Capital Heterogeneity and Investment Prices

How much are investment prices declining?

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Motivation

Farhi and Gourio: "Accounting for Macro-Finance Trends"

- Study joint evolution of big macro-finance trends:
    - declining interest rates despite stable ROA,
    - roughly stable stock market P/D since 2000,
    - weak investment and weak growth,
    - low labor share, etc.
- Why jointly? Because proposed explanations for one trend have implications for the others
    - e.g. demographics can explain low interest rates
    - but they imply low ROA and high investment...
    - whack-a-mole situation!

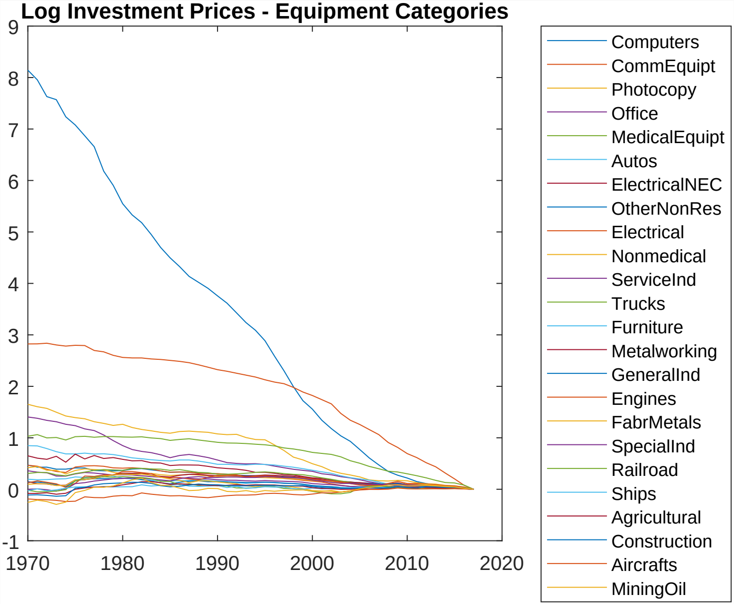
Motivation

- Use simple extension of neoclassical growth model to measure contribution of several drivers
  - Higher perceived risk since 2000,
  - Why? P/D roughly stable despite much lower rates,
  - Risk helps explain investment, ROA, rates, etc.
  - Also: role of market power, savings demand, TFP growth, ... and **Investment-Specific Technical Change (ISTC)**
- We noticed some puzzling patterns in ISTC data, and wanted to improve our framework's approach to ISTC

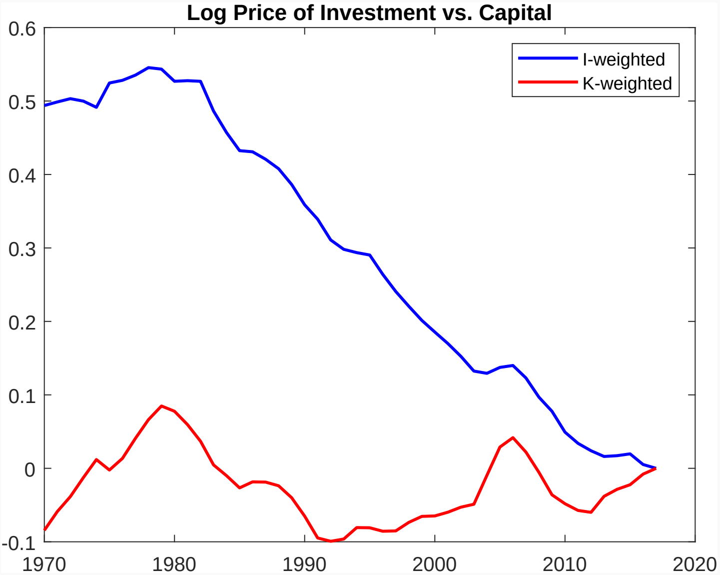
How important is ISTC?

- Vast literature argues ISTC relevant for key macro facts:
  - Growth (e.g., Greenwood, Hercovitz and Krusell 1997)
  - Business cycles (e.g., Fisher 2006)
  - Labor Share (e.g., Karabarbounis and Neiman 2012)
  - Decline of r^* (e.g, Summers 2014, Sajedi and Thwaites 2016)
- ISTC measured using price of new investment goods
- But: huge heterogeneity in price trends - aggregation?

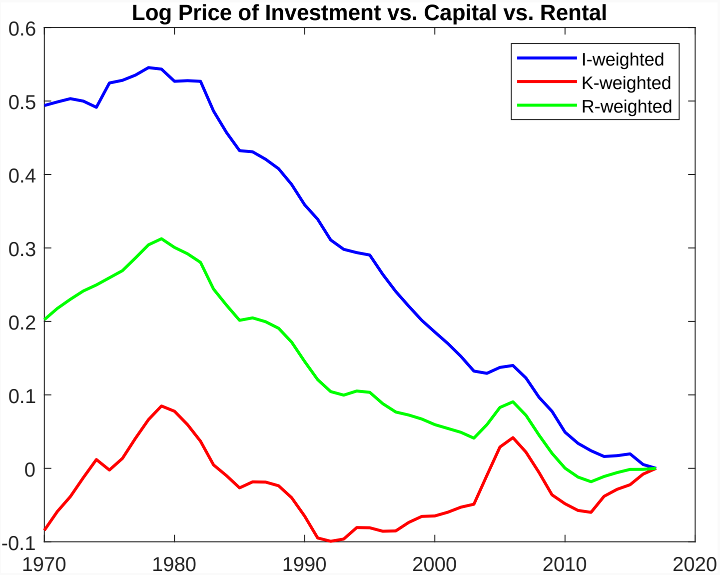
Heterogeneity in Equipment Price Trends



Flow- and Stock-weighted Prices



Flow-, Stock-, and Rental-weighted Prices



Outline

1. Simple framework
2. Role of ISTC for growth
3. Role of ISTC for "big ratios"
4. More quickly:
    - Role of ISTC for business cycles
    - Role of ISTC for labor share
    - Role of ISTC for r^*

Simple Framework

Simple Model

Utility function:

$$U = \int_0^\infty e^{-\rho t} \frac{C_t^{1-\sigma}}{1-\sigma} dt$$

Production function:

$$Y_t = A_t L_t^{\alpha_L} K_{1t}^{\alpha_{K_1}} .. K_{nt}^{\alpha_{K_n}}$$

Capital accumulation for each type:

$$\dot{K}_{it} = I_{it} - \delta_i K_{it}$$

Resource constraint:

$$Y_t = C_t + \sum_{i=1}^{n} p_{it} I_{it}$$

Exogenous: A_t, L_t, p_{it}

Equilibrium

Euler equation:

$$\frac{\dot{C}_t}{C_t} = \frac{r_t - \rho}{\sigma},$$

Perfect competition capital demand:

$$\alpha_{K_i} \frac{Y_t}{K_{it}} = R_{it} = p_{it} \left(r_t + \delta_i - \frac{\dot{p}_{it}}{p_{it}} \right),$$

Rearrange:

$$\frac{p_{it} K_{it}}{Y_t} = \frac{\alpha_{K_i}}{r_t + \delta_i - g_{p_i}}.$$

Implies that on the BGP,

$$g_{K_i} = g_Y - g_{p_i}$$

Equilibrium growth rate

Production function:

$$g_Y = g_A + \alpha_L g_L + \sum_{i=1}^{n} \alpha_{K_i} g_{K_i},$$

Use $g_{K_i} = g_Y - g_{p_i}$:

$$g_Y - g_L = \frac{g_A - \alpha_K g_{p^R}}{\alpha_L}$$

Where

$$g_{p^R} \equiv \frac{\sum_{i=1}^{n} \alpha_{K_i} g_{p_i}}{\sum_{i=1}^{n} \alpha_{K_i}}$$

