Capital Heterogeneity and Investment Prices

How much are investment prices declining?

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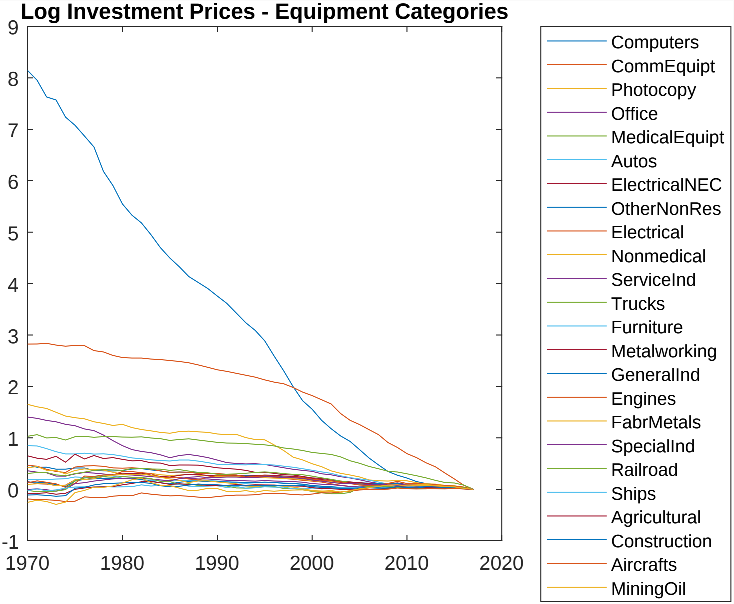
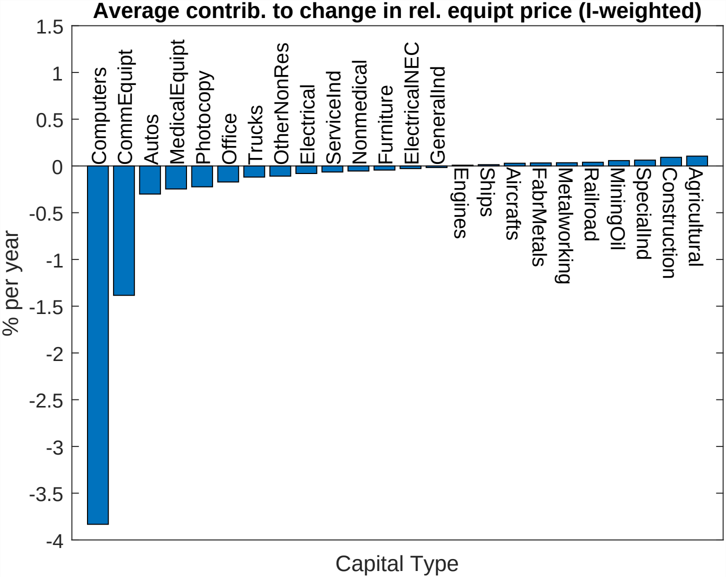
Motivation

- Role of investment-specific technological change (ISTC)
  - Growth (e.g., Greenwood, Hercovitz and Krusell 1997)
  - Labor Share (e.g., Karabarbounis and Neiman 2012)
  - Decline of r^* (e.g, Sajedi and Thwaites 2016)
  - Business cycles (e.g., Fisher 2006)
- ISTC measured using price of new investment goods
- But: huge heterogeneity in price trends - aggregation?

