task labor

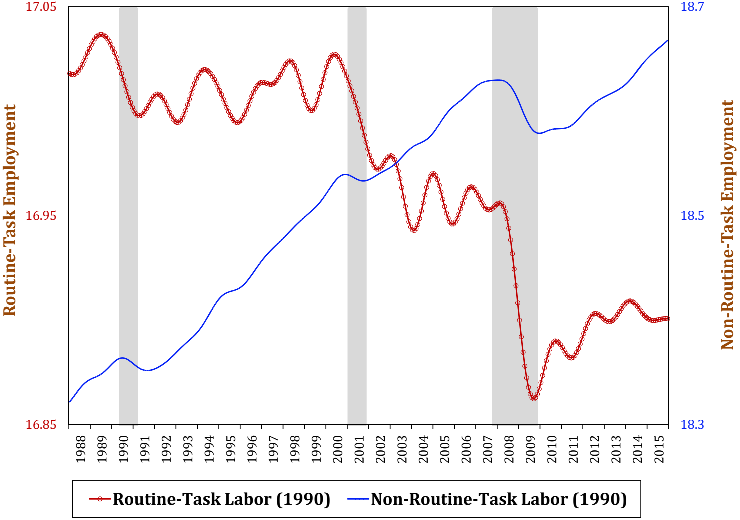
1. Obtain occupations' intensity in three groups of tasks
   - *Routine* task:
     examples: clerks and assemblers
   - *Non-routine abstract* task:
     examples: managers and professionals
   - *Non-routine manual* task:
     examples: janitors and electrical repairers

2. Assign a routine-task intensity score ($RTI$) to each occupation (Autor and Dorn (2013)):

$$RTI_k = \ln(T_k^{Routine}) - \ln(T_k^{Abstract}) - \ln(T_k^{Manual})$$

3. Each year, rank all workers by RTI and define the top quintile of workers as *Routine-Task Labor*.

# A glance at routine-task employment



# Share of routine-task labor

$$RShare_{j,t} = \sum_k \mathbb{1}\left[RTI_k > RTI_t^{P80}\right] \times \frac{emp_{j,k,t} \times wage_{j,k,t}}{\sum_k emp_{j,k,t} \times wage_{j,k,t}}$$

Intuition: Share of labor cost distributed to routine-task labor

# Empirical Findings

# Testing predictions on machinery investment

**Empirical Prediction 1a:**
*If the economy experiences a negative shock, high-RShare firms reduce investment in machines less than low-RShare firms.*

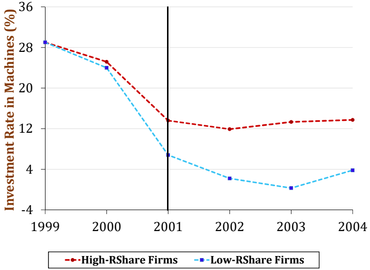
$$I_{f,t}^{M} = a_0 + \sum_{d=2}^{5} a_d D(R_{f,t-1})_d + b_1 Shock_t + \sum_{d=2}^{5} b_d D(R_{f,t-1})_d \times Shock_t + cX_{f,t-1} + F_f + \epsilon_{f,t}$$

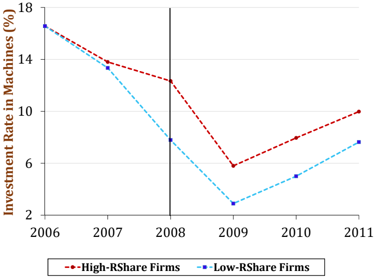
- $D(R_{f,t-1})_d$: *Dummy variable that firm $f$ is in the $d$'s RShare quintile*
- $Shock_t$: *Growth rate of real GDP $\rightarrow$ a positive economic shock*
- *Prediction:* *Facing negative shock, high-RShare firms invest more $\rightarrow$*