$\Longrightarrow$ Aggregate invt prices using **rental weights**

Price Indices: Definitions

General (Divisia) index p_t^s for given shares $\{s_{it}\}$:

$$\frac{\dot{p}_t^s}{p_t^s} = \sum_{i=1}^{n} s_{it} \frac{\dot{p}_{it}}{p_{it}}$$

Flow-weighted (NIPA) (I-w):

$$s_{it}^I \propto p_{it} I_{it}$$

Stock-weighted (FAT) (K-w):

$$s_{it}^K \propto p_{it} K_{it}$$

Rental-weighted (R-w):

$$s_{it}^R \propto R_{it} K_{it}$$

Rental-shares, Stock-shares, Flow-shares

Rental weights:

$$s_{it}^{R} = \frac{R_{it} K_{it}}{\sum_{j=1}^{n} R_{jt} K_{jt}} \propto \alpha_{K_i}$$

Stock weights:

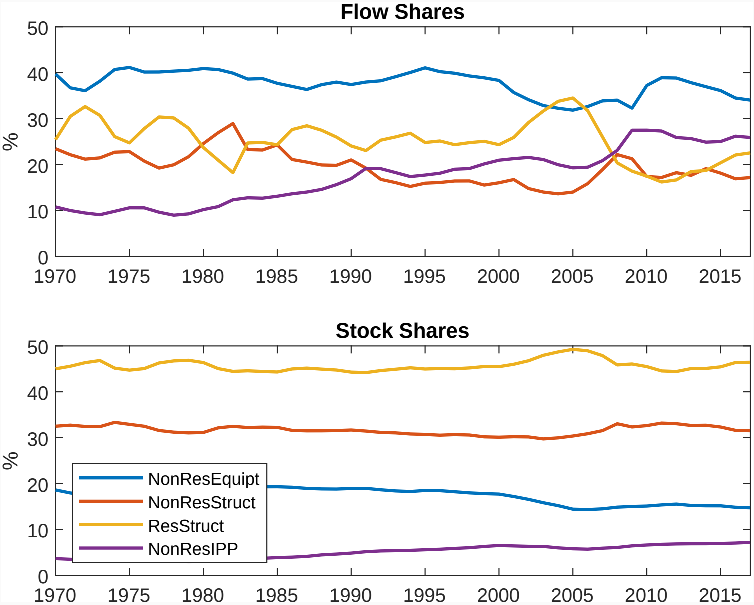
$$s_{it}^{K} = \frac{p_{it} K_{it}}{\sum_{j=1}^{n} p_{jt} K_{jt}} \propto \frac{\alpha_{K_i}}{r_t + \delta_i - g_{p_i}}$$

Investment weights **on the BGP**:

$$s_{it}^{I} = \frac{p_{it} I_{it}}{\sum_{j=1}^{n} p_{jt} I_{jt}} \propto \alpha_{K_i} \frac{g_Y + \delta_i - g_{p_i}}{r + \delta_i - g_{p_i}}$$

These shares are **very** different!

I-share and K-share are different!



How to infer rental shares along the BGP

On the balanced growth path:

$$s_i^R = \omega s_i^I + (1-\omega)\, s_i^K$$

where:

$$\omega = \frac{\text{Agg. Invt}}{\text{Agg. Capital Income}}$$

Hence relation between price indices:

$$g_{p^R} = \omega g_{p^I} + (1-\omega)\, g_{p^K}$$

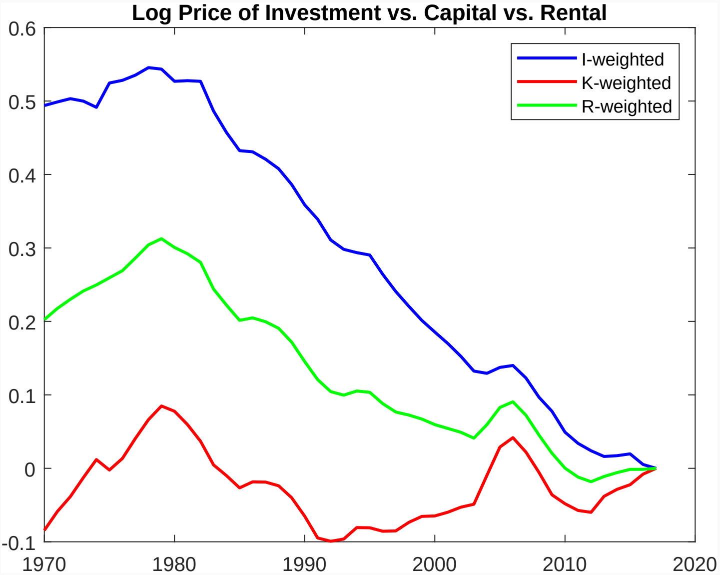
$\implies$ Can infer g_{p^R} from observables

Contribution of ISTC to Growth

Data

- Fixed Asset Tables: All private fixed assets
- Disaggregation in 57 categories
- Ex.: Invt::NonRes Equipt::Info Processing::Computers
- We use the BEA deflators (not Gordon-Violante-Cummins)

Flow- and Stock-weighted Prices



Contribution of ISTC to growth

- GHK: "ISTC contributes 58% to growth"
- Our approach (similar to theirs)
  1. Observe $\alpha_L, \alpha_K, g_{p^R}, g_Y - g_L$
  2. Infer TFP g_A from:

$$g_Y - g_L = \frac{g_A - \alpha_K g_{p^R}}{\alpha_L}$$

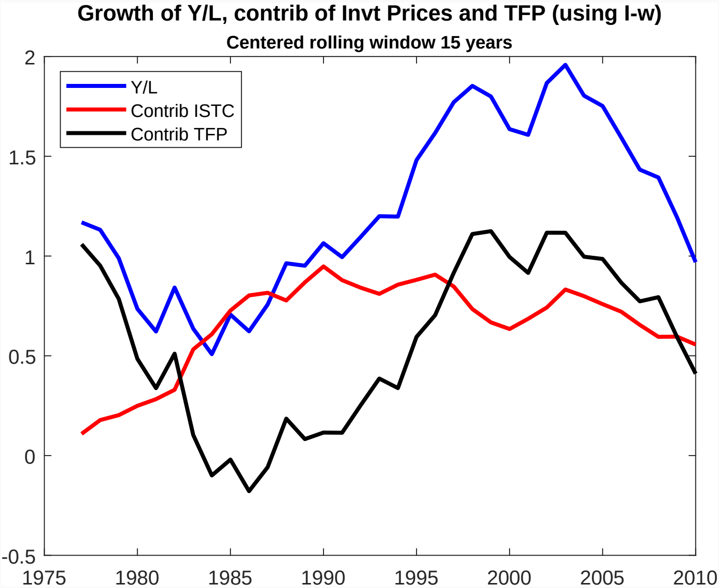
  3. Calculate counterfactual growth if $g_{p^R}=0$
  4. What if use g_{p^I} instead of g_{p^R}

