Measuring the Returns to R&D

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The problem

- Estimating the returns to R&D (and other intangible investments)
  - Intrinsically of interest
  - May help to choose among R&D strategies
  - Needed for "contributions to growth" analysis based on new systems of national accounts that incorporate intangibles
- Existing methods try to deal with several challenges:
  - Lack of secondary markets for R&D output
  - Smoothness of R&D over time
  - Importance of depreciation measure for estimated net returns

Some illustrative examples

- Internet
  - packet-switching technology funded by the U.S. Department of Defense.
  - protocols of the worldwide web conceptualized and developed by researchers on the payroll at CERN
- Technology underlying biotechnology
  - developed jointly by researchers at the UC San Francisco and Stanford University
  - based on earlier double helix work at Cambridge
- Bell Labs – transistor, radio astronomy

How do we measure the returns to these R&D efforts?

Presentation outline

- Basic measurement framework
- Estimating private returns
  - Production functions
  - Market value equations
- Overview of spillover channels
- Estimating social returns
  - Production functions
  - Summary of some results

Starting point for analysis

- Premise: R&D is a kind of investment
- Definition of returns: If we spend one $, euro, or krone on R&D today, how much will we receive from increased sales, GDP, etc in the future?
  - Should we compute this by looking backwards at past expenditure or by looking forward to future output?
- As they say in the financial prospectuses:

Past performance is no guarantee of future results

- In the case of R&D, the uncertainty of returns is magnified

Approaches used

- Backward looking: production function of R&D stock
  - Essentially assumes a stationary world
  - Can be used at any level of aggregation
  - Suitable for social as well as private returns
- Forward looking: market valuation of R&D-doing firms
  - Assumes market efficiency
  - Can be highly volatile
  - Requires a market that prices firm assets (including R&D)

Measurement Methodologies

- Case study – e.g., the development of the laser
- Trace technology flows from one industry to another using purchased inputs or patent data
- Trace research flows to industry using scientific or patent citations
- Willingness to pay in downstream industry as a measure of benefits received
- Relate productivity growth to R&D at various levels of aggregation
- Attempt to determine the price (valuation) of R&D output

Hall, Mairesse, Mohnen (2009)

- Measuring the Returns to R&D. In Hall, B. H. and N. Rosenberg, *Handbook of the Economics of Innovation*, Elsevier, pp. 1034-1076.
- Also available as
  - NBER Working Paper No. w15622 (December 2009)
  - UNU-MERIT Working Paper No. 2010-006
- Surveys econometric results obtained using production and cost functions on firms, industries, and countries
  - Includes spillover evidence
  - Covers a number of developed economies, mostly US, Canada, and European

Some measurement issues

- Long and variable lags, especially for publicly-funded R&D
- Double counting of R&D inputs (excess return?)
- Rate of return depends crucially on rate of depreciation (obsolescence) of the technology
- How to account for quality change in outputs and inputs?
  - Affects the allocation of returns between producing and using sector

Depreciation of R&D

- Assumption: R&D creates a stock of knowledge (*K*)
- What is its depreciation?
  - At the firm level, the rate at which returns to *K* decline
  - The result of Schumpeterian competition – endogenous to the behavior of competitors
  - Sometimes called private obsolescence
- Do we need to estimate it?
  - Yes, to estimate net rate of return
  - Yes, to construct knowledge stock

Hall (2005) reference

Measuring the Returns to R&D: The Depreciation Problem, *Annales d'Economie et de Statistique N° 79/80*, special issue in memory of Zvi Griliches, dated July/December. Also NBER Working Paper No. 13473 (September 2007)

- Assumes R&D capital receives a normal rate of return (plus a risk premium)
- backs out depreciation from both production function and market value estimates
  - MV approach – qualitative similar results
  - Prod fcn approach – depreciation near zero, but badly identified (with an attempt to correct for double counting of R&D inputs)

Productivity framework

- Cobb-Douglas production (first order log approximation to prod function)
- Line of business, firm, industry, or country level
  - At higher levels of aggregation, includes some spillovers
- Variety of estimating equations:
  - Conventional production function
  - Partial productivity
  - R&D intensity formulation
  - Semi-reduced form (add variable factor demand equations)

Productivity framework (cont.)

$$Y = AL^{\alpha}C^{\beta}K^{\gamma}e^{u}$$

where L *= labor*

C *= capital*

K *= research or knowledge capital*

u *= random shock*

Productivity framework (cont.)