  $(0 > b_2 > b_3 > b_4 > b_5)$

# Testing predictions on technology investment

*Graphic evidence: Investment in machines during recessions*




*Data source: Compustat firms*

# Testing predictions on technology investment

*Regression results: Investment in machines and GDP shocks*

| | *Compustat Firms* | | *CiTDB Establishments* | |
|---|---|---|---|---|
| Dep. Var. | Machine Inv. | | Computer Inv. | |
| | (1) | (2) | (3) | (4) |
| *Shock* | 0.86*** | 1.40*** | 0.41*** | 1.04*** |
| | (0.10) | (0.27) | (0.10) | (0.23) |
| $D(R)_2 \times Shock$ | | − 0.49 | | − 0.67** |
| | | (0.34) | | (0.31) |
| $D(R)_3 \times Shock$ | | − 0.63* | | − 0.69** |
| | | (0.33) | | (0.30) |
| $D(R)_4 \times Shock$ | | − 0.65** | | − 0.77** |
| | | (0.33) | | (0.30) |
| $D(R)_5 \times Shock$ | | − 0.80*** | | − 0.94*** |
| | | (0.29) | | (0.31) |
| Observations | 41,601 | 41,601 | 1,405,940 | 1,405,940 |
| Adjusted $R^2$ | 0.21 | 0.21 | 0.07 | 0.07 |

*Firm Controls: *Tobin's Q, Leverage, Total Assets, Cash Flows, and Cash Holding.*

# Testing predictions on routine employment

**Empirical Prediction 1b:**

*If the economy experiences a negative shock, high-RShare firms increase layoffs of routine-task labor more than low-RShare firms.*

$$Chg^{Routine}_{e,t-3,t} = a_0 + \sum_{d=2}^{5} a_d D(R_{f,t-3})_d + b_1 Shock_{t-3,t} + \sum_{d=2}^{5} b_d D(R_{f,t-3})_d \times Shock_{t-3,t} + F_f + \epsilon_{e,t}$$

- $D(R_{f,t-3})_d$: *Dummy variable that firm $f$ is in the $d$'s RShare quintile*
- $Shock_{t-3,t}$: *Growth rate of real GDP $\rightarrow$ a positive economic shock*
- *Prediction:* *Facing negative shock, high-RShare firms reduce more routine labor*

  $\rightarrow (0 < b_2 < b_3 < b_4 < b_5)$

# Testing predictions on routine employment

| Dep. Var. | Routine Employment | | Share of Routine Employment | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| *Shock* | 1.34*** | −0.25 | 0.09*** | −0.11** |
| | (0.15) | (0.43) | (0.03) | (0.06) |
| $D(R)_2 \times Shock$ | | 1.44*** | | 0.12 |
| | | (0.55) | | (0.08) |
| $D(R)_3 \times Shock$ | | 1.81*** | | 0.19** |
| | | (0.52) | | (0.08) |
| $D(R)_4 \times Shock$ | | 1.65*** | | 0.18** |
| | | (0.52) | | (0.09) |
| $D(R)_5 \times Shock$ | | 1.98*** | | 0.35*** |
| | | (0.51) | | (0.10) |
| # Firm-Year | 38,056 | 38,056 | 38,056 | 38,056 |
| Observations | 146,551 | 146,551 | 164,889 | 164,889 |
| Adjusted $R^2$ | 0.08 | 0.12 | 0.07 | 0.12 |

# Testing predictions on cross-sectional asset pricing

**Empirical Prediction 2:** *In the cross-section, high-RShare firms have lower expected returns than low-RShare firms.*

# Testing predictions on cross-sectional asset pricing

Firms sorted on *RShare* within industry

| L | 2 | 3 | 4 | H | H−L |
|---|---|---|---|---|---|
| **Excess Returns** | | | | | |
| 10.19** | 9.72** | 9.24*** | 8.42*** | 6.28** | -3.91* |
| (3.95) | (3.89) | (3.43) | (2.96) | (3.04) | (2.21) |
| **Unlevered Returns** | | | | | |
| 9.23** | 8.82** | 8.59*** | 7.31*** | 5.49** | -3.74* |
| (3.64) | (3.58) | (3.07) | (2.62) | (2.69) | (2.07) |