Smaller ISTC contribution with R-weighting

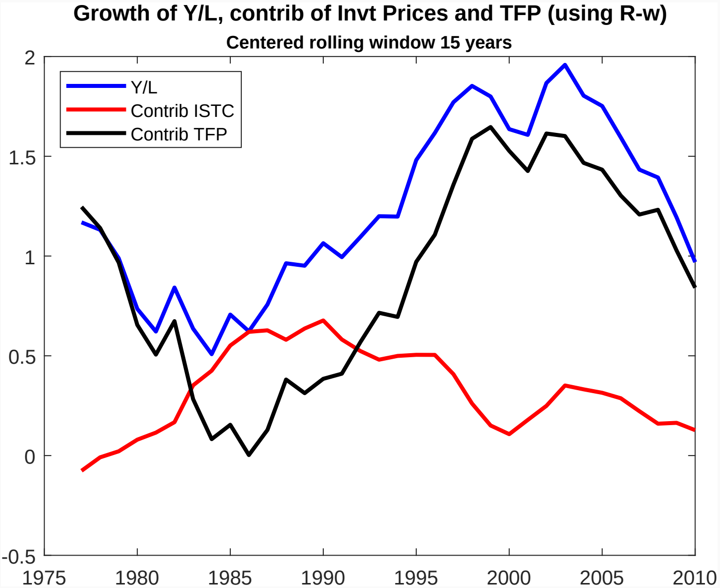
	Data	Iw:ITC	Iw:TFP	Rw:ITC	Rw:TFP
1970-2017	1.19	0.52	0.66	0.21	0.98
(%)	100.00	43.80	55.91	17.46	82.37

Avg. growth of Y/L and contributions of ISTC and TFP using either I-w or R-w to infer ISTC.

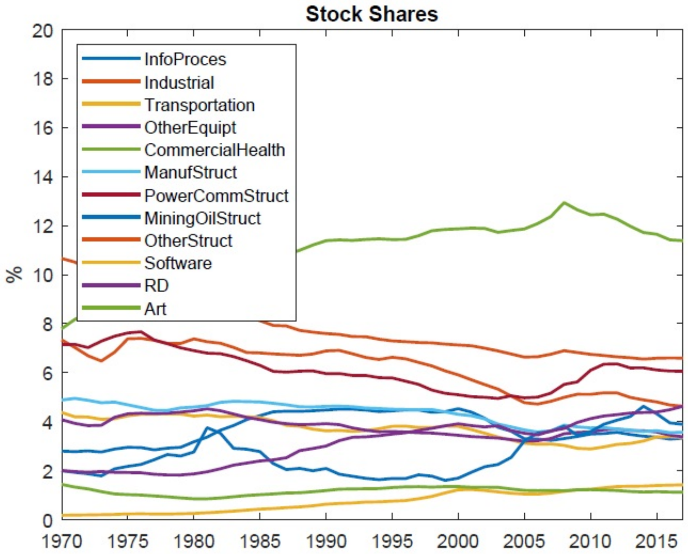
Contributions to Growth: I-w (GHK)



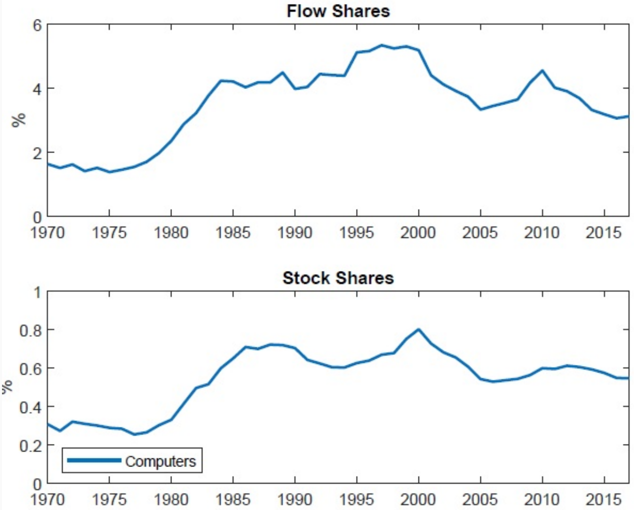
Contributions to Growth: R-w



How stable are shares?



How stable are shares?



ISTC and the Big Ratios

Aggregation

Result: along the BGP,

$$\frac{I}{K} = g_Y + \delta^K - g_{p^K}$$

$$\frac{\Pi}{K} = r + \delta^K - g_{p^K}$$

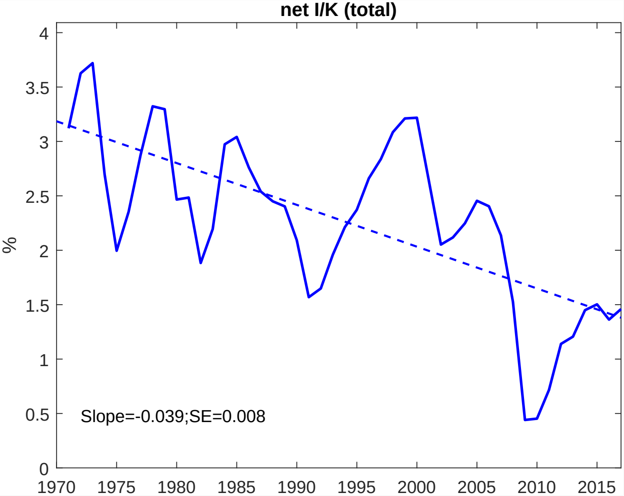
$$\frac{K}{Y} = \frac{\alpha_K}{r + \delta^K - g_{p^K}}$$

where I, K, Π are the (current-cost nominal) aggregates:

$$I = \sum p_i I_i, K = \sum p_i K_i, \Pi = \sum R_i K_i$$

$\Longrightarrow$ To calibrate one-capital model, use **stock-weighted**

Application: the decline of investment



Application: the decline of investment

$$\frac{I}{K} - \delta^K = g_Y - g_{p^K}$$

	Net I/K	Contrib g_y	Contrib g_{pk}	Residual
1990-2004	2.39	2.51	-0.21	0.10
2003-2017	1.51	1.58	-0.37	0.30
Change	-0.89	-0.93	-0.16	0.20
Change If use PI	-0.89	-0.93	-0.69	0.74

ISTC and Business Cycles

Transitional Dynamics (w elastic labor)

$$
\begin{aligned}
\max_{C_t, I_{it}, K_{it}} U &= \int_0^\infty e^{-\rho t} \frac{C_t^{1-\sigma}}{1-\sigma} v(L_t) dt \\
s.t. &: \\
\dot{K}_{it} &= I_{it} - \delta_i K_{it}, i = 1, ..., N \\
Y_t &= C_t + \sum_{i=1}^{N} P_{it} I_{it} \\
Y_t &= A_t L_t^{\alpha_L} K_{1t}^{\alpha_{K_1}} .. K_{nt}^{\alpha_{K_n}}
\end{aligned}
$$

for given $(K_{i0})_{i=1,...,N}$, and $(A_t, (P_{it})_{i=1,...,N})_{t\geq 0}$

Proposition

Consider a "MIT shock" to the level of investment prices P_{i0}: Before $t = 0$, agents expect that

$$P_{it} = P_{i0} e^{g_i t},$$

but after $t = 0$ they expect

$$P_{it} = P'_{i0} e^{g_i t}.$$

Then, for small changes in prices, the *full dynamics* of aggregates $(Y_t, L_t, C_t, I_t)_{t \geq 0}$ (in deviation from BGP) depend only on:

$$\xi = s_I g_{p_I} + (1 - s_I) g_{p_K},$$

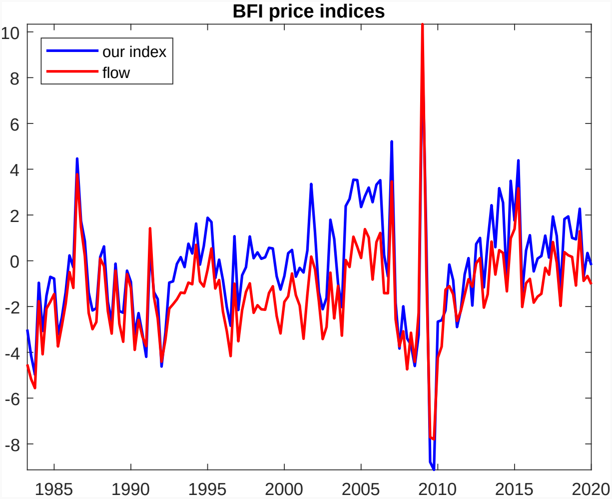
where s_I is the aggregate investment share of GDP, and g_{p_I} and g_{p_K} are the flow-weighted and stock-weighted changes in prices.

Business cycle analysis

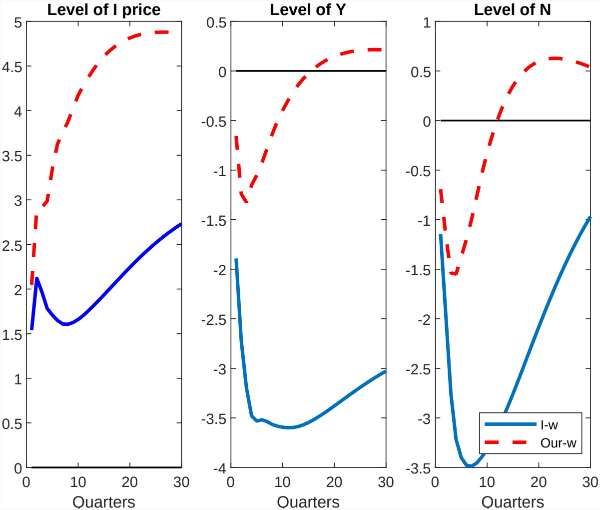
Run Fisher-style VAR:

- 3 variables: dlog(Invt Price), dlog(Y/L), log(L/Pop),
- Long-run restrictions to identify ISTC shock, TFP shock,
- quarterly data, 4 lags, 1982IV-2019IV,
- 14 categories of goods (e.g. info processing),
- Compare I-w and Shock-w.

Price indices

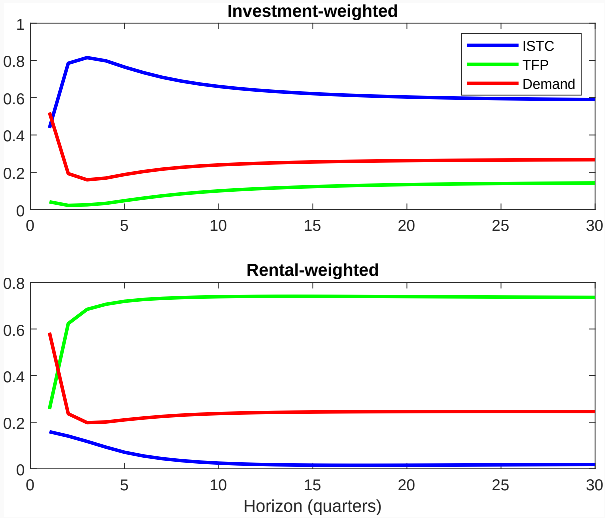


VAR comparison



Variance Decomposition BFI

Share of variance of hours due to ISTC / TFP / demand



ISTC and the Labor share

Labor Share

- If EOS K/L $\sigma \neq 1$, chg invt prices affect labor share
- Model extension:

$$Y = (b_K K^{\frac{\sigma-1}{\sigma}} + b_L L^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}}$$

$$K = K_1^{\gamma_{K_1}} \ldots K_n^{\gamma_{K_n}}.$$

- Note: nonstationary shares if ISTC
- Consider a permanent small shock to vector P_{i0}.
- Then change in gross labor share is:

$$(\sigma - 1)\alpha_K \widehat{p}^R$$

$\implies$ Relevant price for labor share is **R-weighted**

Illustration

Implied change in labor share since 1970
given observed prices changes and assumed EOS:

	Iw	**Rw**
$\sigma = 1.5$	-0.17	-0.07
$\sigma = 1.25$	-0.09	-0.03
$\sigma = 0.75$	0.09	0.03
$\sigma = 0.5$	0.17	0.07

ISTC and the decline of r^*

Decline of r^*

- Lower investment price may reduce eqm interest rate by reducing required invt (e.g. Summers, Sajedi and Thwaites)
- "Lower demand for savings"
- Model extension: upward-sloping savings $W_t L_t S(r_t)$
  - e.g., OLG or Aiyagari
  - Otherwise, r^* pined down by preferences
- Equilibrium in asset market:

$$\sum_{i=1}^{n} p_{it} K_{it} = W_t L_t S(r_t)$$

- Consider a permanent small shock to vector p_{i0}.
- Then change in r^* is $\zeta \widehat{p}^R$
- Correct aggregation for r^* is **R-weighted**

Illustration

Implied change in interest rate since 1990
given observed prices changes and assumed elasticity:

	Iw	**Rw**
$\zeta = .1$	-0.14	-0.06
$\zeta = .2$	-0.27	-0.11
$\zeta = .3$	-0.41	-0.17
$\zeta = .5$	-0.68	-0.28

