# Patent Intensity, Firm Life Cycle Dynamics, and the Pricing of Technological Innovators

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# Motivation

Innovation drives economic growth (Schumpeter, 1911; Solow, 1957; Romer, 1986, 1990; Aghion and Howitt, 1992.)

- Cost-of-capital concern (Arrow, 1962): required returns inefficiently high accounting for social benefits (justifies govt support).
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> "*By the very definition of information, invention must be ...risky.*"

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**Do innovators in fact have high returns and do our asset pricing models reflect this?**

# Existing Evidence / Our Contribution

Some existing evidence based on R&D (Chan, Lakonishok, Sougiannis, 2001; HMXZ, 2021.).

We propose a measure of patent intensity (patents/market) that unifies and expands this literature.

- Time period: A century, 1926-
- Missing data: None
- Life Cycle Dynamics: Ten years
- Explain differences in model costs of capital: investment and profitability are different for innovators and non-innovators.
- Strong links to theory of investment heterogeneity...
- Persistent, low-turnover, low trading cost

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- **Non-innovators:** e.g., Las Vegas Sands

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| Portfolio | Horizon ($K+1$, years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 0 | 7.76 | 7.78 | 7.75 | 7.27 | 7.72 | 7.83 | 9.14 | 8.05 | 8.07 | 7.98 |
| | (3.82) | (3.79) | (3.75) | (3.52) | (3.75) | (3.81) | (4.49) | (4.41) | (4.44) | (4.39) |
| 1 | 7.57 | 7.86 | 7.92 | 7.49 | 8.22 | 8.93 | 9.99 | 8.95 | 8.7 | 8.7 |
| | (3.98) | (4.02) | (4.12) | (3.88) | (4.2) | (4.73) | (5.42) | (5.33) | (5.22) | (5.21) |
| 2 | 10.29 | 9.72 | 8.67 | 9.2 | 8.99 | 9.17 | 11.05 | 8.8 | 9.47 | 9.41 |
| | (5.0) | (4.71) | (3.86) | (3.93) | (4.19) | (4.02) | (4.82) | (4.87) | (5.1) | (5.02) |
| 3 | 10.96 | 10.56 | 9.59 | 9.28 | 9.61 | 9.97 | 10.07 | 9.84 | 9.65 | 9.65 |
| | (4.6) | (4.5) | (4.37) | (4.21) | (4.41) | (4.61) | (4.77) | (4.87) | (4.83) | (5.01) |
| 4 | 15.02 | 14.84 | 12.52 | 10.41 | 10.54 | 11.78 | 14.1 | 11.38 | 11.65 | 11.2 |
| | (4.85) | (4.89) | (4.28) | (3.49) | (3.68) | (4.0) | (4.82) | (4.37) | (4.44) | (4.39) |
| HL | 7.26*** | 7.06*** | 4.77*** | 3.14** | 2.82** | 3.96*** | 4.96*** | 3.32** | 3.59** | 3.22** |
| | (4.42) | (4.36) | (3.09) | (2.03) | (1.96) | (2.72) | (3.3) | (2.3) | (2.39) | (2.16) |

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Important observation in light of Keloharju, Linnainmaa, and Nyberg 2021: "Long-term discount rates do not vary across firms"

# Specific Contributions: Life Cycle and Pricing

**Life-Cycle:**

- Dynamics in growth, investment, profitability
- As characteristics and as factor loadings
- And alphas...