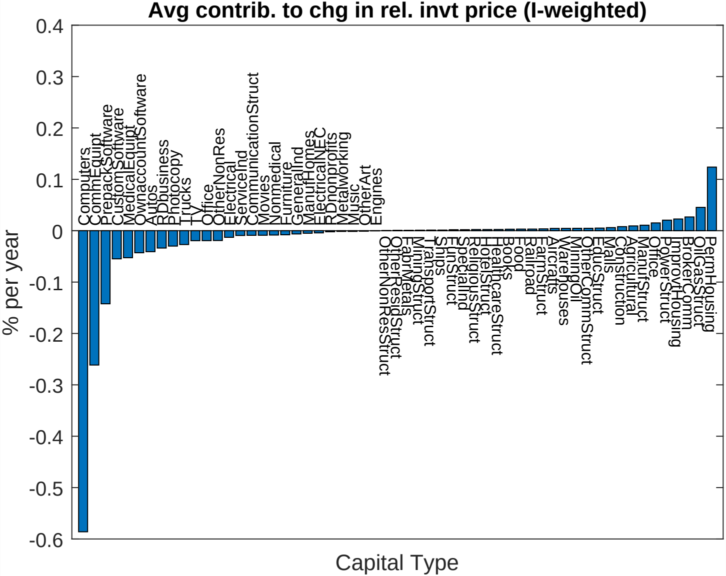
Heterogeneity in Equipment Price Trends



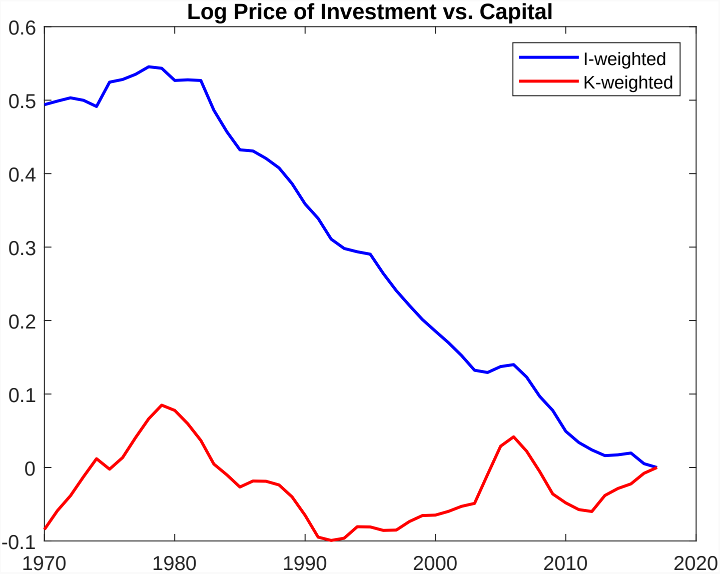
Contributions to Equipment Deflator



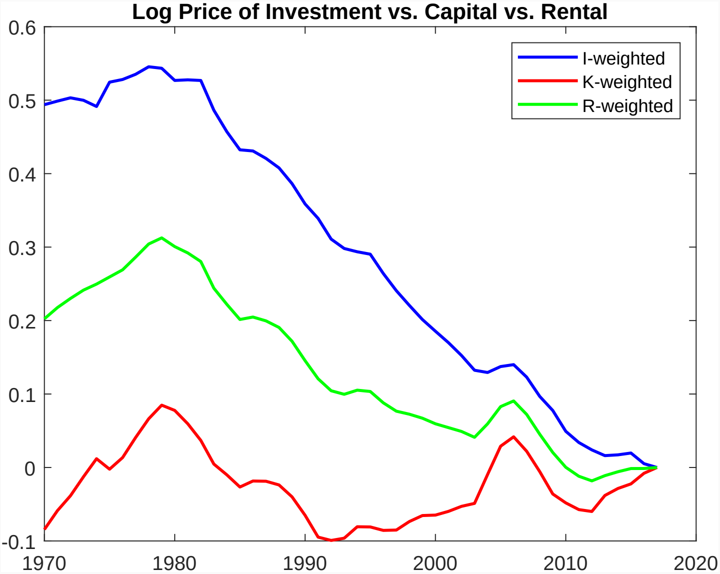
Contributions to Investment Deflator



Flow- and Stock-weighted Prices



Flow- and Stock-weighted Prices



Outline

1. Simple framework
2. Role of ISTC for growth
3. Other roles of ISTC:
    - Labor share
    - Decline of r^*
    - Business cycles
    - Big ratios (& calibration)

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:

$$\alpha_{K_i} \frac{Y_t}{K_{it}} = R_{it},$$

User cost equation:

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

Combining:

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

Balanced growth path assumptions

1. Assume constant growth for forcing variables:

$$g_A = \dot{A}/A,$$
$$g_L = \dot{L}/L,$$
$$g_{p_i} = \dot{p}_i/p_i,$$

2. Look for eqm with constant r_t, growth rate of Y_t, and constant shares of C_t and $p_{it} I_{it}$ in output.

Balanced growth path

- Capital demand:

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

- Production function:

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

- Substitute:

$$g_Y - g_L = \frac{g_A - \alpha_K g_{p^R}}{\alpha_L}, g_{p^R} \equiv \frac{\sum_{i=1}^n \alpha_{K_i} g_{p_i}}{\sum_{i=1}^n \alpha_{K_i}},$$

Aggregate invt prices using **rental weights**

Rental-, Stock-, and Flow-weighted indices

General (Divisia) index for given shares s:

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

Flow-weighted: invt price index (NIPA) used in ISTC research:

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

Stock-weighted: capital price index (FAT)

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

Rental-weighted index:

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

How to calculate these shares? Need R_{it}

Relationship between the three

Stock shares:

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

Rental shares:

$$s_{it}^R \propto (r_t + \delta_i - g_{p_i t}) s_{it}^K$$

Investment shares **along the BGP**:

$$s_i^I \propto (g_Y + \delta_i - g_{p_i}) s_{it}^K$$

These shares are **very** different!

Investment shares put high weight on high-δ_i capital

Stock shares put low weight, rental shares in between

BGP formula for rental shares

Rent on capital has two parts, one $\propto P_i I_i$ and one $\propto P_i K_i$:

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

Sum across all i, left is $\alpha_K Y$, middle is $I = \omega_I Y$
where α_K is capital share and ω_I is investment share.

Dividing by $\alpha_K Y$ on both sides,

$$
s_i^R = \frac{\omega_I}{\alpha_K} s_i^I + \left(1 - \frac{\omega_I}{\alpha_K}\right) s_i^K
$$

Formula for rental-weighted price index

We just found:

$$s_i^R = \frac{\omega_I}{\alpha_K} s_i^I + \left(1 - \frac{\omega_I}{\alpha_K}\right) s_i^K$$

Hence relation between price indices:

$$g_{p^R} = \frac{\omega_I}{\alpha_K} g_{p^I} + \left(1 - \frac{\omega_I}{\alpha_K}\right) g_{p^K}$$

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

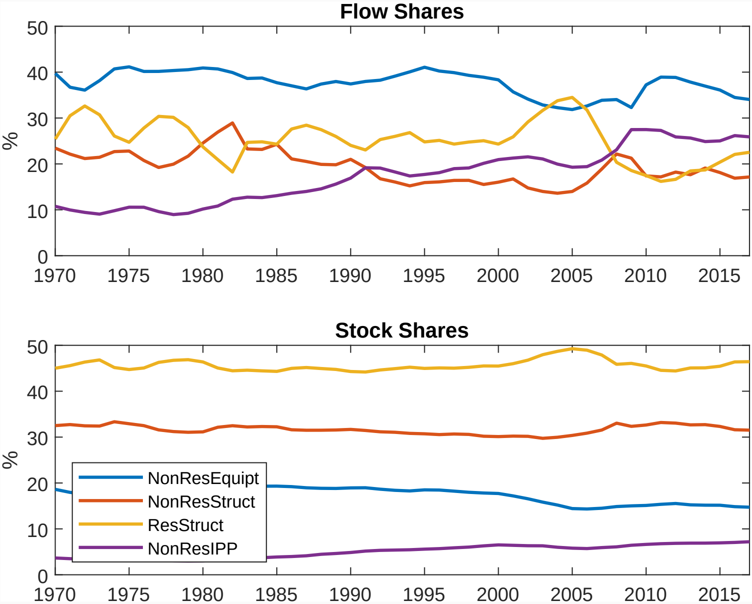
Recently in US: since $\omega_I \approx 1/6$ and $\alpha_K \approx 1/3$, rental-weighted is **roughly 50-50 mix** of stock and flow-weighted indices