Take logarithms and model the intercept with year and firm (or industry) effects:

$$y_{it} = \eta_i + \lambda_t + \alpha l_{it} + \beta c_{it} + \gamma k_{it} + u_{it}$$

$$i = 1,\ldots,N \qquad t = 1,\ldots,T$$

Simultaneity: shock u may possibly be correlated with the current (and future) input levels.

Correlated firm effects: η may also be correlated with the input levels.

R&D input measurement

- Deflation
  - No good measure of "real" costs of R&D
  - With time dummies, little bias from *R* deflation
- Stock computation (δ assumed =15%)

$$K_t = (1-\delta_K)K_{t-1} + R_t$$

$$\Rightarrow K_t \cong R_t / (\delta_K + g_R)$$

- Externalities
  - How to measure the external knowledge that is useful to a particular firm or industry?
  - Does leaving this out lead to bias in own R&D coefficient?

Output deflation

Productivity growth regressions at the firm level:

(1) $\Delta y_{it} = \Delta\lambda_t + \alpha\Delta l_{it} + \beta\Delta c_{it} + \gamma\Delta k_{it} + \Delta u_{it}$

(2) $\Delta s_{it} = \Delta y_{it} + \Delta p_{it} = \Delta\lambda_t + \alpha\Delta l_{it} + \beta\Delta c_{it} + \gamma\Delta k_{it} + \Delta u_{it}$

where s is revenue and y is deflated output

If (2) is estimated instead of (1), we obtain an estimate of

$$\gamma_S = \gamma_Y + \gamma_P$$

The *revenue* productivity of R&D is the sum of

- *true* productivity
- the effect R&D has on the prices at which goods are sold due to
  - quality improvements (decreases)
  - product differentiation (increases)