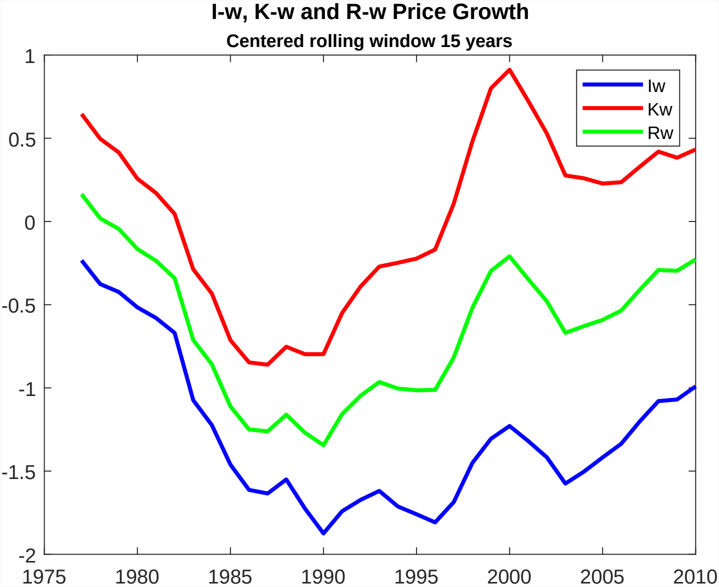
Conclusion

Conclusion

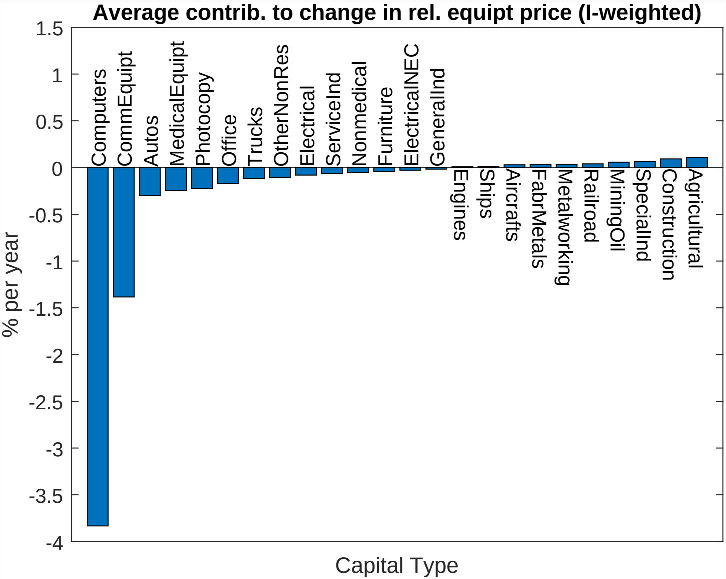
- Methodology: appropriate aggregation
  depends on question at hand! I-w, K-w, R-w, Shock-w ...
- Simple calculations illustrate this can matter
- In progress: relax some simplifying assumptions
  (BGP, perfect competition, Cobb-Douglas, ...)

Backup

Rolling windows: Price Growth



Contributions to Equipment Deflator



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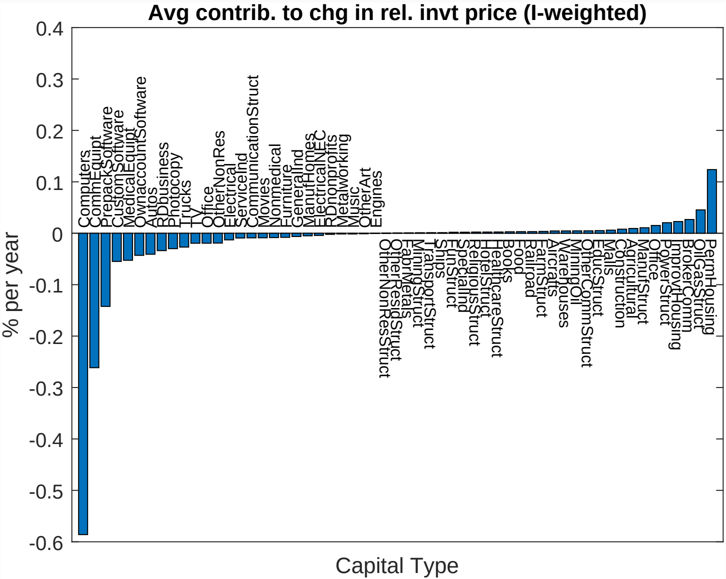
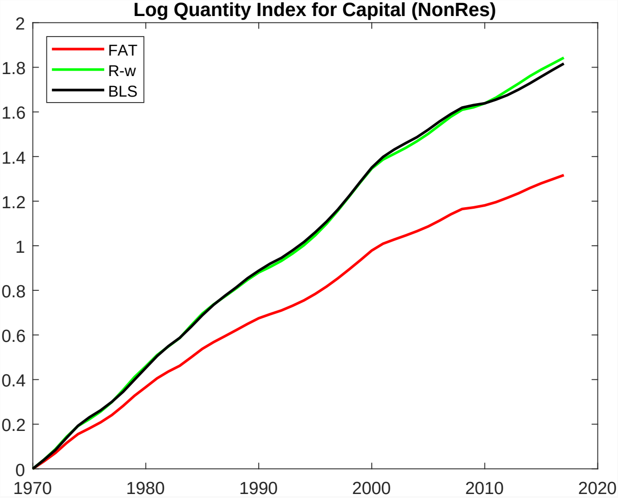
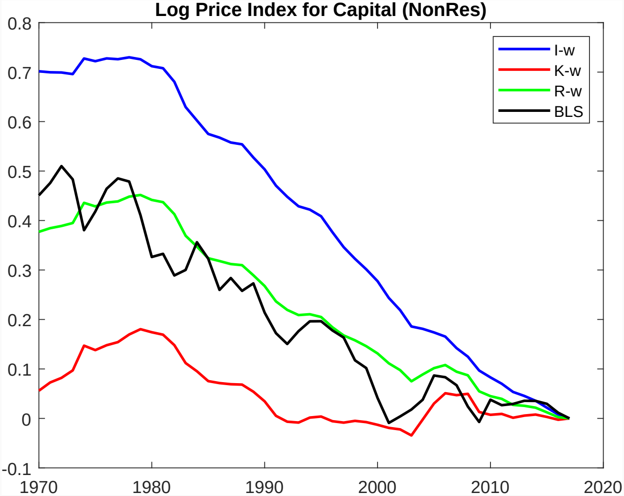