Contribution of ISTC to Growth

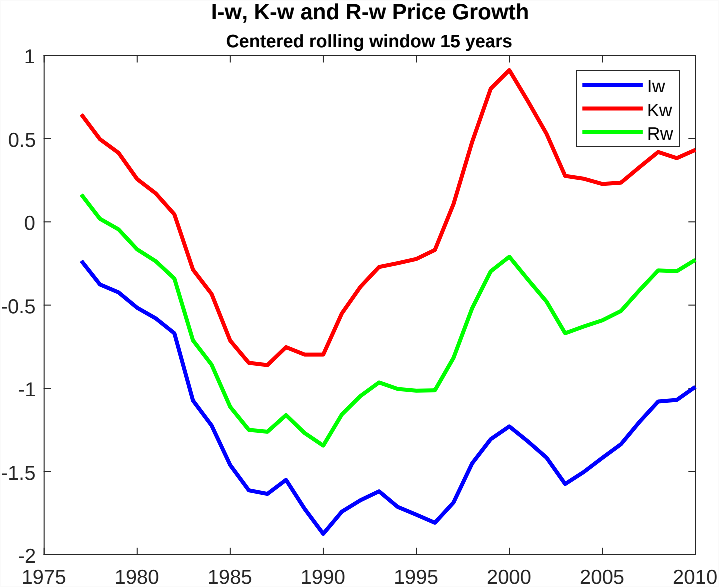
Data

- 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)

I-share and K-share



Rolling windows: Price Growth



Contribution of ISTC to growth

- GHK: "ISTC contributes 58% to growth"
- Our methodology:
  1. Infer TFP g_A from:

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

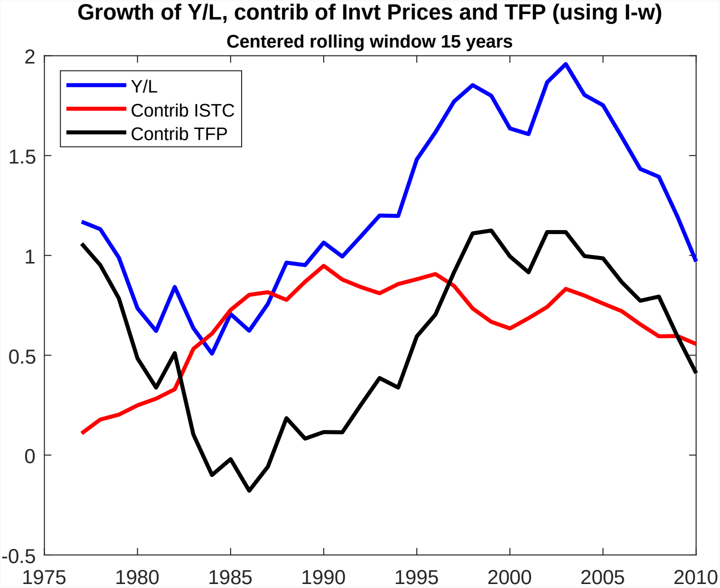
  2. Calculate counterfactual growth if $g_{p^R}=0$
  3. What if use g_{p^I} instead of g_{p^R}

Smaller ISTC contribution with R-weighting

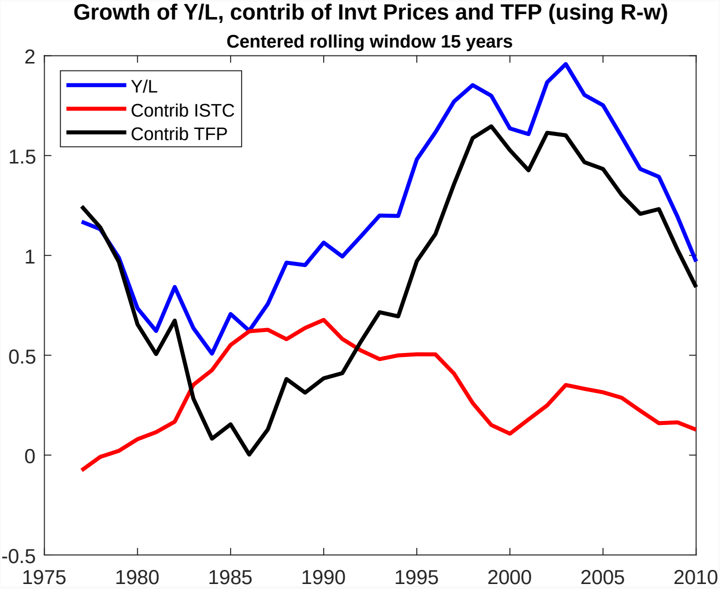
	Data	Iw:ITC	Iw:TFP	Rw:ITC	Rw:TFP
1970-2017	1.19	0.52	0.66	0.21	0.98
(%)	100.00	43.80	55.91	17.46	82.37

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



Other roles of investment prices

Other roles of investment prices

Theory tells us right aggregation for each question.

1. Labor share: **R-weighted**
2. Decline of r^*: **R-weighted**
3. Business cycles: mostly **K-weighted**
4. Great ratios: **K-weighted**

In none of these cases is the usual I-weighted series the right answer!

Labor Share

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

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

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

- Consider a permanent small shock to vector p_i.
- Then change in gross labor share is:

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

- Relevant price for labor share is **R-weighted**
- Smaller role empirically for prices than with I-weighted

Decline of r^*

- Lower investment price may reduce eqm interest rate
- 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:

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

- Again consider permanent small shock to vector p_i, then change in r^* proportional to $\hat{p}^R$
- Correct aggregation for r^* is **R-weighted**
- Again, smaller role for prices than with usual I-weighted

Business cycle shocks

- Back to original framework, assume we start on BGP
- Consider a permanent unexpected small shock to p_{i0}
- Dynamics from K_t/Y_t^{BGP}, where Y_t^{BGP} is BGP output
  - (Single normalized state: K vs. BGP)
- Effect of shock:
  - on K_t is $\hat{p}^K$
  - on Y_t^{BGP} is $\alpha_L^{-1}\alpha_K\hat{p}^R$
- So dynamics (including employment path) summarized by

$$\begin{aligned}
\hat{p}^K - \alpha_L^{-1}\alpha_K\hat{p}^R &= \alpha_L^{-1}\left(\alpha_L\hat{p}^K + \alpha_K\hat{p}^R\right) \\
&= \alpha_L^{-1}\left(\alpha_L\hat{p}^K + (\alpha_K - \omega_I)\hat{p}^K + \omega_I\hat{p}^I\right) \\
&= \alpha_L^{-1}\left((1-\omega_I)\hat{p}^K + \omega_I\hat{p}^I\right)
\end{aligned}$$