*This H-L return spread (of 3.74-3.91) is non-trivial:*

- *During the same period, the returns of the popular asset-pricing factors are: SMB = 2.26; HML = 2.65; RMW = 3.95*; CMA = 3.38**.*

** represents statistical significance. Data from Ken French's website*

# Testing predictions on cross-sectional asset pricing

Firms sorted on *RShare* within industry

| | L | 2 | 3 | 4 | H | H−L |
|---|---|---|---|---|---|---|
| | | | **Unconditional CAPM** | | | |
| MKT $\beta$ | 1.10*** | 1.09*** | 1.02*** | 0.87*** | 0.86*** | -0.23*** |
| | (0.05) | (0.03) | (0.03) | (0.02) | (0.04) | (0.06) |
| $\alpha$ (%) | 1.88 | 1.41 | 1.52 | 1.80* | -0.26 | -2.15 |
| | (1.79) | (1.63) | (1.08) | (1.01) | (1.29) | (2.10) |
| | | | **Conditional CAPM** | | | |
| Avg. MKT $\beta$ | 1.07*** | 1.00*** | 1.02*** | 0.87*** | 0.85*** | -0.22*** |
| | (0.05) | (0.08) | (0.07) | (0.04) | (0.04) | (0.05) |
| Avg. $\alpha$ (%) | 1.48 | 1.77 | 0.82 | 0.30 | -0.62 | -2.14 |
| | (1.52) | (1.44) | (1.16) | (0.82) | (1.05) | (1.66) |

*Large beta for H-L $\rightarrow$ consistent with our risk-based model*

*Cash Flow Beta vs. Discount Rate Beta*

# Testing additional predictions

Additional model predictions:

1. Higher RShare firms have higher operating cost (machines are cheaper)
2. Only firms with high historical cash flows can sustain high RShare
3. Due to 1, higher RShare firms can have higher operating leverage
4. RShare more negatively predict returns if conditional on operating leverage

We examine predictions 1 - 3 below:

| Quint. | RShare | Mach/Struct | Cash Flow | Op. Cost | Op. Lev | B/M |
|---|---|---|---|---|---|---|
| L | 0.02 | 6.86 | −0.82 | 1.07 | 1.57 | 0.59 |
| 2 | 0.07 | 5.23 | −0.06 | 1.08 | 1.72 | 0.62 |
| 3 | 0.12 | 4.73 | 0.12 | 1.11 | 1.94 | 0.66 |
| 4 | 0.20 | 4.37 | 0.31 | 1.18 | 2.01 | 0.66 |
| H | 0.38 | 4.18 | 0.28 | 1.28 | 2.22 | 0.69 |
| | | | 2 | 1 | 3 | 3 |

*Book-to-Market ratio is used to proxy for operating leverage in the literature*

# Testing additional predictions

4. Controlling for operating leverage, higher RShare firms should be even less risky:

$$\beta_u - \beta_a = \underbrace{\frac{V_u^f}{V_u} - \frac{V_a^f}{V_a}}_{\text{Operating leverage channel}} + \underbrace{\frac{V_u^{so}}{V_u}\beta_u^{so}}_{\textit{Switching options channel}}$$

**Betas of Double Sorting Portfolios Conditional on Characteristics**

| Char.: | Uncond. (1) | Op. Lev (2) | B/M (3) | Op. Cost (4) | Cash Flow (5) |
|---|---|---|---|---|---|
| L | 1.10 | 1.14 | 1.16 | 1.12 | 1.12 |
| 2 | 1.09 | 1.05 | 1.06 | 1.06 | 1.10 |
| 3 | 1.02 | 1.00 | 0.97 | 0.97 | 1.06 |
| 4 | 0.87 | 0.91 | 0.89 | 0.89 | 0.98 |
| H | 0.86 | 0.81 | 0.90 | 0.91 | 0.93 |
| H−L | -0.23*** | -0.33*** | -0.26*** | -0.22*** | -0.18*** |
| | (0.06) | (0.06) | (0.05) | (0.05) | (0.04) |