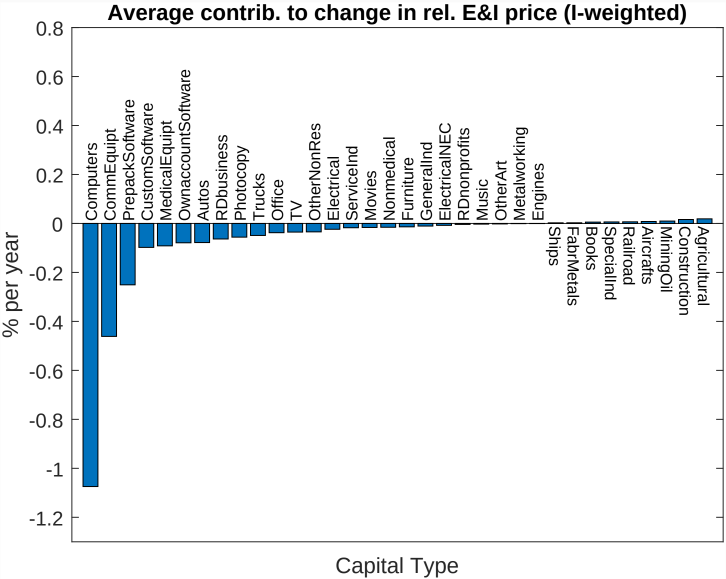
Comparison with BLS



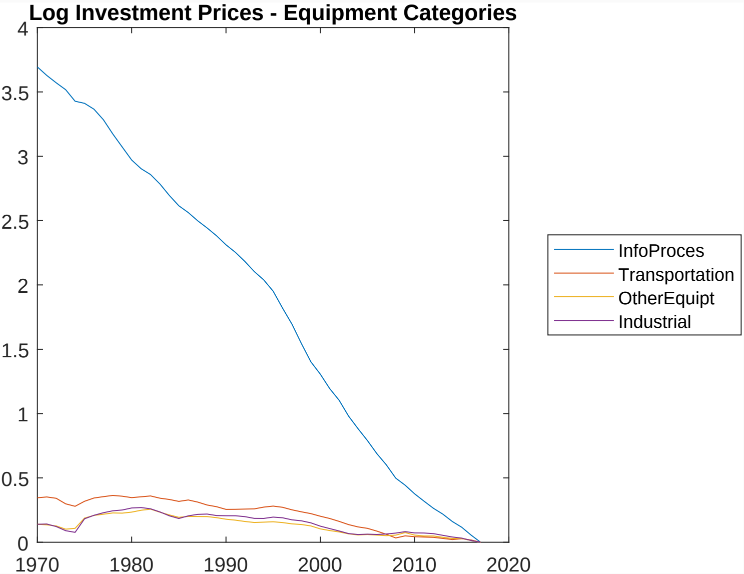
Comparison with BLS



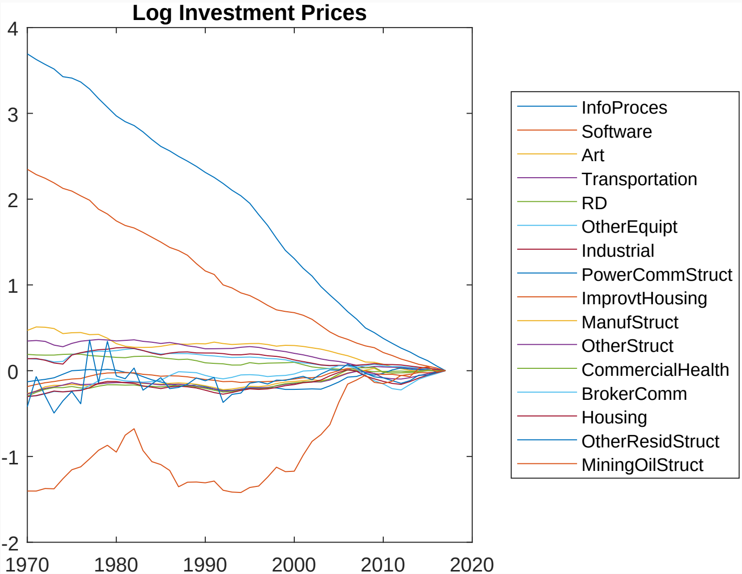
Contributions to I-w E&I price



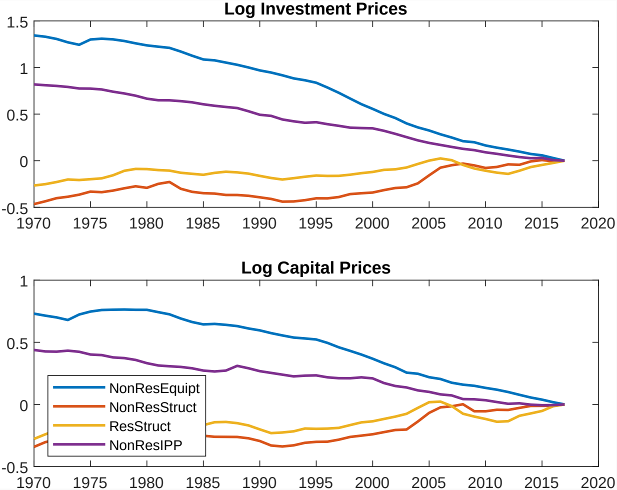
Prices


Log Investment Prices - Equipment Categories
4
3.5
3
2.5
2
1.5
1
0.5
0
1970
1980
1990
2000
2010
2020
InfoProces
Transportation
OtherEquipt
Industrial

Prices


Log Investment Prices
4
3
2
1
0
-1
-2
1970
1980
1990
2000
2010
2020
InfoProces
Software
Art
Transportation
RD
OtherEquipt
Industrial
PowerCommStruct
ImprovtHousing
ManufStruct
OtherStruct
CommercialHealth
BrokerComm
Housing
OtherResidStruct
MiningOilStruct

Prices



Log Investment Prices
1.5
1
0.5
0
-0.5
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Log Capital Prices
1
0.5
0
-0.5
NonResEquipt
NonResStruct
ResStruct
NonResIPP
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

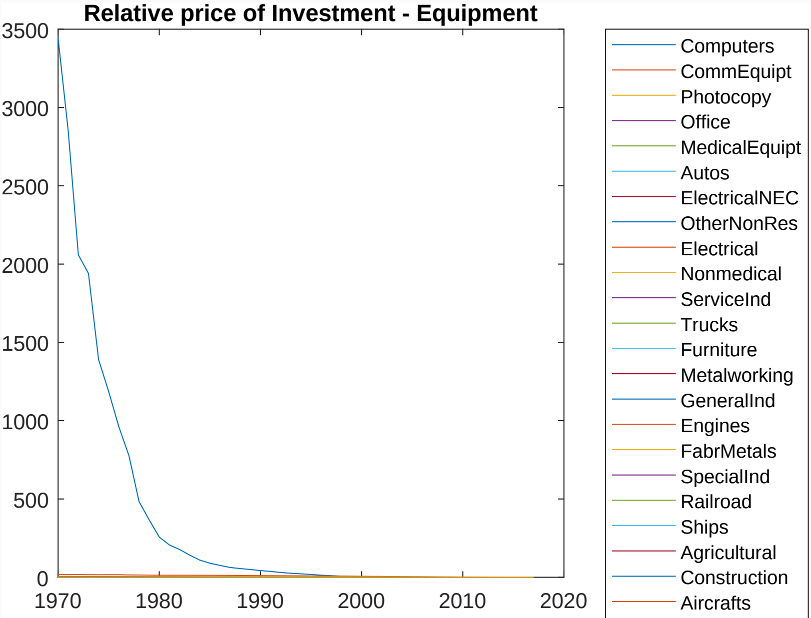
Proof

$$
\begin{aligned}
R_i K_i &= \left(r + \delta_i - g_{p_i}\right) P_i K_i \\
&= \left(r - g_Y\right) P_i K_i + \left(g_Y + \delta_i - g_{p_i}\right) P_i K_i \\
&= \left(r - g_Y\right) P_i K_i + P_i I_i
\end{aligned}
$$

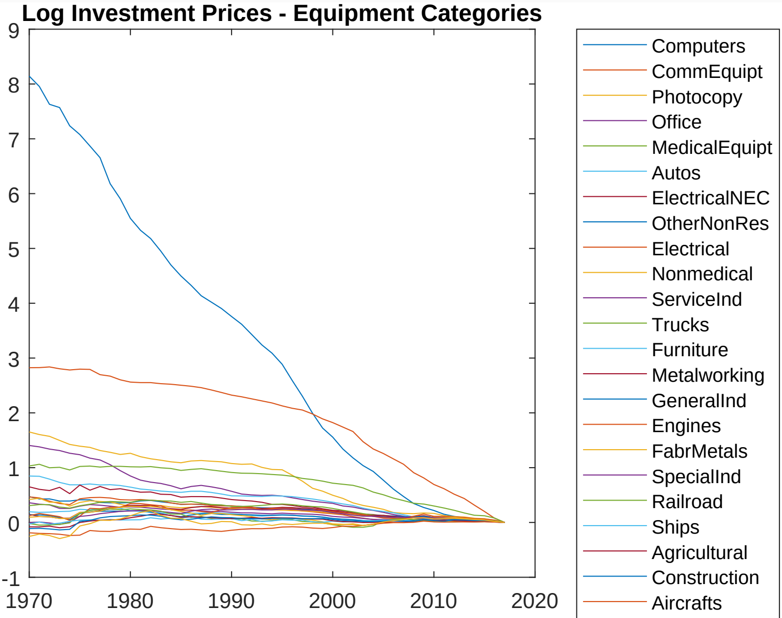
$$
\sum R_i K_i = \alpha_K Y = \left(r - g_Y\right) K + I
$$

$$
\begin{aligned}
s_i^R &= \frac{R_i K_i}{\sum R_j K_j} \\
&= \frac{\left(r - g_Y\right) P_i K_i + P_i I_i}{\left(r - g_Y\right) K + I} \\
&= \frac{P_i K_i}{K}\left(1 - \frac{s_I}{\alpha_K}\right) + \frac{P_i I_i}{I}\frac{s_I}{\alpha_K}
\end{aligned}
$$