Business cycle shocks: summary

- Long-run (BGP) output changes by

$$\alpha_L^{-1}\alpha_K\hat{p}^R$$

- All dynamics relative to this, including path of employment, given by

$$\alpha_L^{-1}\underbrace{\left((1-\omega_I)\hat{p}^K+\omega_I\hat{p}^I\right)}_{\equiv\hat{p}}$$

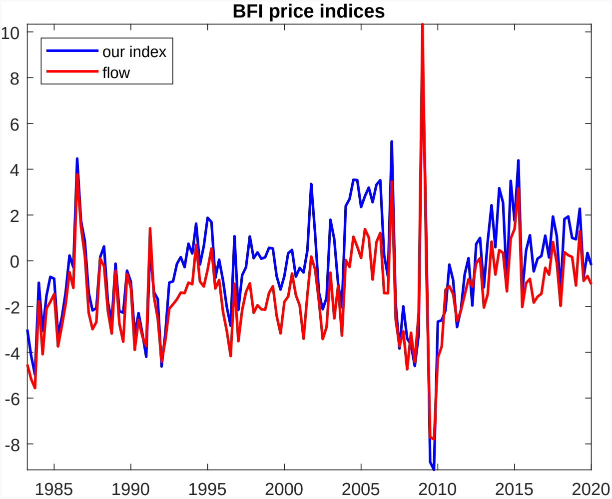
- Since investment share of output ω_I is small, $\hat{p}$ is **close to** K-weighted $\hat{p}^K$, not usual I-weighted $\hat{p}^I$
- What happens when we redo analysis with $\hat{p}$?

Business cycle analysis

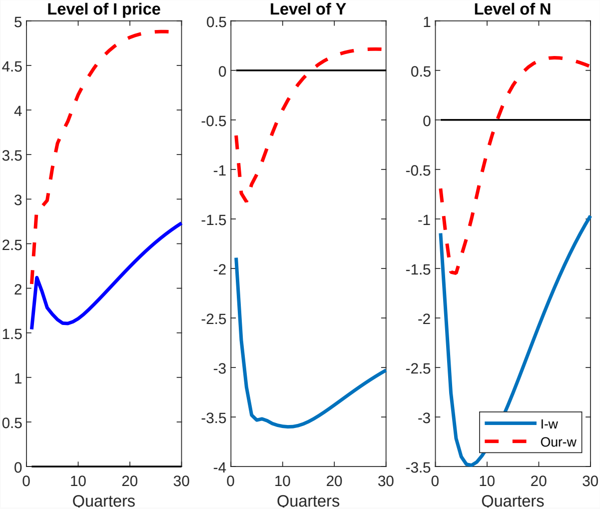
Run Fisher-style VAR:

- 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
- only 14 categories of goods (e.g. info processing)
- Difference: use our weighting

Price indices

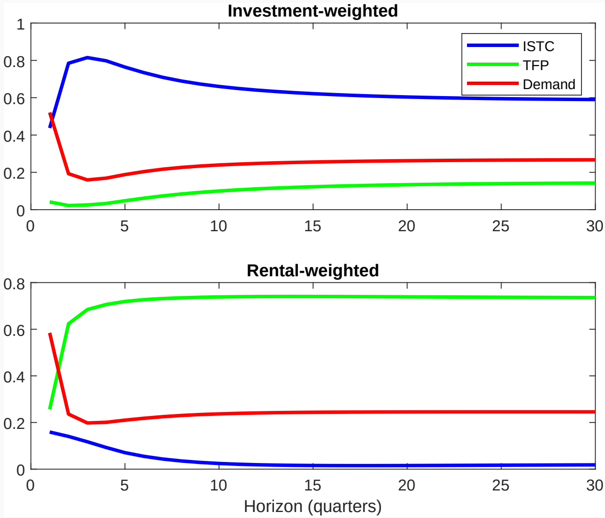


VAR comparison

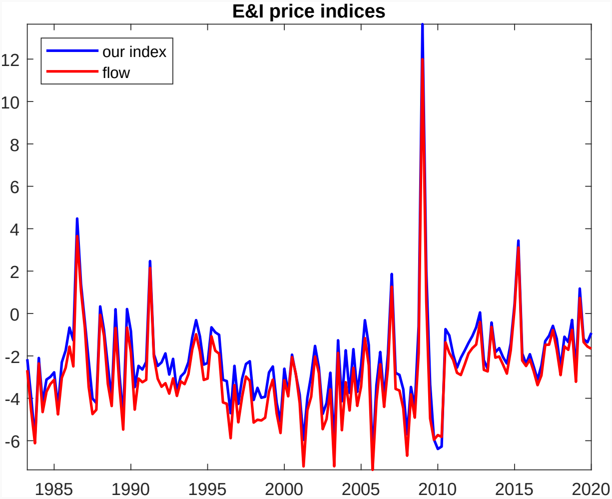


Variance Decomposition BFI

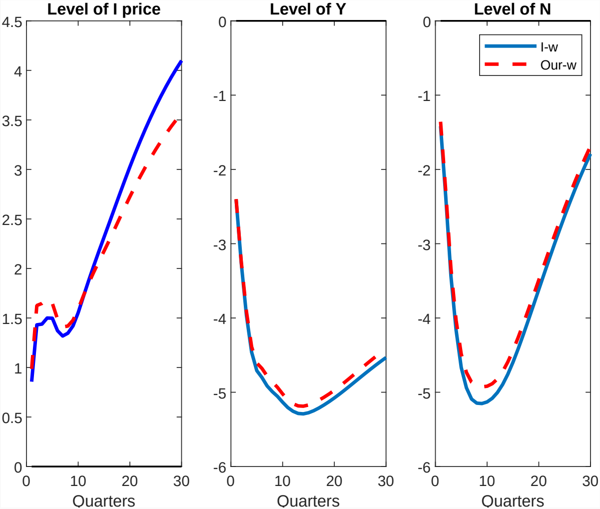
Share of variance of hours due to ISTC / TFP / demand



