Technological Innovation: Winners and Losers

Leonid Kogan

1MIT and NBER

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Traditional asset pricing models relate measures of risk (betas) to expected returns: both are endogenous objects.

Models with production can relate risk and returns to more primitive objects: technology, preferences, etc.

Explore economic sources of stock return dynamics. Aim to model a rich cross-section of firms, ideally with realistic aggregate time-series dynamics.

Focus on the supply side, de-emphasize demand-side considerations like sentiment shocks.

Start with a basic neoclassical model, then introduce embodied technological innovation.
Sources

Firm characteristics and returns I

- A basic neoclassical model.
- Financial markets are complete and frictionless, $\pi_t$ denotes the SDF.
- A competitive firm produces output using physical capital $K$ and labor $L$:

$$Y_t = X_t K_t^\alpha L_t^{1-\alpha}$$

$X_t$: total factor productivity

- The firm accumulates capital through investment:

$$K_{t+1} = (1 - \delta) K_t + I_t$$

- Convex adjustment costs: adding $I_t$ units of capital costs

$$\phi(I_t/K_t) K_t$$
Firm characteristics and returns II

The firm maximizes present value of discounted dividends:

$$V(s_0, K_0) = \max_{\{I_s, L_s\}} E_0 \left[ \sum_{s=0}^{\infty} \pi_s D_s \right]$$

where dividends $D_t$ are

$$D_t = Y_t - \phi \left( \frac{I_t}{K_t} \right) K_t - W_t L_t$$

Firm optimization implies a relation among endogenous variables: expected stock returns, firm investment, and profitability.

Relate all the endogenous variables to the productivity process (TFP).
Models based on the neoclassical framework have had limited empirical success in asset pricing applications.

Typically, these models have several counterfactual properties:

- conditional CAPM tends to hold either perfectly or approximately,
- return comovement and cross-section of average returns are not empirically realistic,
- general equilibrium models also have trouble addressing aggregate time-series patterns,
- etc.

The problem is partly due to how productivity shocks enter the model: they affect new investments in the same manner as existing capital stock.

Consider an alternative approach: model technological progress as embodied in new productive capital.
Not all productivity shocks have the same effect. Some shocks can be viewed as labor-augmenting, while others affect productivity of new capital investments.

Solow (1960) on disembodied technological change:

“The striking assumption is that old and new capital equipment participate equally in technical change. This conflicts with the casual observation that many if not most innovations need to be embodied in new kinds of durable equipment before they can be made effective. Improvements in technology affect output only to the extent that they are carried into practice either by net capital formation or by the replacement of old-fashioned equipment by the latest models...”

We focus on embodied, or investment-specific technology (IST) shocks.

Embodied nature of technological progress has economically significant implications for asset pricing.
Embodied technology shocks II

- Model embodied shocks as changes in the quality-adjusted price of new investment goods.

Cost in 2010 dollars

- $5,000; state-of-the-art IBM server, today:
- $5,100,000; Burroughs 205, in 1960:
- $160,833,333; computer with same CPU power as IBM server, in 1960 (using NIPA quality-adjusted price index for computers)
Embodied technology shocks III

- Key points: we need to think carefully about ownership and risk-sharing arrangements in the economy. Who exactly benefits from embodied shocks? Which firms, which households?

- Representative-household + representative-firm paradigm is not adequate, need an alternative framework.

- Start with a partial-equilibrium model emphasizing firm heterogeneity, then construct a full general equilibrium model with heterogeneous firms, heterogeneous households and imperfect risk sharing.
Firm characteristics and stock returns

(Kogan and Papanikolaou, 2013)

Sorting firms on certain characteristics leads to

- Differences in average returns
  - Return differences not captured by the CAPM: (in most cases) negative relation between average returns and market betas

- Long-short portfolios that are “return factors”
  - These return factors are not spanned by the market portfolio
## Return factors are systematic