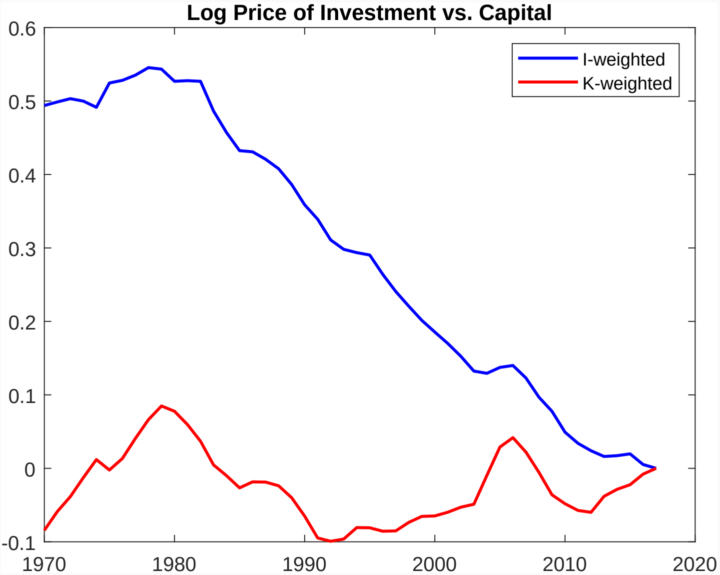
Relative prices



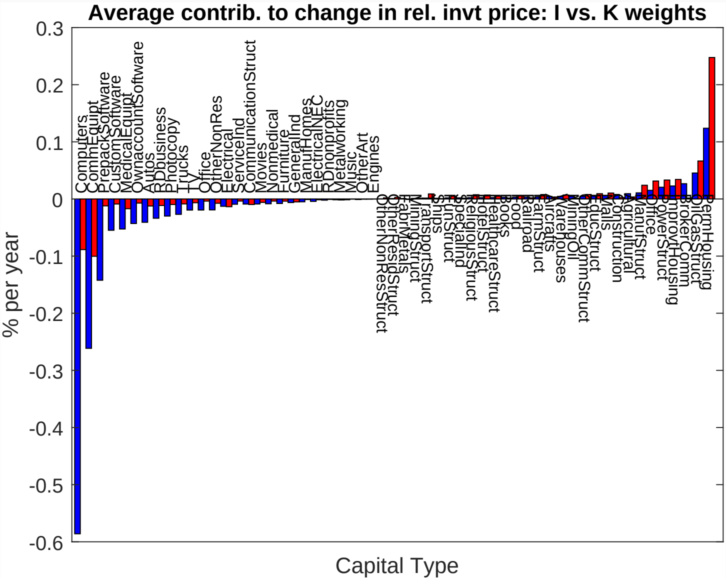
Log relative prices



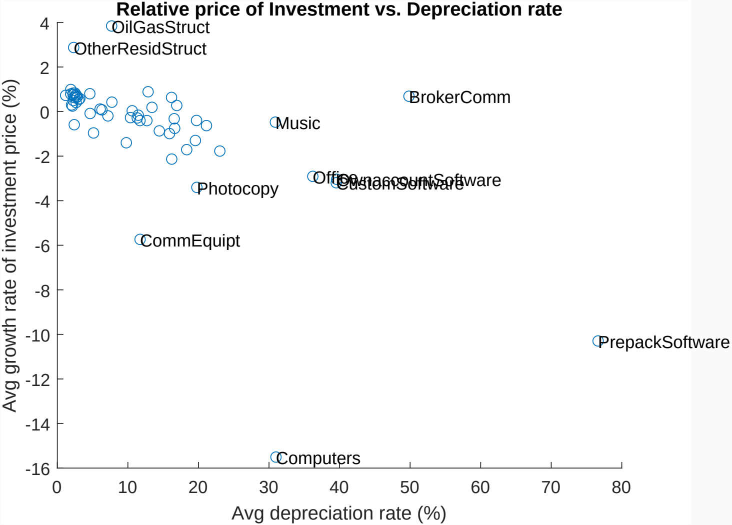
I-w vs. K-w prices



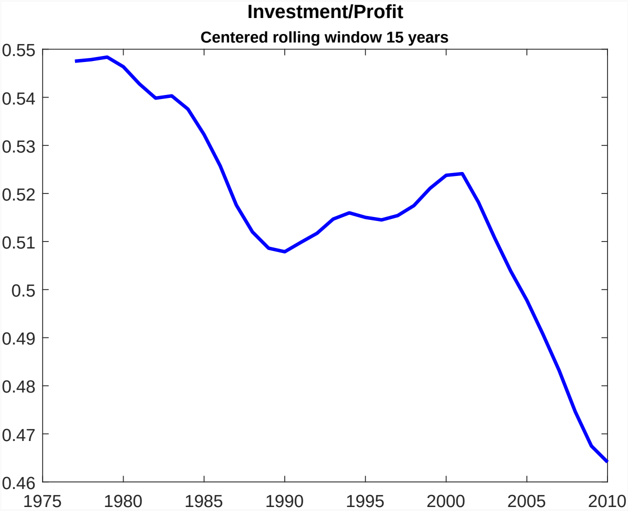
I-w vs. K-w prices



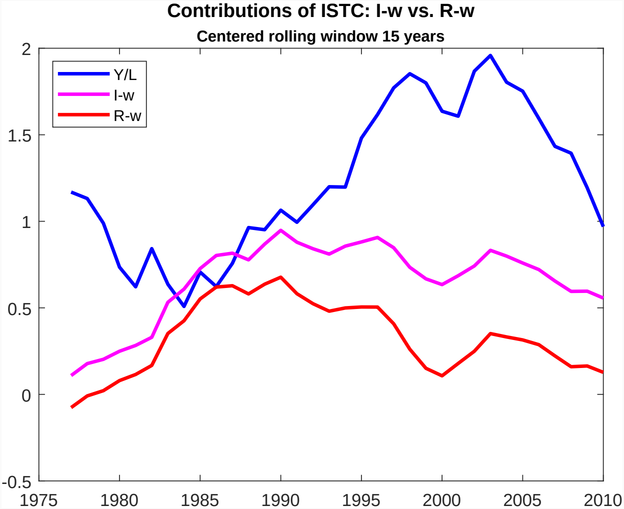
Depreciation and Price Trend



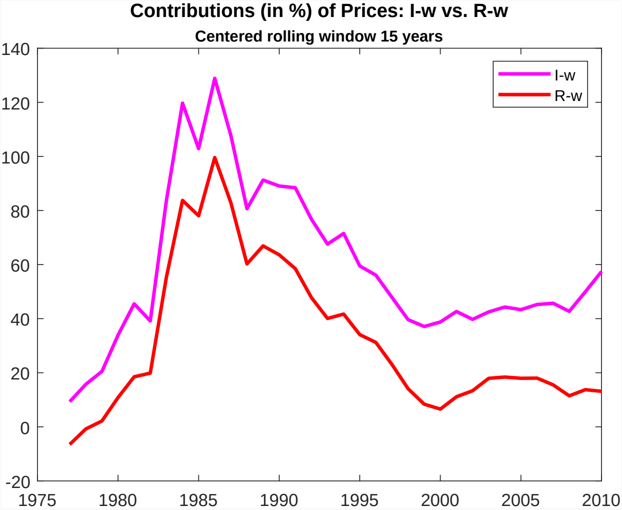
Investment-Profit Ratio



Comparison of contribution of ISTC



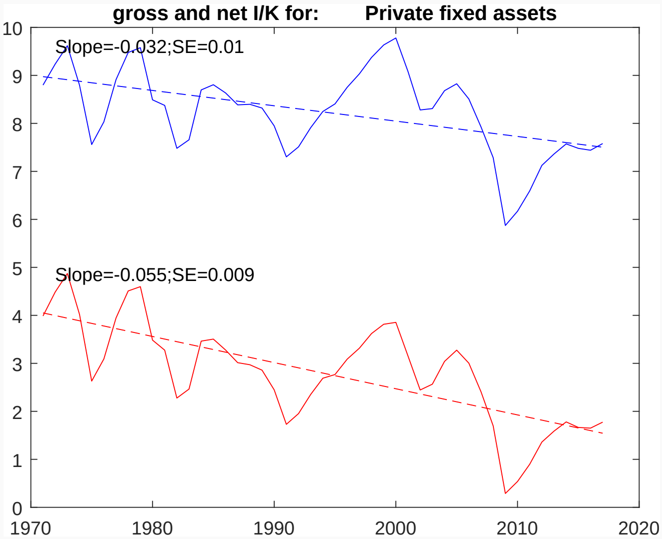
Comparison of contribution of ISTC: Percentages



Macroeconomic Puzzles

- Decline of investment
- High profitability
- Decline of labor share
- Decline of r^* (TBA)

Decline in net I/K



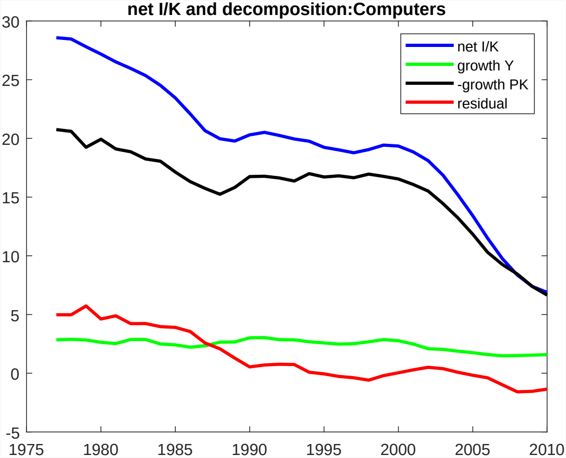
Decline of I/K

Write BGP condition, adding an error term:

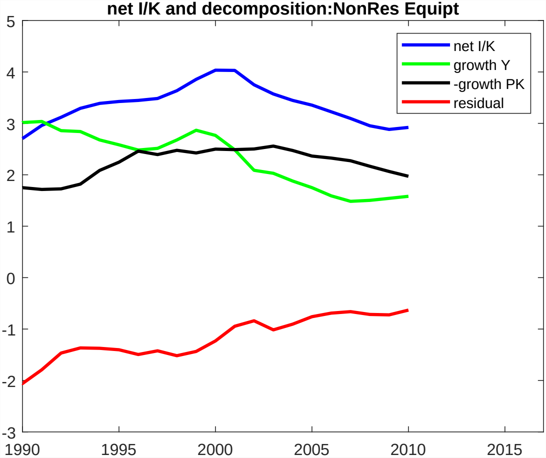
$$\frac{I_{it}}{K_{it}} = \delta_i + g_Y - \frac{\dot{p}_{it}}{p_{it}} + \varepsilon_{it}.$$

True at any level of aggregation (w. stock-weighted indices)

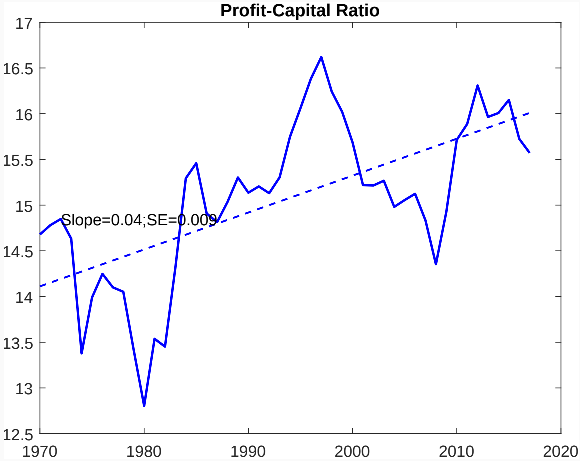
Evolution of net I/K: computers



Evolution of net I/K: non-res equipment



Stability of Profit/K