Price indices

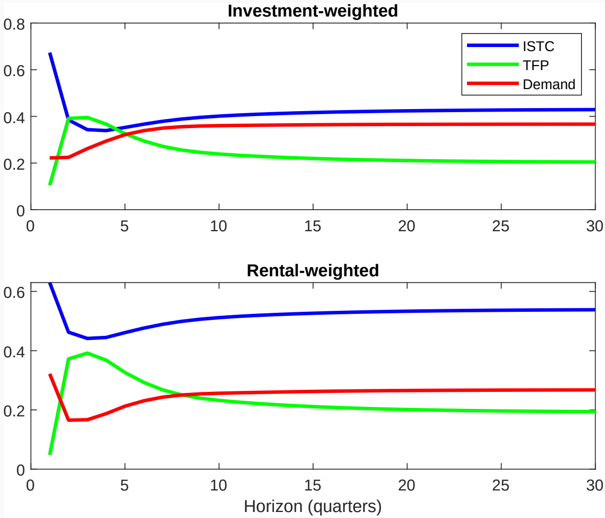


VAR comparison



Variance Decomposition E&I

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



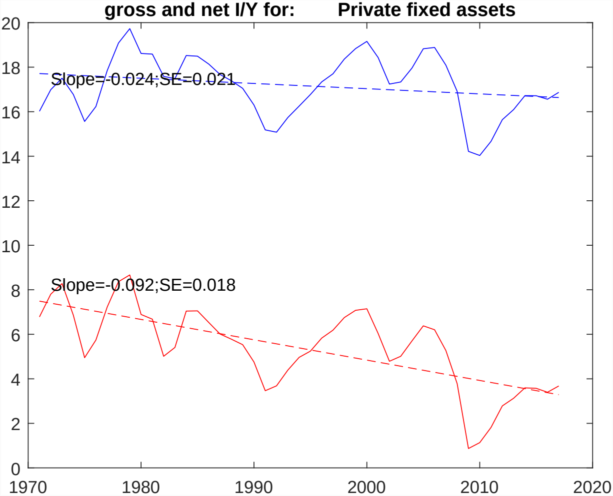
Aggregation and the Big Ratios

Result: along the BGP,

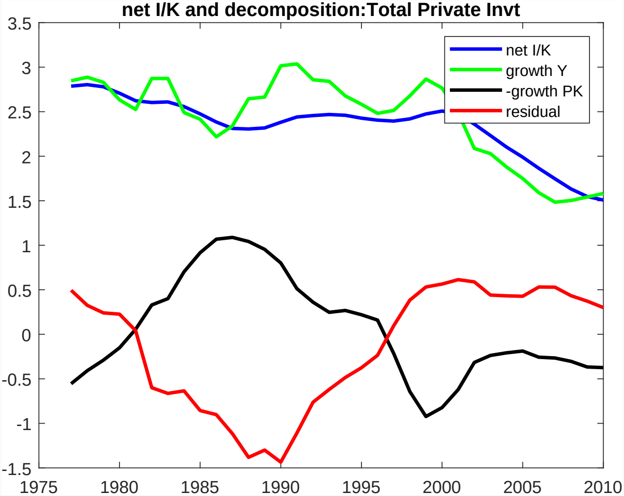
$$\frac{I}{K} = \frac{\sum p_i I_i}{\sum p_i K_i} = g_Y + \delta^K - g_{p^K}$$
$$\frac{\Pi}{K} = \frac{\sum R_i K_i}{\sum p_i K_i} = r + \delta^K - g_{p^K}$$
$$\frac{K}{Y} = \frac{\sum p_i K_i}{Y} = \frac{\alpha_K}{r + \delta^K - g_{p^K}}$$

To calibrate one-capital model, use **stock-weighted** δ and price growth.

Application: Drivers of Decline of I/K



Application: Drivers of Decline of I/K



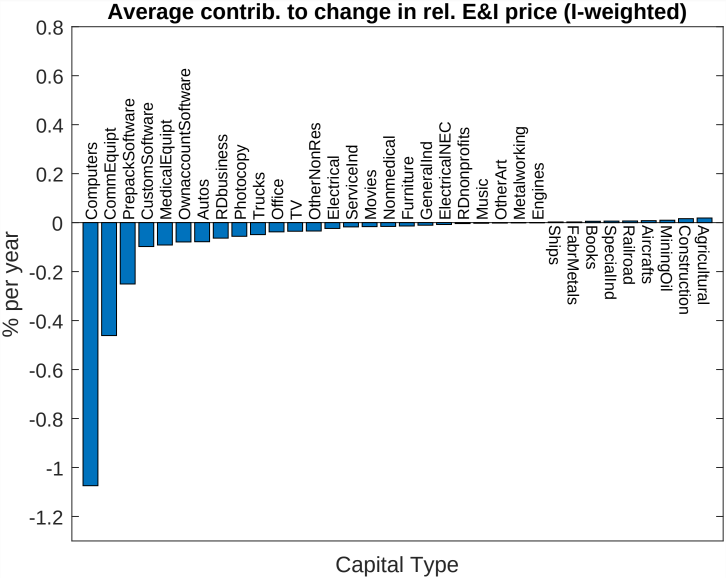
Conclusion

Conclusion

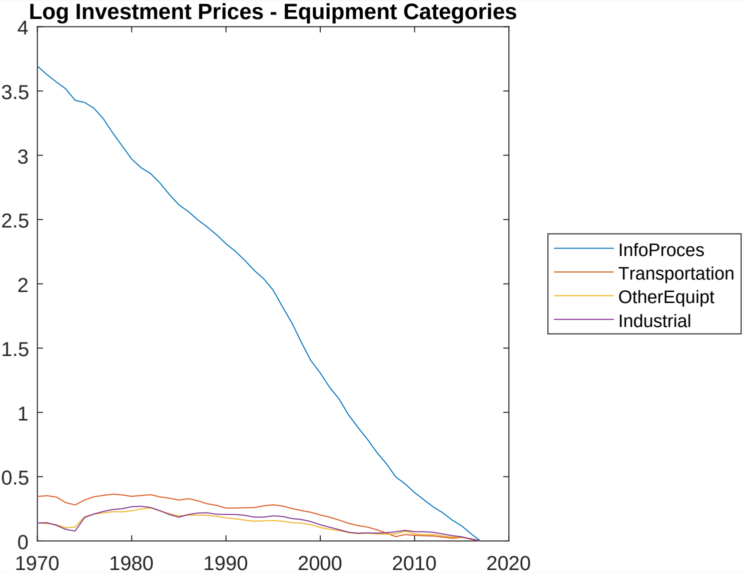
- Correctly aggregating investment prices dramatically decreases the contribution of ISTC to growth, labor share, r^*, etc.
- In progress:
  - relax simplifying assumptions
    - BGP, perfect competition, etc.
  - transitional dynamics;
  - improve empirical analysis;
  - etc.