<table>
<thead>
<tr>
<th></th>
<th>Tobin's Q</th>
<th>IK</th>
<th>EP</th>
<th>$\beta^{mkt}$</th>
<th>IVOL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hi-Lo</td>
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</tr>
<tr>
<td>$E(R) - r_f$(%)</td>
<td>-8.79</td>
<td>-4.94</td>
<td>8.91</td>
<td>-1.97</td>
<td>-5.86</td>
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<tr>
<td></td>
<td>(-3.26)</td>
<td>(-1.42)</td>
<td>(3.00)</td>
<td>(-0.52)</td>
<td>(-0.95)</td>
</tr>
<tr>
<td>$\sigma$(%)</td>
<td>20.75</td>
<td>24.86</td>
<td>19.72</td>
<td>26.47</td>
<td>37.05</td>
</tr>
<tr>
<td>$\beta^{mkt}$</td>
<td>0.29</td>
<td>0.62</td>
<td>-0.25</td>
<td>0.75</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>(1.66)</td>
<td>(2.91)</td>
<td>(-1.62)</td>
<td>(4.26)</td>
<td>(3.97)</td>
</tr>
<tr>
<td>$\alpha$(%)</td>
<td>-10.27</td>
<td>-8.04</td>
<td>10.15</td>
<td>-5.71</td>
<td>-10.78</td>
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<tr>
<td></td>
<td>(-3.64)</td>
<td>(-2.41)</td>
<td>(3.51)</td>
<td>(-1.87)</td>
<td>(-1.83)</td>
</tr>
<tr>
<td>$R^2$(%)</td>
<td>6.55</td>
<td>20.13</td>
<td>5.11</td>
<td>25.93</td>
<td>22.85</td>
</tr>
</tbody>
</table>

- 1965-2008 period.
- Use only the firms producing consumption goods (motivated by the model below). Exclude investment-good producers, utilities, financial firms.
- Tobin's $Q$ is market cap of common equity plus long-term debt (DLTT) plus preferred equity (PSTKRV) minus deferred taxes (TXDB), divided by book value of capital (PPEGT). Investment rate (IK) is capital expenditures (CAPX) divided by lagged gross property, plant and equipment (PPEGT). Earnings to price (EP) is operating income (IB) plus interest payments (XINT) divided by market cap of common equity plus long-term debt (DLTT) plus preferred equity (PSTKRV) minus deferred taxes (TXDB). Estimate market beta using past 1 year of weekly data. Estimate idiosyncratic volatility using past 1 year of weekly data from a two-factor model using market portfolio and IMC returns.
The above patterns are related.

Extract first principal component (PC1) from market-residuals

Return factors from each cross-section are correlated

- I.e. not only do high-IK firms comove with other high-IK firms, but they also comove with high-$\beta^{mkt}$, high-Q, low-EP and high-IVOL firms

- Not mechanically driven by common membership ($\rho(sort) \approx 20 – 30\%$).

Correlation of leading principal components

<table>
<thead>
<tr>
<th></th>
<th>IK</th>
<th>EP</th>
<th>IVOL</th>
<th>$\beta^{mkt}$</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL (IK, EP, IVOL, $\beta^{mkt}$, Q)</td>
<td>92.0</td>
<td>77.9</td>
<td>46.8</td>
<td>89.7</td>
<td>74.2</td>
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<tr>
<td>(p-value)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.03)</td>
<td>(0.00)</td>
<td>(0.00)</td>
</tr>
</tbody>
</table>
Average returns versus model-implied premia

Common principal component prices all five cross-sections

A. CAPM

\[ \beta_{MKT} E(R_p^e) = \beta_{p, MKT} E(R_{M}^e) \]

B. Factor model (MKT, PC1)

\[ \beta_{p, MKT} E(R_p^e) + \beta_{p, PC1} E(R_{PC1}^e) \]

Kogan (2013)
Main idea

- We establish an endogenous relation between firm characteristics and risk exposures.

- A natural way to think about firm heterogeneity in risk exposures is to de-compose firm value into
  - Growth Opportunities (GO)
  - Assets in Place (AP)

- GO and AP components of firm value have different exposures to capital-embodied productivity shocks: AP stand to benefit less from improvements in future real investment opportunities.

