

# Capital Services in Microprocessor Production

## Quantitative Implications of a Vintage Model

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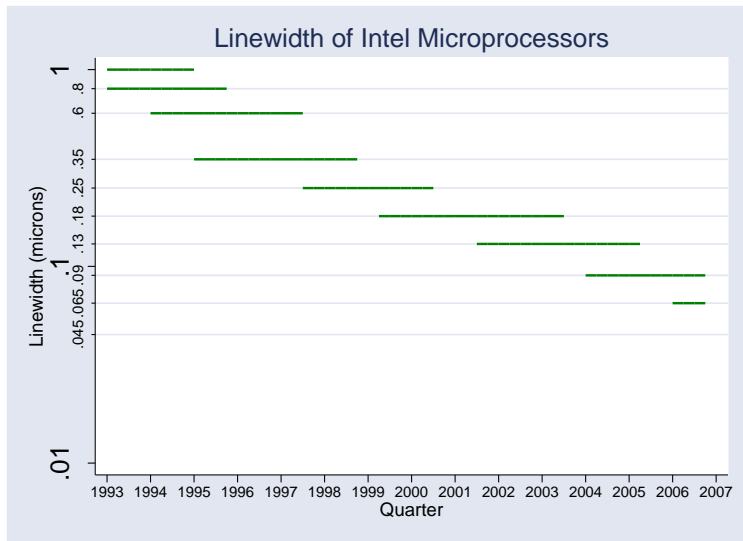
<sup>3</sup>University at Albany - SUNY

9 Aug 2012

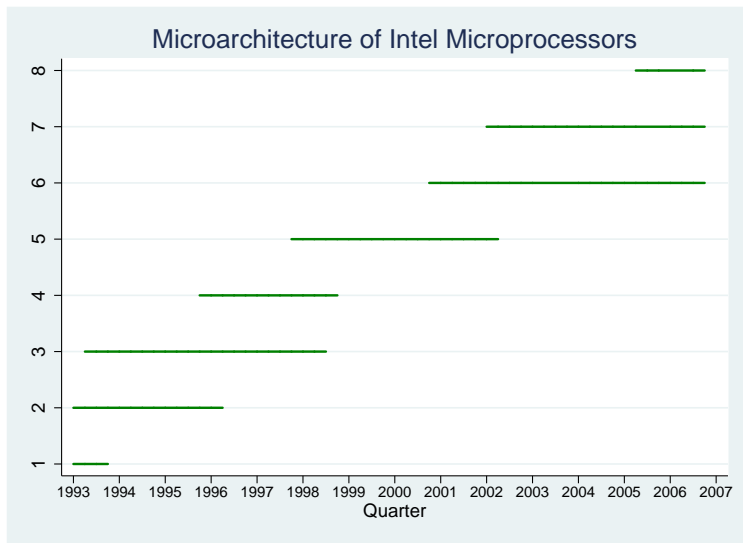
# OBJECTIVES

- Derive implications for capital services when technological progress is embodied in new vintages of capital equipment.
- Use these implications, together with detailed data on microprocessor production, to calculate capital services in this industry.
- Calculate the contribution of capital services in microprocessor production.

# EMBODIED TECHNOLOGICAL CHANGE - EQUIPMENT



# EMBODIED TECHNOLOGICAL CHANGE - DESIGN/MICROARCHITECTURE



# MICROPROCESSORS - LINEWIDTHS AND DESIGNS

Vintage	Linewidth	Design
1	1.0	386
2	1.0	486
3	0.8	486
4	0.6	486
5	0.8	P5
6	0.6	P5
7	0.35	P5
8	0.35	PII
9	0.25	PII
10	0.25	PIII
11	0.18	PIII
12	0.13	PIII
13	0.18	P4
14	0.13	P4
15	0.09	P4
16	0.09	Core
17	0.065	Core
18	0.065	P4
19	0.25	P5
20	0.09	Pentium - M
21	0.13	Pentium - M

- Time is discrete,  $t=1,2,3\dots$
- - Linewidth introduced at time  $t = v$  indexed by  $v$ .
  - Design/Microarchitecture introduced at time  $t = m$  indexed by  $m$ .
  - Microprocessor vintage indexed by  $(v, m)$ .
- For vintage  $(v, m)$  chip, quality  $A_t(v, m)$ , and unit variable cost  $c_t(v, m)$ , at time  $t$  are given.
- The total available capacity of vintage  $(v, m)$  capital at time  $t$ ,  $K_t(v, m)$ , satisfies  $K_t(v, m) \geq K_{t'}(v, m), \forall t \geq t'$
- Total microprocessor units produced using vintage  $(v, m)$  capital,  $y_t(v, m)$ , satisfies  $y_t(v, m) \leq K_t(v, m)$