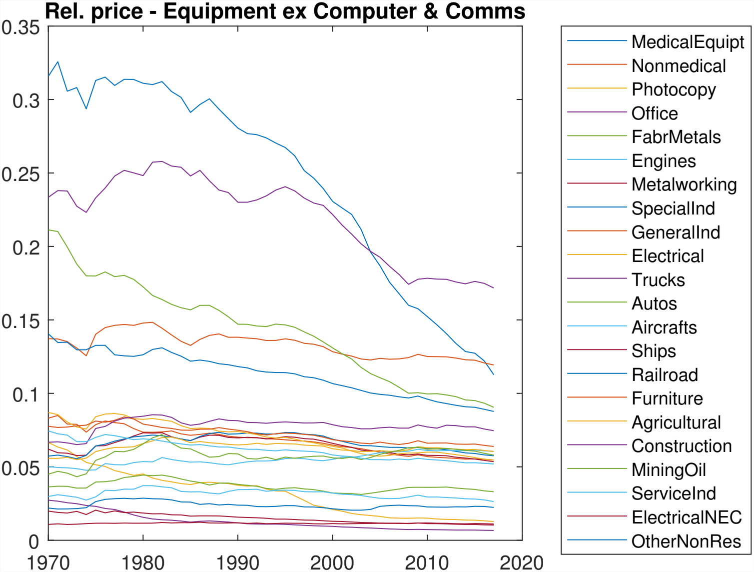


Data

	DlogY/H	Inv/Prof	Price IW	Price KW	Price RW
1970-2017	1.19	0.51	-1.02	0.23	-0.41
1970-1984	1.17	0.55	-0.23	0.65	0.16
1985-2005	1.49	0.52	-1.49	0.09	-0.73
2006-2017	0.68	0.45	-1.12	-0.01	-0.51

Avg. growth of Y/L, I/Profits, and I-w, K-w, R-w prices

Heterogeneity in Equipment Price Trends



Transitional Dynamics

- Single capital state variable: total wealth

$$K_t^W = \sum_{i=1}^{N} P_{it} K_{it}.$$

- Can characterize equilibrium using standard household FOCs plus:

$$\begin{aligned}
\frac{K_t^W}{Y_t} &= \sum_{i=1}^{N} \frac{\alpha_i}{r_t + \delta_i - g_{it}}, \\
\dot{K}_t^W &= \alpha_L Y_t - C_t + r_t K_t^W, \\
Y_t &= A_t^{\frac{1}{\alpha_L}} L_t \prod_{i=1}^{N} \left(\frac{\alpha_i}{P_{it}} \frac{1}{r_t + \delta_i - g_{it}} \right)^{\frac{\alpha_i}{\alpha_L}}.
\end{aligned}$$

Intuition

- State variable = total capital relative to BGP,
- The shock shifts BGP to a parallel path,
- Shock also shifts total capital at $t = 0$,
- Overall effect on deviation depends,
  only on its effect on state variable at $t = 0$.

Graphical Illustration