- Characteristics reflect the share of growth opportunities in firm value – IST shocks give rise to a return factor common to various characteristic-sorted portfolios.
Assets in Place

- Each firm $f$ operates a finite portfolio of projects.
- Project $j$ produces a stochastic stream of cash flows

$$y_{jt} = x_t u_{jt} K_j^\alpha$$

- $K_j$: physical capital, invested irreversibly
- $x_t$: aggregate disembodied productivity process

$$dx_t = \mu x_t \, dt + \sigma x_t \, dB_x, t$$

- $u_{jt}$: project-specific productivity component
Investment

- Projects arrive exogenously at different rates across firms, $\lambda_{f,t}$.
- At time $t$, cost of creating a project with scale $K_j$ is
  \[ z_t^{-1} x_t K_j \]
- Quality-adjusted cost of investment declines with IST shock $z_t$
  \[ dz_t = \mu_z z_t \, dt + \sigma_z z_t \, dB_{z,t}, \quad dB_{z,t} \, dB_{x,t} = 0 \]
Valuation

- Assume that aggregate productivity shocks and investment specific shocks have constant market prices of risk \( \gamma_x \) and \( \gamma_z \):

\[
\frac{d\pi_t}{\pi_t} = -r \, dt - \gamma_x \, dB_{x,t} - \gamma_z \, dB_{z,t}
\]

- Present value of assets is place is

\[
VAP_{f,t} = \sum_j A(u_{j,t}) x_t K_j^{\alpha}
\]

- Present value of growth opportunities equals the NPV of future projects

\[
PVGO_{f,t} = E_t \left[ \int_t^\infty \left( \frac{\pi_s}{\pi_t} \right) \lambda_f \, NPV_t \, ds \right] = z_t^{\frac{\alpha}{1-\alpha}} \, x_t \, F(\lambda_{f,t})
\]

- Growth opportunities benefit from reduction in investment cost, assets in place do not.
Growth opportunities and systematic risk

- Firm value can be decomposed as
  \[ V_{f,t} = VAP_{f,t} + PVGO_{f,t} \]

- VAP and PVGO have different risk exposures:
  \[
  \begin{array}{c|cc}
  & \beta_x & \beta_z \\
  \hline
  VAP & 1 & 0 \\
  PVGO & 1 & \frac{\alpha}{1-\alpha}
  \end{array}
  \]

- Firm’s risk:
  \[ \beta_{f,x} = 1, \quad \beta_{f,z} = \frac{\alpha}{1-\alpha} \left( \frac{PVGO_{f,t}}{V_{f,t}} \right) \]

- IST shocks generate return comovement.

- Firm risk premium depends on mix between PVGO and VAP
  \[
  \frac{1}{dt} E_t[R_{ft}] - r_f = \gamma_x \sigma_x + \frac{\alpha}{1-\alpha} \gamma_z \sigma_z \frac{PVGO_{ft}}{V_{ft}}
  \]
Calibration

- Calibrate model to match
  - First two moments of aggregate dividend and investment growth;
  - Firm-level relation between investment, Tobin’s Q and stock returns;
  - Persistence of firm profitability and investment;
  - Dispersion in firm size, investment rate, Tobin’s Q, profitability, IST-beta.

- Dispersion in risk premia depends on price of IST risk $\gamma_z$.
  - Estimate $\gamma_z = -0.57$ from cross-section of industry portfolios using shocks to equipment price as proxy.
### Asset prices

<table>
<thead>
<tr>
<th></th>
<th>Tobin’s Q</th>
<th>IK</th>
<th>EP</th>
<th>MBETA</th>
<th>IVOL</th>
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<tbody>
<tr>
<td><strong>Data</strong></td>
<td>Hi-Lo</td>
<td>Hi-Lo</td>
<td>Hi-Lo</td>
<td>Hi-Lo</td>
<td>Hi-Lo</td>
</tr>
<tr>
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<td>37.05</td>
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<tr>
<td>$\beta_{mkt}$</td>
<td>0.29</td>
<td>0.62</td>
<td>-0.25</td>
<td>0.75</td>
<td>0.98</td>
</tr>
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<td>5.11</td>
<td>25.93</td>
<td>22.85</td>
</tr>
<tr>
<td><strong>Model</strong></td>
<td>Hi-Lo</td>
<td>Hi-Lo</td>
<td>Hi-Lo</td>
<td>Hi-Lo</td>
<td>Hi-Lo</td>
</tr>
<tr>
<td>$E(R) - rf$ (%)</td>
<td>-5.27</td>
<td>-4.81</td>
<td>7.21</td>
<td>-5.55</td>
<td>-5.24</td>
</tr>
<tr>
<td>$\sigma$ (%)</td>
<td>6.89</td>
<td>4.41</td>
<td>13.33</td>
<td>9.84</td>
<td>7.03</td>
</tr>
<tr>
<td>$\beta_{mkt}$</td>
<td>0.31</td>
<td>0.22</td>
<td>-0.74</td>
<td>0.54</td>
<td>0.36</td>
</tr>
<tr>
<td>$\alpha$ (%)</td>
<td>-7.13</td>
<td>-6.23</td>
<td>11.94</td>
<td>-8.98</td>
<td>-7.56</td>
</tr>
<tr>
<td>$R^2$ (%)</td>
<td>53.34</td>
<td>53.01</td>
<td>64.23</td>
<td>63.49</td>
<td>54.79</td>
</tr>
</tbody>
</table>
Further empirical tests