**Pricing:** Models derived from static valuation (FF5, HXZ) severely misprice for full decade

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2. HMXZ lasting contribution: *idea* of expected growth
3. Specific EG construction can be critiqued and may change
4. PI is simple, directly connected to theory and variables at core of growth theory, and provides a durable benchmark

# Nonpatenters, Low PI and High PI Firms

| | Non-patenting | Low PI | High PI |
|---|---|---|---|
| *Portfolio shares (columns sum to 1)* | | | |
| Share of firms | 0.68 | 0.16 | 0.16 |
| Share of cap | 0.35 | 0.54 | 0.11 |
| Share of patents | 0.00 | 0.37 | 0.63 |
| Share of patents (next year) | 0.01 | 0.39 | 0.60 |
| Share of patents (next 3 years) | 0.01 | 0.41 | 0.58 |
| Share of patents (next 5 years) | 0.02 | 0.42 | 0.57 |

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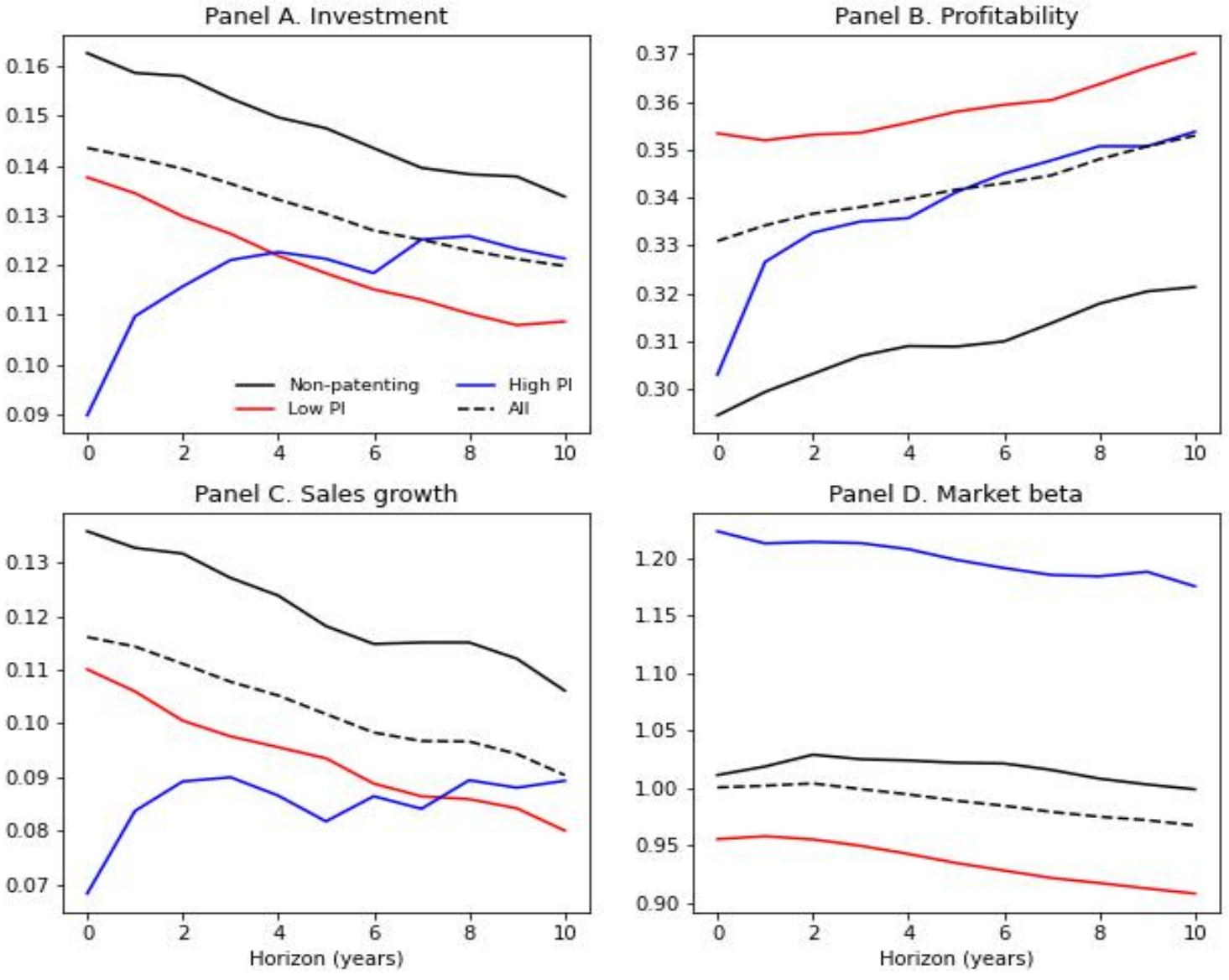
# Innovator Life-Cycle in Characteristics