# Panel regressions to control for alternative channels

$$\beta_{f,t}^{Cond} = b_0 + b_1 RShare_{f,t-1} + b_2 Char_{f,t-1} + F_{Ind\times Year} + \epsilon_{f,t}$$

| | Conditional Betas | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| $RShare_{t-1}$ | -0.59*** | -0.61*** | -0.59*** | -0.58*** | -0.55*** | -0.61*** | -0.62*** | -0.54*** |
| | (0.14) | (0.14) | (0.14) | (0.14) | (0.14) | (0.14) | (0.13) | (0.14) |
| $Op.Lev_{t-1}$ | | 0.02 | | | | | | 0.02 |
| | | (0.01) | | | | | | (0.01) |
| $B/M_{t-1}$ | | | 0.01 | | | | | -0.12** |
| | | | (0.05) | | | | | (0.05) |
| $Op.Cost_{t-1}$ | | | | -0.03 | | | | -0.12*** |
| | | | | (0.04) | | | | (0.04) |
| $Cash\ Flow_{t-1}$ | | | | | -0.03*** | | | -0.02*** |
| | | | | | (0.01) | | | (0.01) |
| $Size_{t-1}$ | | | | | | -0.08*** | | -0.09*** |
| | | | | | | (0.02) | | (0.03) |
| $Mkt.Lev_{t-1}$ | | | | | | | 0.28 | 0.17 |
| | | | | | | | (0.18) | (0.16) |
| Fixed Effects | Ind×Yr | Ind×Yr | Ind×Yr | Ind×Yr | Ind×Yr | Ind×Yr | Ind×Yr | Ind×Yr |
| N | 40,416 | 40,416 | 40,416 | 40,416 | 40,416 | 40,416 | 40,416 | 40,416 |
| Adjusted $R^2$ | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 |

# Panel regressions to control for alternative channels

$$R_{f,t} - RF_t = b_0 + b_1 RShare_{f,t-1} + b_2 Char_{f,t-1} + F_{Ind \times Year} + \epsilon_{f,t}$$

| Annual Stock Returns | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| $RShare_{t-1}$ | -6.48* | -10.28*** | -9.14** | -7.83** | -6.47* | -6.22* | -6.75** | -9.00*** |
| | (3.46) | (3.76) | (3.61) | (3.44) | (3.33) | (3.50) | (3.32) | (3.25) |
| $Op.Lev_{t-1}$ | | 2.93*** | | | | | | 4.23*** |
| | | (0.71) | | | | | | (1.07) |
| $B/M_{t-1}$ | | | 7.97*** | | | | | 8.19*** |
| | | | (1.78) | | | | | (1.41) |
| $Op.Cost_{t-1}$ | | | | 3.23*** | | | | -3.08 |
| | | | | (0.85) | | | | (2.24) |
| $Cash\ Flow_{t-1}$ | | | | | -0.01 | | | -0.23 |
| | | | | | (0.27) | | | (0.24) |
| $Size_{t-1}$ | | | | | | 1.41** | | 3.97*** |
| | | | | | | (0.59) | | (0.43) |
| $Mkt.Lev_{t-1}$ | | | | | | | 2.81 | -3.57*** |
| | | | | | | | (5.94) | (0.75) |
| Fixed Effects | Ind×Yr | Ind×Yr | Ind×Yr | Ind×Yr | Ind×Yr | Ind×Yr | Ind×Yr | Ind×Yr |
| N | 40,416 | 40,416 | 40,416 | 40,416 | 40,416 | 40,416 | 40,416 | 40,416 |
| Adjusted $R^2$ | 0.13 | 0.14 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.15 |

# Conclusion

- Study labor-technology substitution and asset pricing.
- Present a model that highlights technology switching options.
- Construct the first measure of firms' share of routine-task labor using administrative data.
- High-RShare firms have higher hedging option values through automation and lower systematic risk.