# RELATIVE PRICE MEASURES RELATIVE QUALITY

- Consumers care only about total quality units
- At date  $t$ , if positive demand for vintage  $(v, m)$  and  $(v', m')$ , then

$$\frac{p_t(v', m')}{p_t(v, m)} = \frac{A_t(v', m')}{A_t(v, m)}.$$

# TECHNOLOGICAL PROGRESS

- Vintages improve over time.
- Modeled as decrease in cost of producing a unit of quality.

$$\frac{c_t(v', m')}{A_t(v', m')} < \frac{c_t(v, m)}{A_t(v, m)},$$

if  $(v' > v, m' \geq m)$  or  $(v' \geq v, m' > m)$



# CAPITAL RENT CALCULATION

- Capital rent per unit of vintage  $(v, m)$  capital equals cost saving per unit of vintage  $(v, m)$  capital.
- Production on newer vintage  $(v, m)$ , reduces production on oldest vintage  $(v_t^*, m_t^*)$  by  $\frac{A_t(v, m)}{A_t(v_t^*, m_t^*)}$  quality units
- Hence, cost saving (and rent) per unit of vintage  $(v, m)$  is

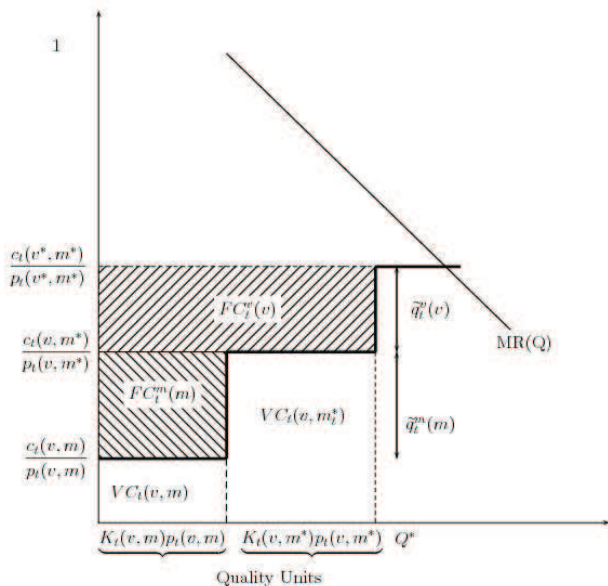
$$\begin{aligned}q_t(v, m) &= \frac{A_t(v, m)}{A_t(v_t^*, m_t^*)} c_t(v_t^*, m_t^*) - c_t(v, m) \\ &= \frac{p_t(v, m)}{p_t(v_t^*, m_t^*)} c_t(v_t^*, m_t^*) - c_t(v, m) \\ &= p_t(v, m) \left[ \frac{c_t(v_t^*, m_t^*)}{p_t(v_t^*, m_t^*)} - \frac{c_t(v, m)}{p_t(v, m)} \right]\end{aligned}$$

# RENT TO EQUIPMENT AND RENT TO DESIGN

- Rent to  $(v, m)$  capital can be split into rent to vintage  $v$  linewidth and rent to vintage  $m$  design.

$$\begin{aligned}q_t(v, m) &= p_t(v, m) \left[ \frac{c_t(v_t^*, m_t^*)}{p_t(v_t^*, m_t^*)} - \frac{c_t(v, m)}{p_t(v, m)} \right] \\&= p_t(v, m) \left[ \frac{c_t(v_t^*, m_t^*)}{p_t(v_t^*, m_t^*)} - \frac{c_t(v, m_t^*)}{p_t(v, m_t^*)} \right] \\&\quad + p_t(v, m) \left[ \frac{c_t(v, m_t^*)}{p_t(v, m_t^*)} - \frac{c_t(v, m)}{p_t(v, m)} \right] \\&= q_t^v(v) + q_t^m(m)\end{aligned}$$