Compare with Jovanovic (1982) survivorship

# Average Excess Returns and CAPM and FF3 Alphas

| | Nonpatenters | Low PI | 2 | 3 | High PI | HL |
|---|---|---|---|---|---|---|
| Panel A. Excess returns | | | | | | |
| Excess return | 6.75*** | 6.26*** | 8.76*** | 9.7*** | 13.81*** | 7.06*** |
| | (2.98) | (3.15) | (3.96) | (3.82) | (4.12) | (3.42) |
| Panel B. CAPM | | | | | | |
| Constant | -0.32 | -0.24 | 1.68** | 1.68 | 4.93** | 5.25*** |
| | (-0.48) | (-0.45) | (2.46) | (1.59) | (2.57) | (2.63) |
| Mkt-RF | 1.01*** | 0.93*** | 1.01*** | 1.15*** | 1.27*** | 0.26*** |
| | (57.79) | (71.22) | (60.69) | (43.28) | (27.14) | (5.34) |
| $R^2$ | 0.93 | 0.94 | 0.9 | 0.82 | 0.67 | 0.07 |
| Panel C. Fama-French 1993 | | | | | | |
| Constant | -1.33*** | 0.44 | 1.93*** | 1.31 | 3.79** | 5.12*** |
| | (-2.76) | (1.04) | (2.77) | (1.23) | (2.2) | (2.62) |
| Mkt-RF | 1.02*** | 0.95*** | 1.01*** | 1.08*** | 1.13*** | 0.11* |
| | (68.83) | (99.1) | (52.89) | (31.28) | (21.04) | (1.75) |
| SMB | 0.09** | -0.19*** | -0.01 | 0.31*** | 0.72*** | 0.63*** |
| | (2.14) | (-15.23) | (-0.23) | (3.63) | (5.78) | (3.85) |
| HML | 0.22*** | -0.11*** | -0.06* | 0.0 | 0.08 | -0.14* |
| | (7.31) | (-5.54) | (-1.84) | (0.09) | (1.24) | (-1.68) |
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| Constant | -1.67*** | 0.24 | 2.19*** | 2.19** | 5.22*** | 6.89*** |
| | (-3.48) | (0.55) | (3.12) | (2.09) | (3.07) | (3.55) |
| Mkt-RF | 1.02*** | 0.96*** | 1.01*** | 1.09*** | 1.13*** | 0.11** |
| | (77.74) | (95.13) | (64.79) | (34.01) | (24.3) | (2.13) |
| SMB | 0.13*** | -0.18*** | -0.05* | 0.23*** | 0.59*** | 0.46*** |
| | (5.39) | (-13.73) | (-1.65) | (3.9) | (7.61) | (4.83) |
| HML | 0.22*** | -0.08*** | -0.08** | -0.09 | -0.1 | -0.32*** |
| | (6.6) | (-3.68) | (-2.03) | (-1.28) | (-1.11) | (-2.84) |
| CMA | -0.04 | 0.0 | 0.08 | 0.14 | 0.22 | 0.26 |
| | (-1.14) | (0.13) | (1.37) | (1.53) | (1.52) | (1.6) |
| RMW | 0.12*** | 0.04* | -0.12*** | -0.3*** | -0.47*** | -0.58*** |
| | (2.98) | (1.86) | (-3.18) | (-3.79) | (-3.16) | (-3.4) |
| $R^2$ | 0.96 | 0.96 | 0.9 | 0.86 | 0.78 | 0.32 |

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| $R^2$ | 0.96 | 0.96 | 0.9 | 0.86 | 0.78 | 0.32 |