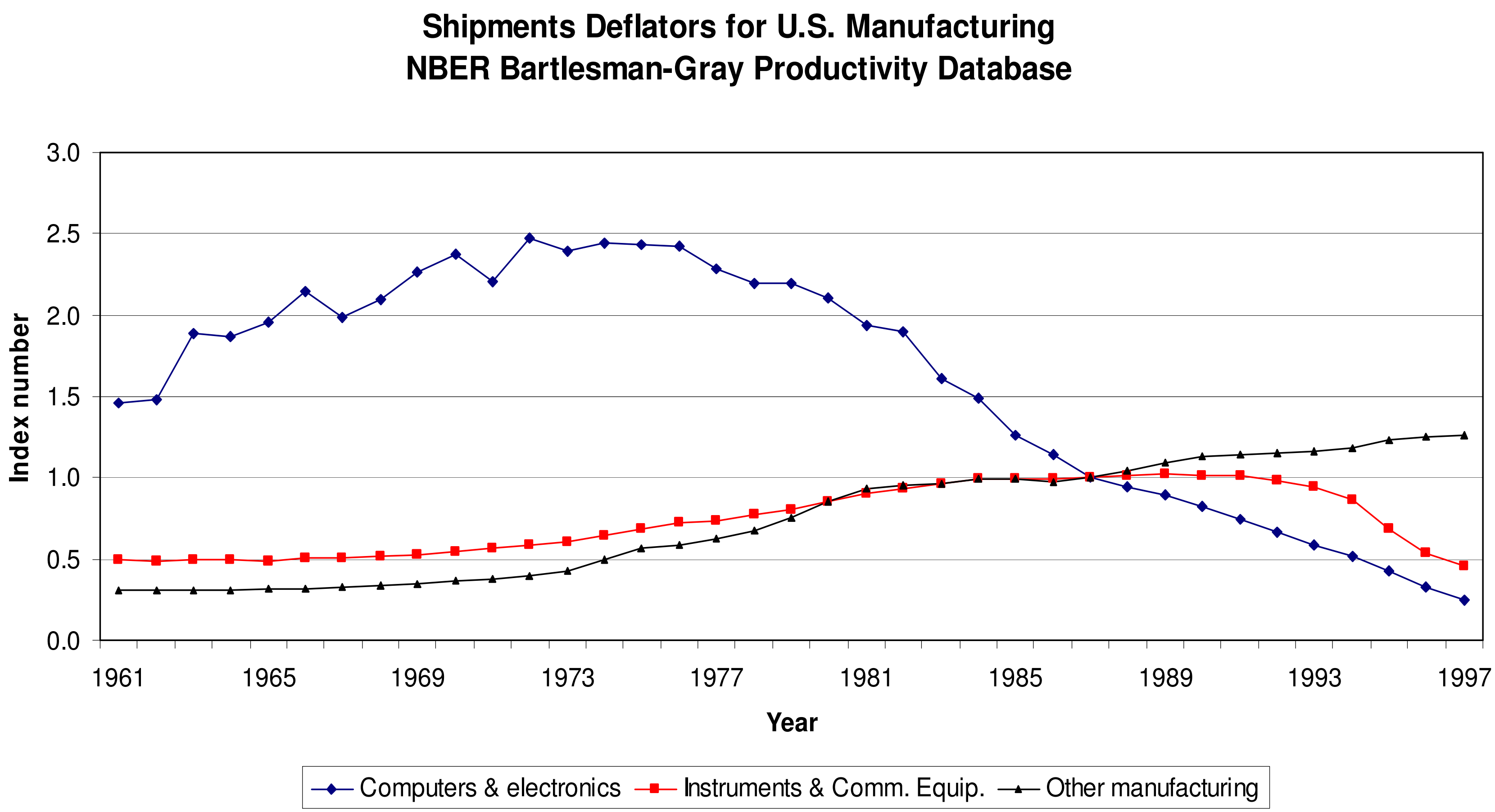
Interpretation

- Revenue productivity is a determinant of private returns
- True productivity (more constant quality output for a given set of inputs) is closer to social returns
- The difference represents
  - Negative – pecuniary externalities
  - Positive – output "stealing" or market power increases due to R&D

Illustration

- Some U.S. deflators at the industry level are hedonic, notably those for the computer industry and now the communications equipment industry (see next slide)
- Deflate firm sales by 2-digit deflators instead of one overall deflator
- Result: true productivity is substantially higher than revenue productivity, because of hedonic price declines in these R&D-intensive industries.

Hedonic Price Deflator for Computers



Estimated R&D Elasticity – U.S. Manufacturing Firms

Period	Dep. Var = Log Sales	Dep. Var = Log Sales, 2-digit deflators	Difference ("price effect")
1974-1980	-.003 (.025)	.102 (.035)	0.099
1983-1989	.035 (.030)	.131 (.049)	0.096
1992-1998	.118 (.031)	.283 (.041)	0.165

Method of estimation is GMM-system with lag 3 and 4 instruments.
Sample sizes for the three subperiods are 7156, 6507, and 6457.

Private firm level returns to R&D

Authors	*Country*	*Years*	*Rate of return to R&D*
Griliches-Mairesse (1984)	US	1966-77	35% *
Cuneo-Mairesse (1984)	France	1974-79	~90% *
Mairesse-Cuneo (1985)	France	1974-79	~128% **
Griliches (1986)	US	1967, 72, 77	51% to 76% *
Hall (1993)	US	1964-90	18% to 43% *
Hall-Mairesse (1995)	France	1980-87	78% *
Mairesse-Hall (1994)	France	1981-89	75% *,**
	US	1981-89	28% *
Harhoff (1998)	Germany	1979-89	71% *
Medda-Piga-Siegel (2003)	Italy	1992-95	29%, 36%
Wang-Tsai (2003)	Taiwan	1994-2000	8% to 35% *,**
Bond-Harhoff-van Reenen (2005)	Germany	1988-96	19%
	UK	1988-96	38%
Mairesse-Mohnen-Kremp (2005)	France	2000	16%
	France	2000	27%
Griffith-Harrison-van Reenen (2006)	UK	1990-2000	14% *
Rogers (2009)	UK	1989-2000	40% to 58% (mfg)** 53% to 108% (non-mfg)**
Hall-Foray-Mairesse (2009)	US	2004-06	23% *
Ortega-Argilés et al. (2009)	EU	2000-05	35%