# THEORY : COST DIAGRAM



# DATA SOURCES

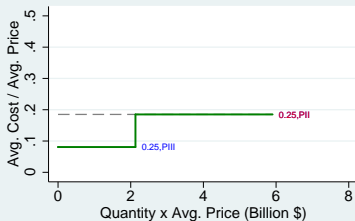
- Quarterly quantity and price data on microprocessors from MDR
- Unit variable cost data from MDR, IC Knowledge
- Linewidth, Microarchitecture of microprocessors from MDR, checked against Intel sources
- Fab production technology from MDR, checked against Intel sources
- Desktop and Laptop Microprocessors used, Servers and Workstations excluded
- Quarterly data on Fab level investments, from SMA
- Quarterly Interest Rates from LIBOR

# MEASURING EQUIPMENT COST

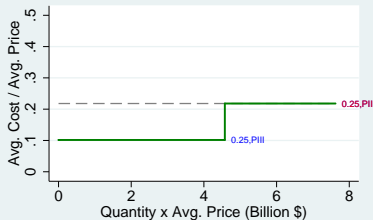
Quarter – 1999



Quarter – 1999.25



Quarter – 1999.5



Quarter – 1999.75



# RESULT: EQUIPMENT COSTS

Table : Equipment costs by vintage

Linewidth (microns)	Equip. Cost(Lower Bound) (Billion \$)	Equip. Cost(Upper Bound) (Billion \$)
1.0	-	-
0.8	0.96	0.99
0.6	1.18	2.19
0.35	5.16	5.16
0.25	1.64	1.64
0.18	2.17	3.00
0.13	5.81	14.4
0.09	3.22	5.01
0.065	3.70	3.70

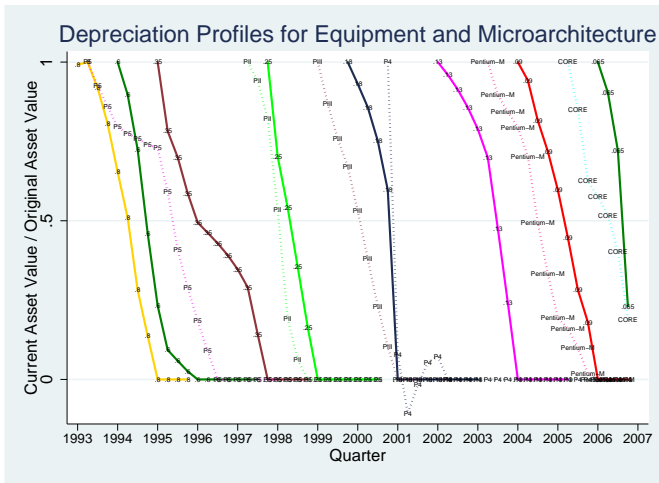
# RESULT: MICROARCHITECTURE COSTS

Table : Microarchitecture costs by vintage

Microarchitecture	Cost(Lower Bound) (Billion \$)	Cost(Upper Bound) (Billion \$ )
486	0.26	0.38
Pentium	2.74	2.74
Pentium-II	0.82	0.82
Pentium-III	4.3	3.54
Pentium 4	0.01	0.01
Core	2.63	2.63
Pentium-M	0.98	1.35

# RESULT: DEPRECIATION PROFILES

Calculated on Per Unit basis





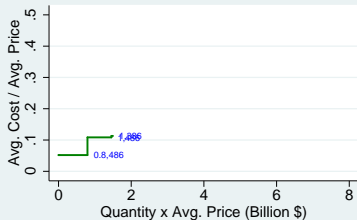
# CONCLUSION

Table : Decomposition of Real Output Growth

Year	Real Output	Linewidth	Design	Disembodied	Labor
1993	0.68	0.27	0.32	-0.133	0.27
1994	1.17	1.32	0.08	-0.031	0.13
1995	1.31	1.00	0.51	-0.009	0.03
1996	1.08	0.37	0.35	0.43	0.12
1997	1.08	0.70	0.19	0.46	-0.02
1998	1.04	0.55	0.46	0.13	0.14
1999	1.35	0.13	0.69	0.25	0.25
2000	0.65	0.10	0.24	0.44	-0.03
2001	0.53	0.00	-0.01	0.21	-0.43
2002	0.68	1.52	0.05	0.06	0.46
2003	0.61	0.22	0.01	0.30	0.06
2004	0.61	0.56	0.09	-0.21	0.14
2005	0.59	0.05	0.06	0.094	0.05
2006	0.22	0.20	0.19	-1.189	0.02
Avg	0.85	0.50	0.23	0.059	0.084