# Mispricing: Roles of Profitability and Investment

1. Split firms into **non-innovators** and **innovators** by past patenting activity

2. Within subsamples, sort by **profitability** (or **investment**)

3. The return spreads / alphas of non-innovators look similar to existing literature, but innovator results are opposite
   - E.g., for innovators, profitability return spread is *negative*!
   - Explains why these factors in isolation worsen pricing of innovators

# Subsample Sorts: Profitability

| | Ex. ret. | Alpha | Mkt-RF | SMB | HML | CMA | RMW |
|---|---|---|---|---|---|---|---|
| Non-innovative | | | | | | | |
| Low Prof. | 3.78 | -0.32 | 1.14*** | 0.4*** | -0.15** | -0.35*** | -1.14*** |
| | (1.12) | (-0.2) | (34.21) | (5.77) | (-2.3) | (-3.08) | (-11.18) |
| High Prof. | 8.11*** | -1.6*** | 1.08*** | 0.24*** | 0.12*** | -0.11** | 0.46*** |
| | (3.46) | (-2.58) | (59.91) | (7.47) | (3.16) | (-2.21) | (10.76) |
| HL | 4.33* | -1.28 | -0.06 | -0.16** | 0.27*** | 0.24* | 1.6*** |
| | (1.91) | (-0.75) | (-1.43) | (-2.36) | (4.04) | (1.84) | (17.53) |
| Innovative | | | | | | | |
| Low Prof. | 10.89*** | 6.66*** | 1.07*** | 0.48*** | -0.52*** | 0.32* | -1.32*** |
| | (3.05) | (3.59) | (24.93) | (5.83) | (-5.41) | (1.82) | (-8.05) |
| High Prof. | 8.39*** | 1.63*** | 0.95*** | -0.13*** | -0.16*** | 0.02 | 0.3*** |
| | (4.27) | (3.02) | (82.74) | (-6.2) | (-5.83) | (0.52) | (8.46) |
| HL | -2.5 | -5.03*** | -0.12*** | -0.61*** | 0.36*** | -0.29* | 1.62*** |
| | (-0.91) | (-2.81) | (-2.77) | (-7.92) | (3.9) | (-1.77) | (11.49) |
| Difference (Innovative - Non-innovative) | | | | | | | |
| HL | -6.83*** | -3.75 | -0.06 | -0.45*** | 0.09 | -0.53** | 0.02 |
| | (-3.07) | (-1.43) | (-1.12) | (-4.21) | (0.75) | (-2.38) | (0.09) |

# Expected Growth

$q5$ factors (Hou, Mo, Xue, and Zhang, 2020, RoF):

- No B/M factor (FF acknowledge redundant with Profitability and Investment)
- Four factors similar to FF5 (beta, size, investment, profitability)

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Expected-growth captures the *dynamic* implications of innovation (where investment is going)

- loadings increase monotonically across PI sorts
- resolves mispricing at all horizons

# $q5$ Pricing

| | Nonpatenters | Low PI | 2 | 3 | High PI | HL |
|---|---|---|---|---|---|---|
| Constant | -0.65 | 0.41 | 0.59 | 1.43 | 1.97 | 2.62 |
| | (-1.16) | (0.83) | (0.82) | (1.18) | (1.25) | (1.43) |
| MKT | 1.0*** | 0.96*** | 1.03*** | 1.09*** | 1.16*** | 0.16*** |
| | (55.9) | (89.61) | (60.53) | (28.98) | (24.3) | (2.71) |
| ME | 0.12** | -0.19*** | -0.05 | 0.24*** | 0.64*** | 0.52*** |
| | (2.3) | (-11.34) | (-1.25) | (2.95) | (5.18) | (3.06) |
| IA | 0.23*** | -0.06** | -0.1** | -0.09 | -0.14 | -0.36** |
| | (4.45) | (-2.06) | (-2.48) | (-1.15) | (-1.11) | (-2.3) |
| ROE | 0.09** | 0.08*** | -0.23*** | -0.37*** | -0.66*** | -0.75*** |
| | (2.33) | (3.41) | (-5.22) | (-4.92) | (-6.82) | (-6.12) |
| EG | -0.16*** | -0.04 | 0.28*** | 0.25*** | 0.59*** | 0.75*** |
| | (-3.96) | (-1.39) | (6.1) | (3.03) | (5.4) | (5.66) |
| $R^2$ | 0.95 | 0.96 | 0.91 | 0.86 | 0.8 | 0.34 |