Backup

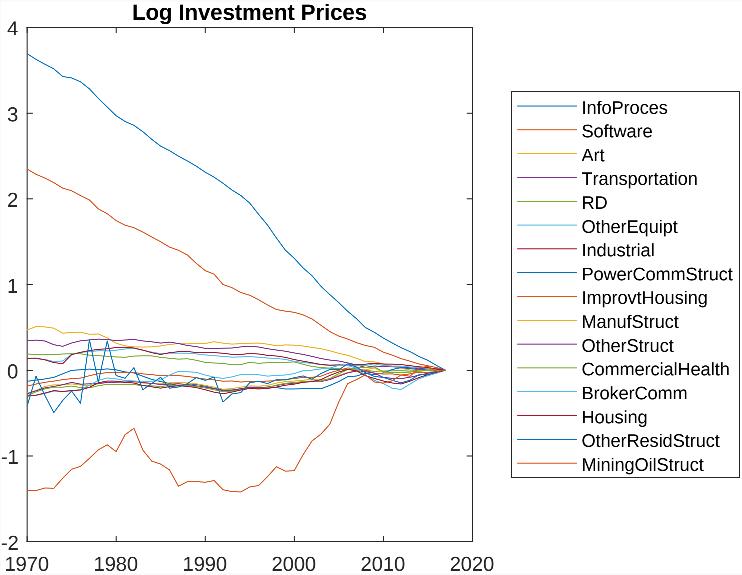
Contributions to I-w E&I price



Prices

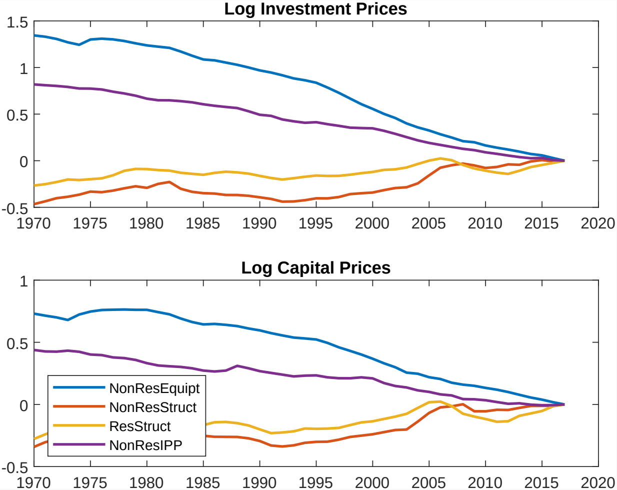

Log Investment Prices - Equipment Categories
4
3.5
3
2.5
2
1.5
1
0.5
0
1970
1980
1990
2000
2010
2020
InfoProces
Transportation
OtherEquipt
Industrial

Prices



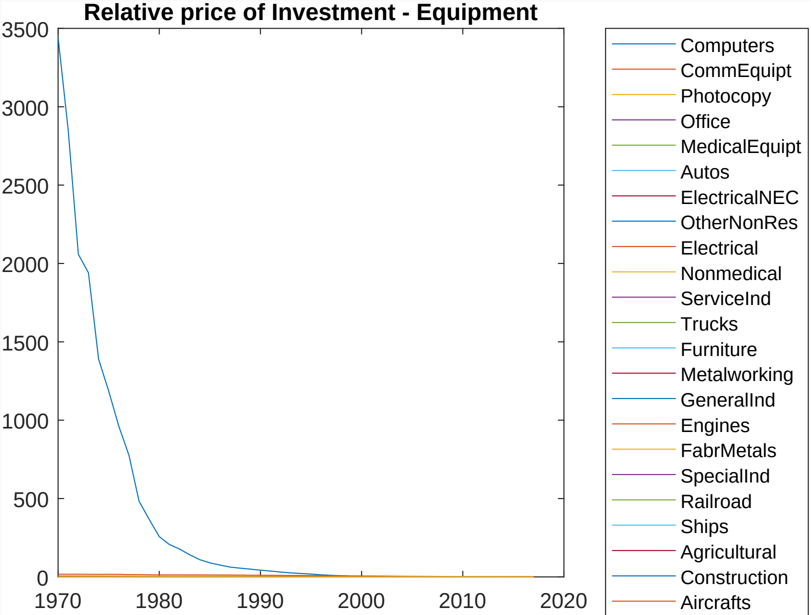
Log Investment Prices
4
3
2
1
0
-1
-2
1970
1980
1990
2000
2010
2020
InfoProces
Software
Art
Transportation
RD
OtherEquipt
Industrial
PowerCommStruct
ImprovtHousing
ManufStruct
OtherStruct
CommercialHealth
BrokerComm
Housing
OtherResidStruct
MiningOilStruct

Prices

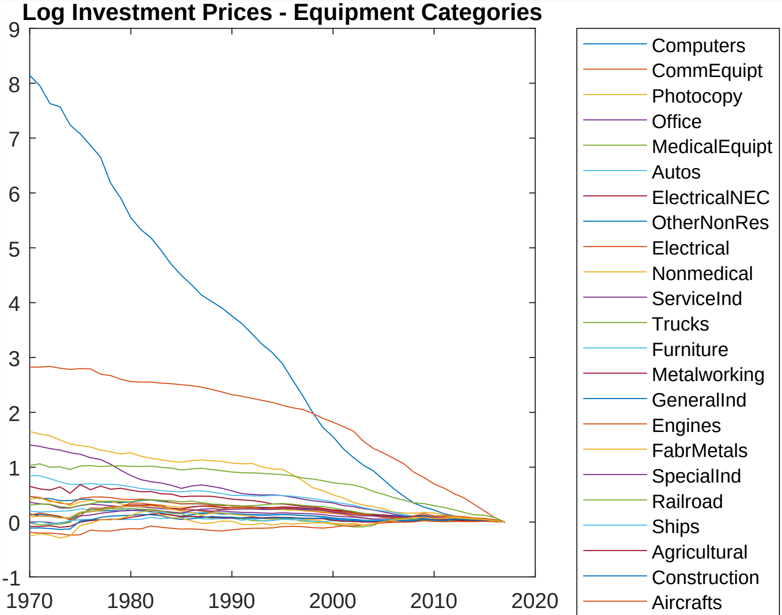


Log Investment Prices
1.5
1
0.5
0
-0.5
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Log Capital Prices
1
0.5
0
-0.5
NonResEquipt
NonResStruct
ResStruct
NonResIPP