# MEASURING EQUIPMENT COST

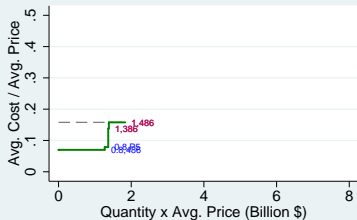
Quarter – 1993



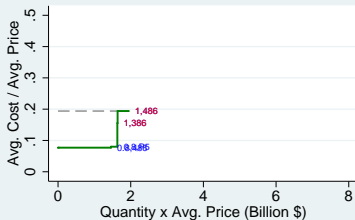
Quarter – 1993.25



Quarter – 1993.5



Quarter – 1993.75



# MEASURING EQUIPMENT COST

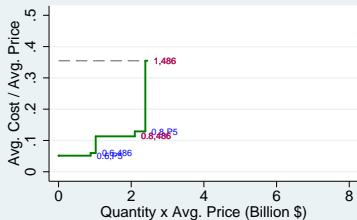
Quarter – 1994



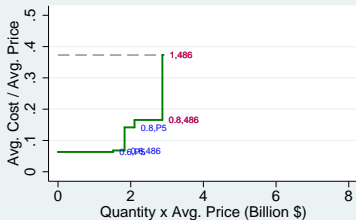
Quarter – 1994.25



Quarter – 1994.5

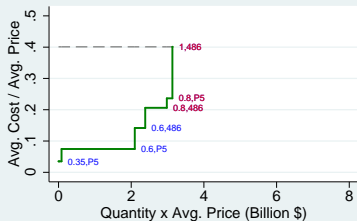


Quarter – 1994.75



# MEASURING EQUIPMENT COST

Quarter – 1995



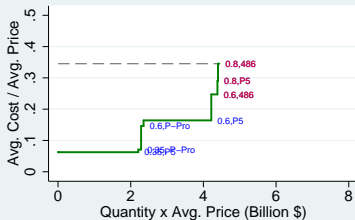
Quarter – 1995.25



Quarter – 1995.5

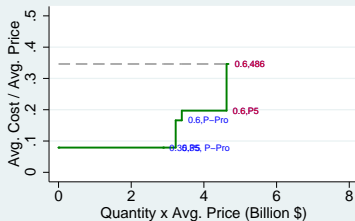


Quarter – 1995.75

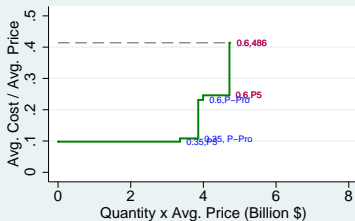


# MEASURING EQUIPMENT COST

Quarter – 1996



Quarter – 1996.25



Quarter – 1996.5



Quarter – 1996.75



# MEASURING EQUIPMENT COST

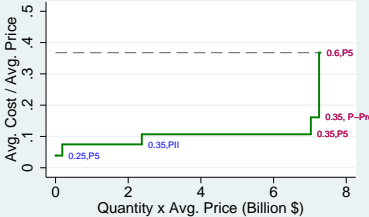
Quarter – 1997



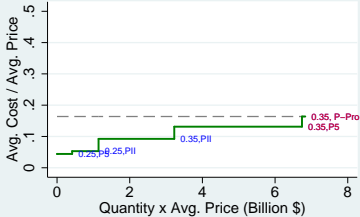
Quarter – 1997.25



Quarter – 1997.5

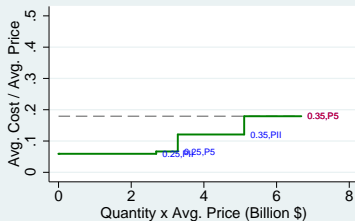


Quarter – 1997.75

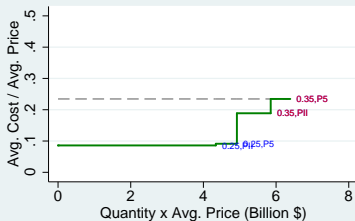


# MEASURING EQUIPMENT COST

Quarter – 1998



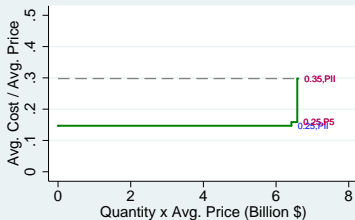
Quarter – 1998.25



Quarter – 1998.5



Quarter – 1998.75



# MEASURING EQUIPMENT COST

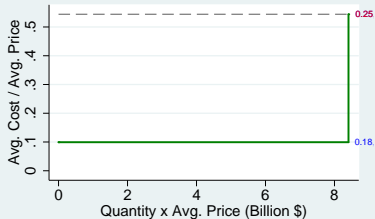