- IST shocks and
  - Stock return comovement;
  - Investment rate comovement;
  - Output growth comovement.

- Firm characteristics and IST-shock exposures

- Asset pricing tests
  - GMM asset-pricing tests;
  - Cross-sectional relations between risk and characteristics.
Investment comovement

- Model: investment of high-PVGO/V firms is more responsive to IST shocks.

- Estimate investment response to proxy for $z$-shock as a function of characteristic $G$

$$i_{ft} = a_1 + \sum_{d=2}^{5} a_d D(G_{f,t-1})_d + cX_{f,t-1} + \gamma_f$$

$$+ b_1 \Delta z_{t-1} + \sum_{d=2}^{5} b_d D(G_{f,t-1})_d \times (\Delta z_{t-1}) + u_{ft}$$

- $G_f \in \{Q, IK, EP, \beta_m^{mkt}, IVOL\}$. 

Kogan (2013)
Investment response to embodied shocks

Proxy for IST shocks empirically using quality-adjusted price of equipment

<table>
<thead>
<tr>
<th>$IK_{ft}$</th>
<th>Model</th>
<th>Data ($\Delta z^t$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$Q$</td>
<td>$IK$</td>
</tr>
<tr>
<td>$\Delta z_{t-1}$</td>
<td>2.49</td>
<td>1.93</td>
</tr>
<tr>
<td></td>
<td>(5.12)</td>
<td>(4.73)</td>
</tr>
<tr>
<td>$D(G_f)<em>{2} \times \Delta z</em>{t-1}$</td>
<td>0.17</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>(1.27)</td>
<td>(3.53)</td>
</tr>
<tr>
<td>$D(G_f)<em>{3} \times \Delta z</em>{t-1}$</td>
<td>0.50</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td>(2.83)</td>
<td>(4.84)</td>
</tr>
<tr>
<td>$D(G_f)<em>{4} \times \Delta z</em>{t-1}$</td>
<td>0.82</td>
<td>1.56</td>
</tr>
<tr>
<td></td>
<td>(4.19)</td>
<td>(5.66)</td>
</tr>
<tr>
<td>$D(G_f)<em>{H} \times \Delta z</em>{t-1}$</td>
<td>1.42</td>
<td>2.34</td>
</tr>
<tr>
<td></td>
<td>(4.97)</td>
<td>(6.84)</td>
</tr>
</tbody>
</table>

- *t*-statistics in parentheses, SE clustered by firm and year
### Investment response to PC1

<table>
<thead>
<tr>
<th>$IK_{ft}$</th>
<th>Q</th>
<th>IK</th>
<th>EP</th>
<th>$\beta^{mkt}$</th>
<th>IVOL</th>
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<td>$\Delta z_{t-1}$</td>
<td>-0.23</td>
<td>0.17</td>
<td>1.14</td>
<td>-0.10</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>(-0.84)</td>
<td>(0.77)</td>
<td>(2.00)</td>
<td>(-0.29)</td>
<td>(0.13)</td>
</tr>
<tr>
<td>$D(G_f)<em>2 \times \Delta z</em>{t-1}$</td>
<td>0.24</td>
<td>-0.08</td>
<td>-1.03</td>
<td>-0.07</td>
<td>0.05</td>
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<tr>
<td></td>
<td>(2.03)</td>
<td>(-0.65)</td>
<td>(-1.89)</td>
<td>(-0.44)</td>
<td>(0.36)</td>
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<tr>
<td>$D(G_f)<em>3 \times \Delta z</em>{t-1}$</td>
<td>0.40</td>
<td>0.13</td>
<td>-1.18</td>
<td>0.03</td>
<td>0.38</td>
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<td></td>
<td>(2.92)</td>
<td>(0.93)</td>
<td>(-2.20)</td>
<td>(0.18)</td>
<td>(0.19)</td>
</tr>
<tr>
<td>$D(G_f)<em>4 \times \Delta z</em>{t-1}$</td>
<td>0.54</td>
<td>0.13</td>
<td>-1.22</td>
<td>0.20</td>
<td>0.50</td>
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<td></td>
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<td>(-2.92)</td>
<td>(3.07)</td>
<td>(2.53)</td>
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Innovation: Winners and Losers  
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Price of IST shocks: GMM