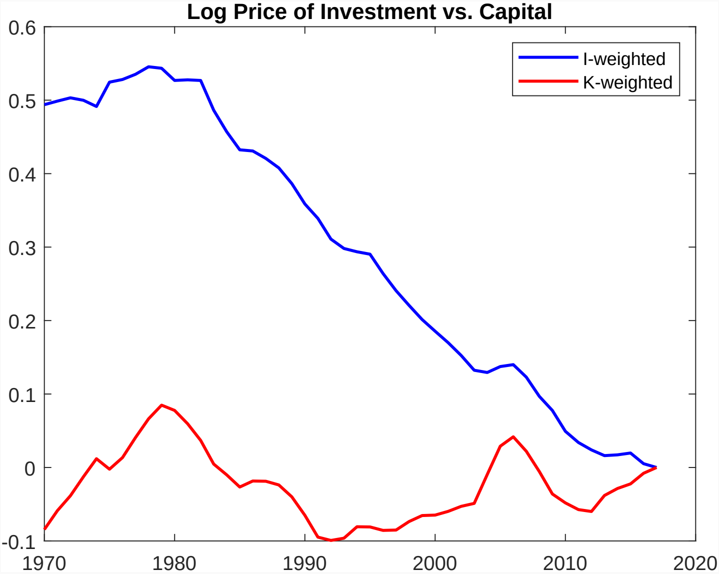
Relative prices



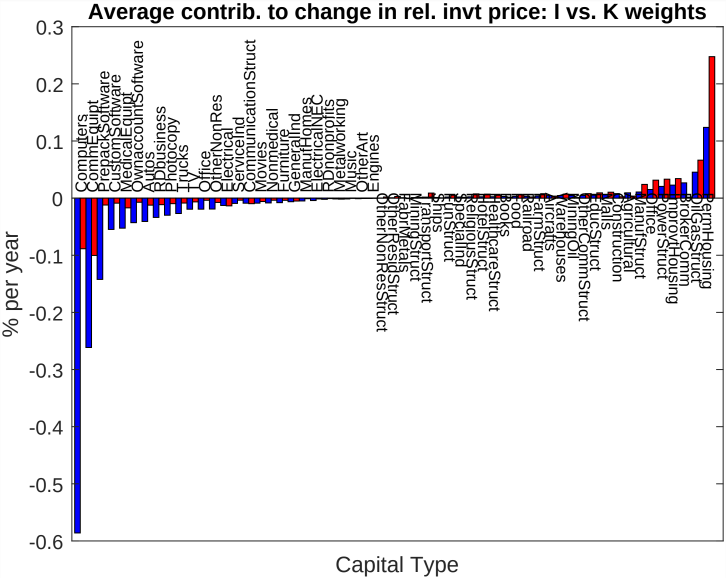
Log relative prices



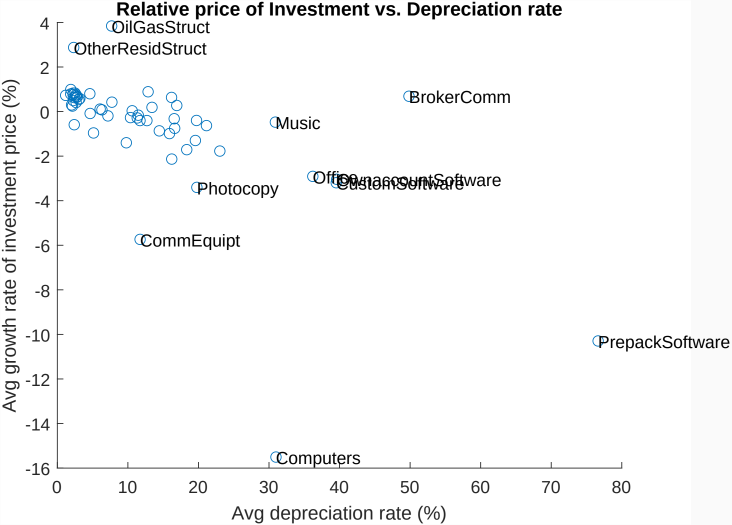
I-w vs. K-w prices



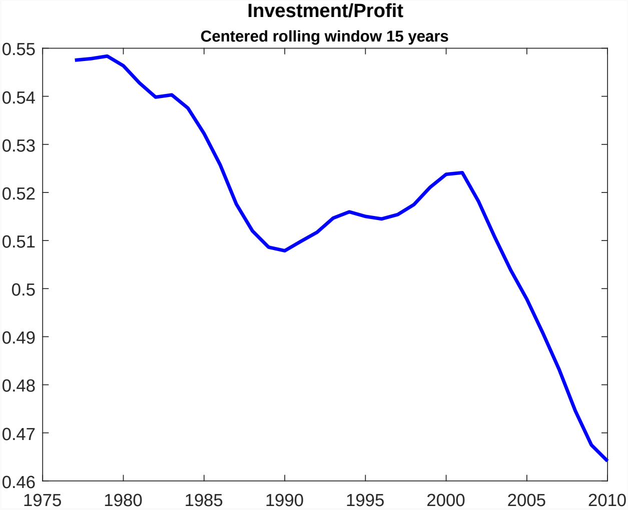
I-w vs. K-w prices



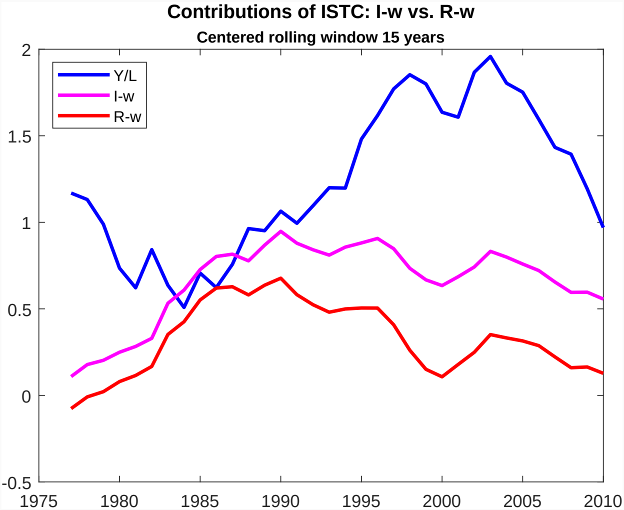
Depreciation and Price Trend



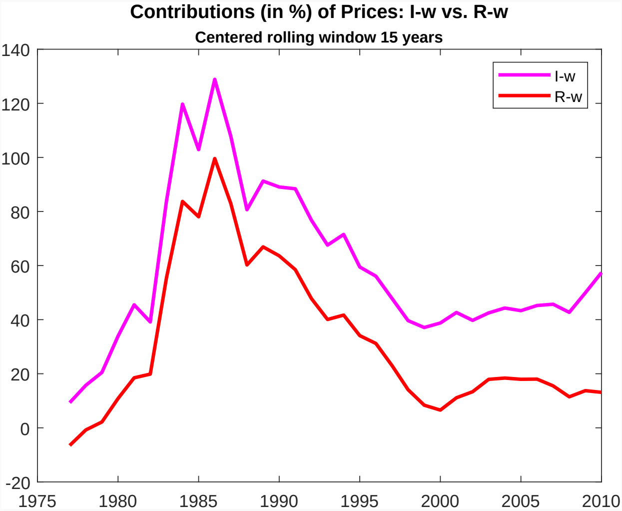
Investment-Profit Ratio



Comparison of contribution of ISTC



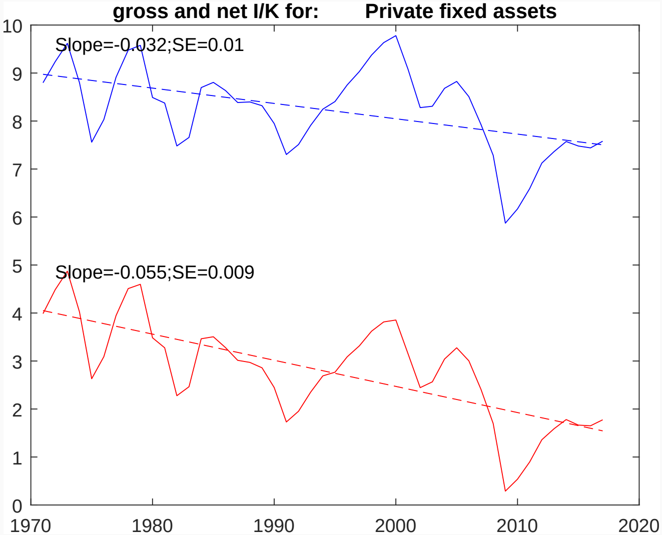
Comparison of contribution of ISTC: Percentages