# FF5 Alpha Dynamics

| | Horizon ($K+1$, years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 0 | -1.67*** | -1.68*** | -1.66*** | -1.91*** | -1.79*** | -1.77*** | -1.73*** | -1.47*** | -1.58*** | -1.64*** |
| | (-3.48) | (-3.62) | (-3.43) | (-3.99) | (-3.73) | (-3.75) | (-3.65) | (-3.21) | (-3.43) | (-3.5) |
| 1 | 0.24 | -0.05 | 0.11 | -0.04 | -0.03 | 0.27 | 0.32 | 0.19 | 0.03 | 0.35 |
| | (0.55) | (-0.11) | (0.26) | (-0.09) | (-0.06) | (0.55) | (0.71) | (0.45) | (0.07) | (0.79) |
| 2 | 2.19*** | 2.68*** | 1.64*** | 1.64** | 1.14* | 0.56 | 0.76 | 0.42 | 1.06* | 0.46 |
| | (3.12) | (3.92) | (2.65) | (2.5) | (1.84) | (0.92) | (1.34) | (0.72) | (1.76) | (0.79) |
| 3 | 2.19** | 1.61* | 1.19 | 1.54* | 1.84** | 1.83** | 0.98 | 1.73** | 0.54 | 0.84 |
| | (2.09) | (1.68) | (1.42) | (1.78) | (2.06) | (2.03) | (1.05) | (2.0) | (0.55) | (0.94) |
| 4 | 5.22*** | 6.46*** | 5.01*** | 2.5* | 1.98 | 2.19* | 3.39** | 3.0** | 2.7* | 3.49** |
| | (3.07) | (4.05) | (3.24) | (1.82) | (1.51) | (1.66) | (2.37) | (2.08) | (1.9) | (2.42) |
| HL | 6.89*** | 8.14*** | 6.67*** | 4.42*** | 3.77** | 3.96*** | 5.12*** | 4.47*** | 4.28*** | 5.12*** |
| | (3.55) | (4.57) | (3.8) | (2.8) | (2.44) | (2.6) | (3.11) | (2.72) | (2.62) | (3.06) |

- Alphas persist a decade, $\sim$5%p.a., compounding...
- Either the model or the market is really, really wrong
- Crucial economic implications, these are not the firms to misprice

# $q5$ Alpha Dynamics

| | Horizon ($K+1$, years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 0 | -0.65 | -0.79 | -0.69 | -1.07* | -0.87 | -0.95* | -0.91 | -0.62 | -1.08* | -1.04* |
| | (-1.16) | (-1.38) | (-1.2) | (-1.91) | (-1.56) | (-1.7) | (-1.61) | (-1.12) | (-1.94) | (-1.79) |
| 1 | 0.41 | 0.52 | 0.29 | 0.02 | -0.31 | -0.01 | -0.14 | -0.55 | -0.77 | -0.4 |
| | (0.83) | (0.98) | (0.56) | (0.03) | (-0.59) | (-0.01) | (-0.23) | (-0.98) | (-1.28) | (-0.71) |
| 2 | 0.59 | 0.68 | 0.26 | 0.62 | 0.23 | 0.02 | 0.13 | -0.05 | 1.25 | 0.25 |
| | (0.82) | (0.87) | (0.33) | (0.75) | (0.32) | (0.03) | (0.18) | (-0.07) | (1.57) | (0.33) |
| 3 | 1.43 | 0.6 | 0.44 | 1.22 | 1.59 | 1.14 | 0.63 | 0.89 | -0.41 | 0.14 |
| | (1.18) | (0.51) | (0.39) | (1.04) | (1.42) | (1.01) | (0.58) | (0.9) | (-0.39) | (0.14) |
| 4 | 1.97 | 3.69 | 2.9 | 0.6 | -0.39 | -0.26 | 0.66 | 1.3 | 0.98 | 2.17 |
| | (1.25) | (1.59) | (1.33) | (0.37) | (-0.25) | (-0.17) | (0.4) | (0.76) | (0.57) | (1.24) |
| HL | 2.62 | 4.48* | 3.59 | 1.67 | 0.48 | 0.69 | 1.58 | 1.93 | 2.06 | 3.21 |
| | (1.43) | (1.68) | (1.45) | (0.89) | (0.26) | (0.4) | (0.81) | (0.99) | (1.03) | (1.57) |