- GMM tests of the stochastic discount factor (SDF): deciles 1, 2, 9, and 10 of portfolios sorted on all five characteristics

\[ m = a - \gamma_x \Delta x - \gamma_z \Delta z, \quad E[R_i^e] = -\text{Cov}(R_i^e, m) \]

<table>
<thead>
<tr>
<th>Factor price</th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta x )</td>
<td>0.75</td>
<td>-0.77</td>
</tr>
<tr>
<td></td>
<td>[0.04, 1.46]</td>
<td>[-1.80, 0.25]</td>
</tr>
<tr>
<td>( \Delta z^I )</td>
<td>-1.35</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[-2.24, -0.46]</td>
<td></td>
</tr>
<tr>
<td>MAPE (%)</td>
<td>3.85</td>
<td>1.87</td>
</tr>
</tbody>
</table>

- Negative price of IST shocks. Consistent with estimation using B/M, \( \beta^{inc} \), industry portfolios; and Q/Profitability double-sort.
IST shocks are an important source of stock return comovement.

Firm characteristics (Q, EP, IK, $\beta^{mkt}$, IVOL) are correlated with firms’ exposures to IST shocks.

Connect the cross-section of asset returns and macroeconomic shocks.

To understand how embodied innovation shocks are priced, need a general-equilibrium model.

Emphasize heterogeneous impact of innovation on firms and households: there are winners and losers due to innovation shocks.
Innovation and displacement

- Key idea – embodied innovations lead to displacement: existing firms by new firms, existing households by future innovators.
Technological innovation: winners and losers

(Kogan, Papanikolaou and Stoffman, 2013)

- Technological innovation and displacement (Schumpeter (1942) and creative destruction).
  - “innovation” = embodied technological change;
  - “innovation” ≠ total factor productivity.

- What determines the price of innovation risk?

- What determines cross-sectional differences in exposures to innovation risk?

- Technological innovation can have heterogenous impact on economic agents:
  - workers vs owners of capital;
  - new vs existing households;
  - growth versus value firms.
A two-period illustration I

- Consumption is produced using capital and labor.
- Two vintages of capital, new and old.
- Stockholders:
  - At time 0, old capital stock $K_0$ owned by existing shareholders;
  - At time 1, measure $\mu$ of new capital owners arrives with new capital $K_n$;
  - Capital owners have preferences over consumption:
    \[
    U(C_0, C_1) = \ln C_0 + E_0 \ln C_1
    \]
- Workers:
  - At time 0 unit measure of workers, $L_0 = 1$;
  - At time 1 measure $\mu$ of workers arrives, $L_1 = 1 + \mu$
  - Workers do not participate in financial markets.
A two-period illustration II

- In period 0 or 1, output can be produced with the old technology:

\[ Y_{o,t} = K_o^\alpha L_{o,t}^{1-\alpha}, \quad t = 0, 1. \]

- In period 1, a new technology becomes available:

\[ Y_{n,1} = (\xi K_n)^\alpha L_{n,1}^{1-\alpha}, \quad \text{where} \quad \xi > 0 \]

- Capital is technology-specific.

- Labor can work in either the old or the new technology:

\[ L_{o,1} + L_{n,1} = L_1 \]
A two-period illustration III

- Labor allocation at time 1 determines output of old and new technology

\[ L_{o,1} = \frac{1 + \mu}{1 + \xi \mu} \quad \text{and} \quad L_{n,1} = \xi \mu \frac{1 + \mu}{1 + \xi \mu} \]

- At time 0, only old capital owners participate in the stock market.