# Appendix

# Cash flow beta vs. Discount rate beta

**Campbell and Vuolteenaho (2004) Decomposition**

Firms sorted on *RShare* within industry

| | L | 2 | 3 | 4 | H | H−L |
|---|---|---|---|---|---|---|
| $\beta_{CF}$ | 0.60*** | 0.55*** | 0.54*** | 0.46*** | 0.45*** | -0.14*** |
| | (0.07) | (0.07) | (0.06) | (0.05) | (0.06) | (0.05) |
| $\beta_{DR}$ | 0.56*** | 0.59*** | 0.49*** | 0.44*** | 0.46*** | -0.10** |
| | (0.08) | (0.09) | (0.07) | (0.07) | (0.06) | (0.04) |
| $\beta$ | 1.16*** | 1.14*** | 1.04*** | 0.90*** | 0.91*** | -0.24*** |
| | (0.11) | (0.11) | (0.09) | (0.08) | (0.08) | (0.08) |

*Large cash flow beta → consistent with the model which emphasize cash flow risks*

Go back

# Definition of beta

$$\beta = -\frac{\mathrm{Cov}\left(\frac{dV}{V}, \frac{d\Lambda}{\Lambda}\right)}{\mathrm{Var}\left(\frac{d\Lambda}{\Lambda}\right)}$$

# Model calibration — Parameters

| Parameters | Symbol | Value | Source |
|---|---|---|---|
| *Technology* | | | |
| Volatility of aggregate shock | $\sigma_x$ | 0.13 | KP (2014) |
| Volatility of firm-specific shock | $\sigma_z$ | 0.20 | KP (2014) |
| Volatility of project-specific shock | $\sigma_\epsilon$ | 1.50 | KP (2014) |
| Rate of mean reversion | $\theta$ | 0.35 | KP (2014) |
| *Project* | | | |
| Operating cost except for wage expense | $f$ | 2.05 | Match Moments |
| Total wages for non-routine-task labor | $c_N$ | 0.25 | Match Moments |
| Total wages for routine-task labor | $c_R$ | 0.45 | Match Moments |
| Investment for project initiation | $I$ | 3.90 | Match Moments |
| Investment in machines per auto. project | $I_M$ | 0.50 | Match Moments |
| Required time for technology adoption | $T$ | 0.75 | KP (1982) |
| Project obsolescence rate | $\delta$ | 0.10 | KP (2014) |
| Project arrival rate | $\lambda$ | 12 | Match Moments |
| *Stochastic discount factor* | | | |
| Risk-free rate | $r$ | 0.025 | KP (2014) |
| Price of risk of aggregate shock | $\sigma_\Lambda$ | 1.30 | Match Moments |

*KP (1982): Kydland and Prescott (1982); KP (2014): Kogan and Papanikolaou (2014).

# Model calibration — Target moments

| Moments | Data | Model |
|---|---|---|
| *Aggregate economic moments* | | |
| Mean of aggregate dividend growth | 0.02 | 0.02 |
| Aggregate share of routine-task labor | 0.14 | 0.14 |
| Correlation between gross investment and GDP Growth | 0.64 | 0.54 |
| Correlation between gross hiring and GDP Growth | 0.74 | 0.69 |
| *Asset pricing moments* | | |
| Mean of equal-weighted aggregate risk premium | 0.13 | 0.13 |

# Portfolio sorting using model-simulated data

Simulate the model under economically sensible parameters:

| | L | 2 | 3 | 4 | H | H−L |
|---|---|---|---|---|---|---|
| $E[R] - r_f$ (%) | 14.20*** | 13.60*** | 12.94*** | 12.27*** | 11.96*** | -2.24*** |
| | (1.62) | (1.59) | (1.45) | (1.39) | (1.32) | (0.29) |
| MKT $\beta$ | 1.13*** | 1.08*** | 1.02*** | 0.96*** | 0.95*** | -0.18*** |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| *RShare* | 0.06 | 0.11 | 0.14 | 0.18 | 0.22 | 0.17 |

**Empirical Prediction 2:** *In the cross-section, high-RShare firms have lower expected returns than low-RShare firms.*