Mispricing resolved at all horizons

# EG Loadings: Persistent

| | Horizon ($K+1$, years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 0 | -0.16*** | -0.14*** | -0.15*** | -0.15*** | -0.15*** | -0.14*** | -0.14*** | -0.13*** | -0.12*** | -0.13*** |
| | (-3.96) | (-3.34) | (-3.59) | (-3.41) | (-3.48) | (-3.56) | (-3.21) | (-3.34) | (-2.98) | (-3.01) |
| 1 | -0.04 | -0.05 | -0.0 | 0.02 | 0.05 | 0.05 | 0.09** | 0.1*** | 0.14*** | 0.15*** |
| | (-1.39) | (-1.49) | (-0.09) | (0.68) | (1.38) | (1.16) | (2.07) | (2.63) | (3.3) | (3.92) |
| 2 | 0.28*** | 0.27*** | 0.21*** | 0.2*** | 0.19*** | 0.14*** | 0.14*** | 0.13*** | 0.05 | 0.07 |
| | (6.1) | (5.62) | (4.52) | (4.21) | (3.75) | (2.83) | (3.3) | (3.3) | (1.12) | (1.53) |
| 3 | 0.25*** | 0.22** | 0.16** | 0.1 | 0.12* | 0.16** | 0.1* | 0.15** | 0.12** | 0.09 |
| | (3.03) | (2.53) | (2.09) | (1.27) | (1.73) | (2.53) | (1.73) | (2.5) | (2.02) | (1.51) |
| 4 | 0.59*** | 0.38*** | 0.27** | 0.24** | 0.3*** | 0.34*** | 0.28*** | 0.21* | 0.23** | 0.17 |
| | (5.4) | (2.88) | (2.3) | (2.19) | (2.83) | (3.45) | (2.72) | (1.77) | (1.97) | (1.52) |
| HL | 0.75*** | 0.52*** | 0.42*** | 0.39*** | 0.45*** | 0.48*** | 0.42*** | 0.34** | 0.35** | 0.3** |
| | (5.66) | (3.26) | (2.86) | (2.86) | (3.36) | (3.88) | (3.22) | (2.41) | (2.45) | (2.15) |