- Stockholder consumption growth between 0 and 1 is

\[ \frac{C_{o,1}}{C_{o,0}} = \left( \frac{1 + \mu}{1 + \xi \mu} \right)^{1-\alpha} \]

- A claim on output of \( K_n \) is a hedge against consumption decline and has a relatively low expected return:

\[ E[R_{n,1}] < E[R_{0,1}] \]
Main insight

- Technological progress embodied in new capital
  - Reduces value of old capital;
  - Benefits labor if not tied to a specific technology.

- Inability to share risks with workers or the unborn implies that existing capital owners are willing to “overpay” to invest in new technology.
The model

- A general-equilibrium model with heterogeneous firms and households, imperfect risk sharing.

- Technological progress is embodied in new vintages of capital.

- Innovation reduces value of old capital relative to new.

- Embodied shock raises marginal utility of **financial market participants**
  - Limited intergenerational risk-sharing: new cohorts of inventors benefit relative to existing capital owners;
  - Limited stock market participation: workers benefit relative to capital owners.

- Assets that help hedge displacive innovation shocks earn lower risk premia
  - Labor income and firms with high growth opportunities.
Quantitative performance highlights

- High equity risk premium with low consumption volatility, low and stable risk-free rate.
- Low correlation between consumption growth and stock market returns.
- Volatile dividend growth, low correlation with aggregate consumption.
- Value premium, value factor, failure of the CAPM.

**Key feature:** consumption of marginal investors diverges from aggregate consumption due to embodied shocks.
Response to disembodied shock

- a. Investment
- b. Dividends
- c. Labor income
- d. Consumption, aggregate
- e. Consumption, existing stockholders
- f. Consumption, existing stockholders (relative to total)
Response to embodied shock

- Investment
- Dividends
- Labor income
- Consumption
- Consumption of existing stockholders
- Consumption of existing stockholders relative to total
Measurement of innovation shocks I

■ How to measure embodied shocks?

■ Use KPSS2012 innovation measure:

  → patents \approx \text{new projects};

  → measure market reaction to a patent, \hat{A}_j;

  → aggregate across all patents in a given year, A_t;

  → \hat{A}_t is a function of the aggregate state in the model – reveals the rate of displacement in the economy.
Measurement of innovation shocks II

<table>
<thead>
<tr>
<th>Moment</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation of $\Delta \ln A_t$ with $\Delta \xi_t$</td>
<td>75.3</td>
</tr>
<tr>
<td>Correlation of $\Delta \ln A_t$ with $\Delta x_t$</td>
<td>1.3</td>
</tr>
<tr>
<td>Correlation of $\ln A_t$ with aggregate state</td>
<td>93.4</td>
</tr>
</tbody>
</table>
### Stochastic discount factor: GMM test

#### 4 B/M + 4 I/K portfolios

<table>
<thead>
<tr>
<th>Factor</th>
<th>Data</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>Δ ln $X_t$</td>
<td>3.19</td>
<td>-0.54</td>
</tr>
<tr>
<td></td>
<td>[3.99]</td>
<td>[-1.08]</td>
</tr>
<tr>
<td>Δ ln $C_t$</td>
<td></td>
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<tr>
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</tr>
<tr>
<td>Δ ln $A$</td>
<td>-0.83</td>
<td>-1.03</td>
</tr>
<tr>
<td></td>
<td>[-3.64]</td>
<td>[-3.88]</td>
</tr>
<tr>
<td>MAPE</td>
<td>3.10</td>
<td>1.06</td>
</tr>
</tbody>
</table>

- Aggregate CCAPM fails in the model and the data.
Additional evidence

- Innovation predicts lower consumption for stockholders relative to non-stockholders.

- Household cohorts:
  - Positive innovation has negative impact on consumption of earlier cohorts;
  - Level of innovation upon entry has permanent effect on consumption level.

- Firms:
  - Revenue of value/growth firms responds differently to innovation by competitors;
  - Stock returns of value/growth firms have different sensitivity to aggregate innovation shocks.
Focusing on embodied technological growth, rather than modeling technology shocks as disembodied, matters for asset pricing.

Models with embodied shocks can overcome many weaknesses of the standard models driven by TFP shocks.

More importantly, considering embodied shocks forces us to focus on a different set of issues, bringing in new types of data to bear on asset pricing question (e.g., cohort effects in household consumption, patent data, etc.).

Many research questions can be re-examined in this framework with new insights.