Quarter – 2000



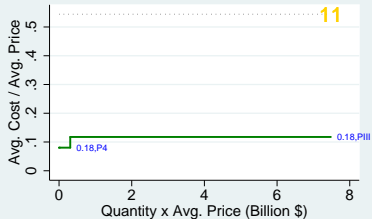
Quarter – 2000.25



Quarter – 2000.5



Quarter – 2000.75



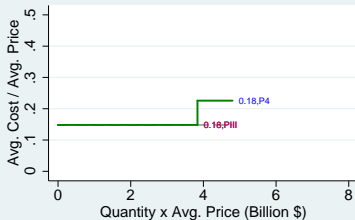


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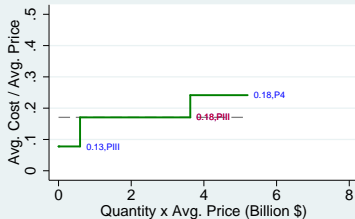
Quarter – 2001



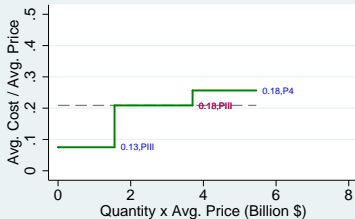
Quarter – 2001.25



Quarter – 2001.5



Quarter – 2001.75

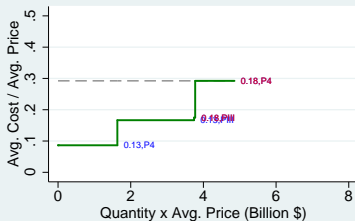


# MEASURING EQUIPMENT COST

Quarter – 2002



Quarter – 2002.25



Quarter – 2002.5



Quarter – 2002.75



# MEASURING EQUIPMENT COST

Quarter – 2003



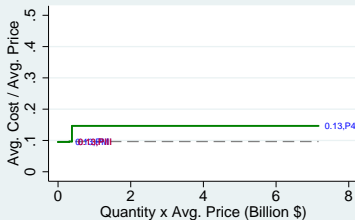
Quarter – 2003.25



Quarter – 2003.5



Quarter – 2003.75



# MEASURING EQUIPMENT COST

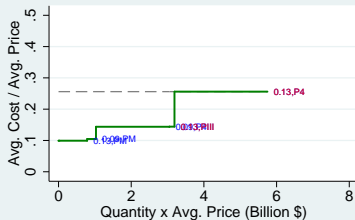
Quarter – 2004



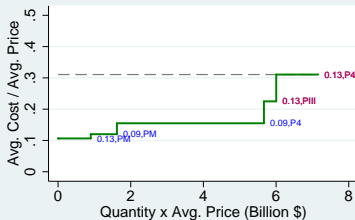
Quarter – 2004.25



Quarter – 2004.5

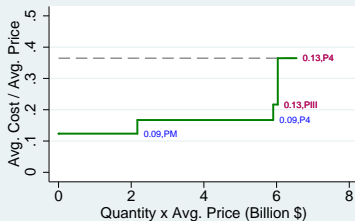


Quarter – 2004.75

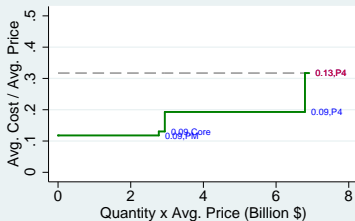


# MEASURING EQUIPMENT COST

Quarter – 2005



Quarter – 2005.25



Quarter – 2005.5

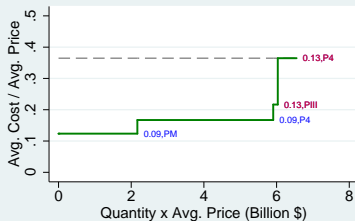


Quarter – 2005.75

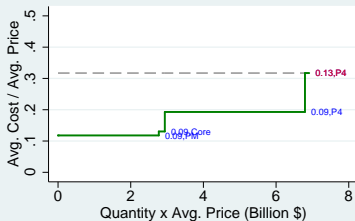


# MEASURING EQUIPMENT COST

Quarter – 2005



Quarter – 2005.25



Quarter – 2005.5



Quarter – 2005.75