# Investment Loadings: Diverge!

| | Horizon ($K+1$, years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 0 | 0.23*** | 0.25*** | 0.26*** | 0.28*** | 0.28*** | 0.27*** | 0.27*** | 0.28*** | 0.29*** | 0.28*** |
| | (4.45) | (4.7) | (5.12) | (5.13) | (5.73) | (6.29) | (5.89) | (5.94) | (6.92) | (6.6) |
| 1 | -0.06** | -0.03 | 0.02 | 0.05** | 0.07*** | 0.07* | 0.07* | 0.05 | 0.05 | 0.06** |
| | (-2.06) | (-1.28) | (0.79) | (2.12) | (2.68) | (1.91) | (1.87) | (1.46) | (1.4) | (2.06) |
| 2 | -0.1** | -0.07 | -0.14** | -0.13** | -0.08* | -0.02 | 0.01 | 0.07* | 0.03 | 0.03 |
| | (-2.48) | (-1.62) | (-2.42) | (-2.3) | (-1.93) | (-0.52) | (0.15) | (1.83) | (0.86) | (0.89) |
| 3 | -0.09 | -0.13 | -0.11 | -0.18** | -0.15*** | -0.17*** | -0.13** | -0.17*** | -0.06 | -0.07 |
| | (-1.15) | (-1.6) | (-1.53) | (-2.42) | (-2.67) | (-2.9) | (-2.0) | (-2.78) | (-0.95) | (-1.35) |
| 4 | -0.14 | -0.19 | -0.44*** | -0.33*** | -0.26*** | -0.21** | -0.29*** | -0.35*** | -0.37*** | -0.38*** |
| | (-1.11) | (-1.3) | (-3.03) | (-3.83) | (-3.24) | (-2.33) | (-3.25) | (-3.95) | (-4.14) | (-4.33) |
| HL | -0.36** | -0.44** | -0.7*** | -0.61*** | -0.54*** | -0.47*** | -0.56*** | -0.63*** | -0.66*** | -0.67*** |
| | (-2.3) | (-2.31) | (-3.8) | (-5.07) | (-4.96) | (-4.41) | (-4.75) | (-5.28) | (-5.78) | (-5.94) |

# Profitability Loadings: Improving

| | Horizon ($K+1$, years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 0 | 0.09** | 0.09** | 0.1** | 0.11*** | 0.09** | 0.08** | 0.06 | 0.06 | 0.07* | 0.07* |
| | (2.33) | (2.38) | (2.33) | (2.62) | (2.18) | (2.03) | (1.46) | (1.34) | (1.72) | (1.81) |
| 1 | 0.08*** | 0.05** | 0.04 | 0.03 | 0.04* | 0.04 | 0.04 | 0.05* | 0.03 | 0.01 |
| | (3.41) | (2.21) | (1.6) | (1.27) | (1.92) | (1.61) | (1.48) | (1.87) | (1.17) | (0.3) |
| 2 | -0.23*** | -0.18*** | -0.14*** | -0.16*** | -0.13*** | -0.11** | -0.1*** | -0.07** | -0.04 | 0.0 |
| | (-5.22) | (-4.78) | (-3.31) | (-2.97) | (-2.69) | (-2.55) | (-2.59) | (-2.1) | (-1.26) | (0.0) |
| 3 | -0.37*** | -0.29*** | -0.21*** | -0.18*** | -0.2*** | -0.18*** | -0.12** | -0.14*** | -0.08* | -0.09* |
| | (-4.92) | (-5.17) | (-4.56) | (-3.24) | (-3.71) | (-3.5) | (-2.39) | (-2.71) | (-1.69) | (-1.79) |
| 4 | -0.66*** | -0.44*** | -0.3*** | -0.35*** | -0.34*** | -0.39*** | -0.24*** | -0.25*** | -0.29*** | -0.27*** |
| | (-6.82) | (-4.65) | (-2.77) | (-4.68) | (-4.1) | (-4.0) | (-3.03) | (-3.05) | (-2.89) | (-2.8) |
| HL | -0.75*** | -0.54*** | -0.4*** | -0.45*** | -0.43*** | -0.47*** | -0.3*** | -0.3*** | -0.36*** | -0.34*** |
| | (-6.12) | (-4.48) | (-2.96) | (-5.01) | (-4.19) | (-3.96) | (-2.87) | (-2.81) | (-2.84) | (-2.87) |

A complete life-cycle story

# Conclusions

**Patent Intensity:** Unifies and expands the literature. High PI firms have higher cost of capital, in line with theories of innovation heterogeneity.

**Life Cycle:** Dynamics of returns, characteristics, and loadings match innovator life cycle

**Pricing:** Cannot use FF5 for innovators (so really no point using it at all)

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- The best way to know: Ask McLean and Pontiff in 20 years :)

Thank you!