Macroeconomic Puzzles

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

Decline in net I/K



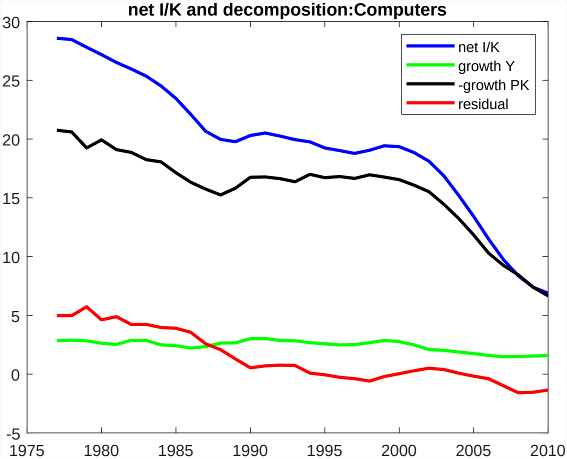
Decline of I/K

Write BGP condition, adding an error term:

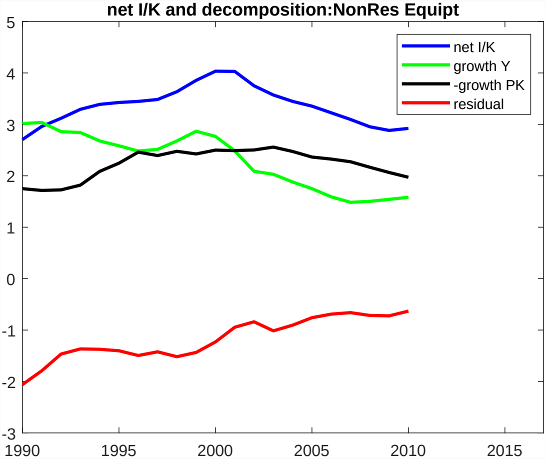
$$\frac{I_{it}}{K_{it}} = \delta_i + g_Y - \frac{\dot{p}_{it}}{p_{it}} + \varepsilon_{it}.$$

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

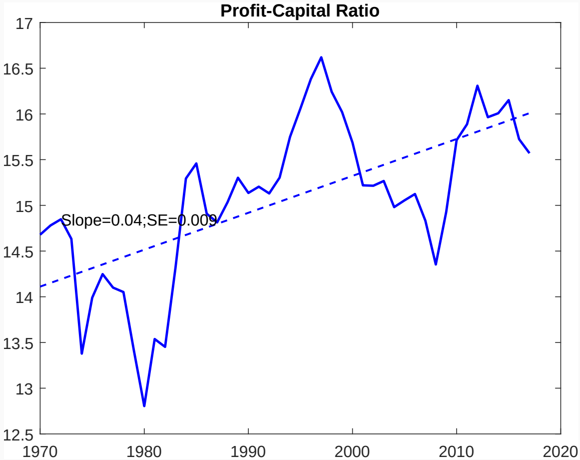
Evolution of net I/K: computers



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