* computed from the elasticities using means or medians of the R&D and output variables

** estimates using capital and labor corrected for double counting.

Unless otherwise noted, estimates use uncorrected data.

Market value model

- Assumes market efficiency
- Two versions
  - Theoretical – value function from firm's dynamic program as a function of state variables (capital, R&D, etc.)
  - Hedonic – value of a set of goods that have a lower-dimensional vector of characteristics – yields a measure of current shadow value of the assets (not stable over time)

Hedonic regression for market value

$$V_{it}(A_{it}, K_{it}) = b_t\,[A_{it} + \gamma K_{it}]$$

Non linear:

$$log(V_{it}/A_{it}) = logQ_{it} = log\ b_t + log(1+\gamma_t K_{it}/A_{it})$$

Linear approx.: $$log\ Q_{it} = log\ b_t + \gamma_t\ K_{it}/A_{it}$$

Interpretation:

$Q_{it} = V_{it} / A_{it}$ is Tobin's q for firm i in year t

b_t = overall market level (approximately one).

γ_t = relative shadow value of K assets

($\gamma = 1$ if depreciation correct, investment strategy optimal, and no adjustment costs => no rents).

Summary of past results

- Market value positively related to R&D
- Range of estimates for shadow value
  - R&D expenditure coefficient: ~1.5 to 8 or 9
  - R&D stock coefficient: 0.2 to 2
- Wide variability over time and industry
- Substantial variability in specification, making comparisons difficult
  - Intangibles, patents, trademarks
  - Leverage, sales growth, market share

Extracting depreciation rate

- Strong assumptions:
  - Equilibrium in R&D
  - Market efficiency
  - Negligible adjustment costs
  - Only mismeasurement in K is using wrong depreciation rate to construct it

Market value estimates – US manufacturing sector

Period	K/A Coefficient	(s.e.)	Median depreciation	(s.e.)
1974-1978	0.398	0.028	42.8%	9.2%
1979-1983	0.573	0.028	30.3%	4.9%
1984-1988	0.362	0.029	54.0%	9.0%
1989-1993	0.352	0.033	55.3%	7.8%
1994-1998	0.507	0.040	37.8%	5.5%
1999-2003	0.745	0.044	21.8%	2.9%

Estimated depreciation of R&D for selected sectors

Period	Drugs & medical instruments	Computers & electronics
1974-1978	*9.9% (4.2%)*	*31.9% (8.1%)*
1979-1983	*19.6% (7.9%)*	*50.1% (14.5%)*
1984-1988	5.8% (3.1%)	*88.1% (27.6%)*
1989-1993	*20.6% (6.6%)*	*51.3% (8.6%)*
1994-1998	*18.8% (5.6%)*	*51.2% (11.6%)*

Differences across sectors are plausible, but there is high variability over time.

Returns to R&D

- Private
  - firms do R&D and improve their products and processes
  - have higher sales and/or lower costs
  - returns are amount of additional profit achieved per unit of R&D spending
- Social
  - firms, universities, PROs in the economy do R&D
  - achieve higher profits and other improvements to health, defense, the environment
  - real output increases more than inputs of capital, labor, materials
  - returns are increase in welfare due to aggregate R&D

Why are these two measures different? spillovers

Evidence on social returns

- Early papers show high social returns, using a wide variety of methods
- Most econometric evidence on the direct immediate contribution of public (govt-funded) R&D to private firm returns finds little contribution
  - However, weak identification due to high correlation of company and govt-funded R&D within firms

R&D Spillovers

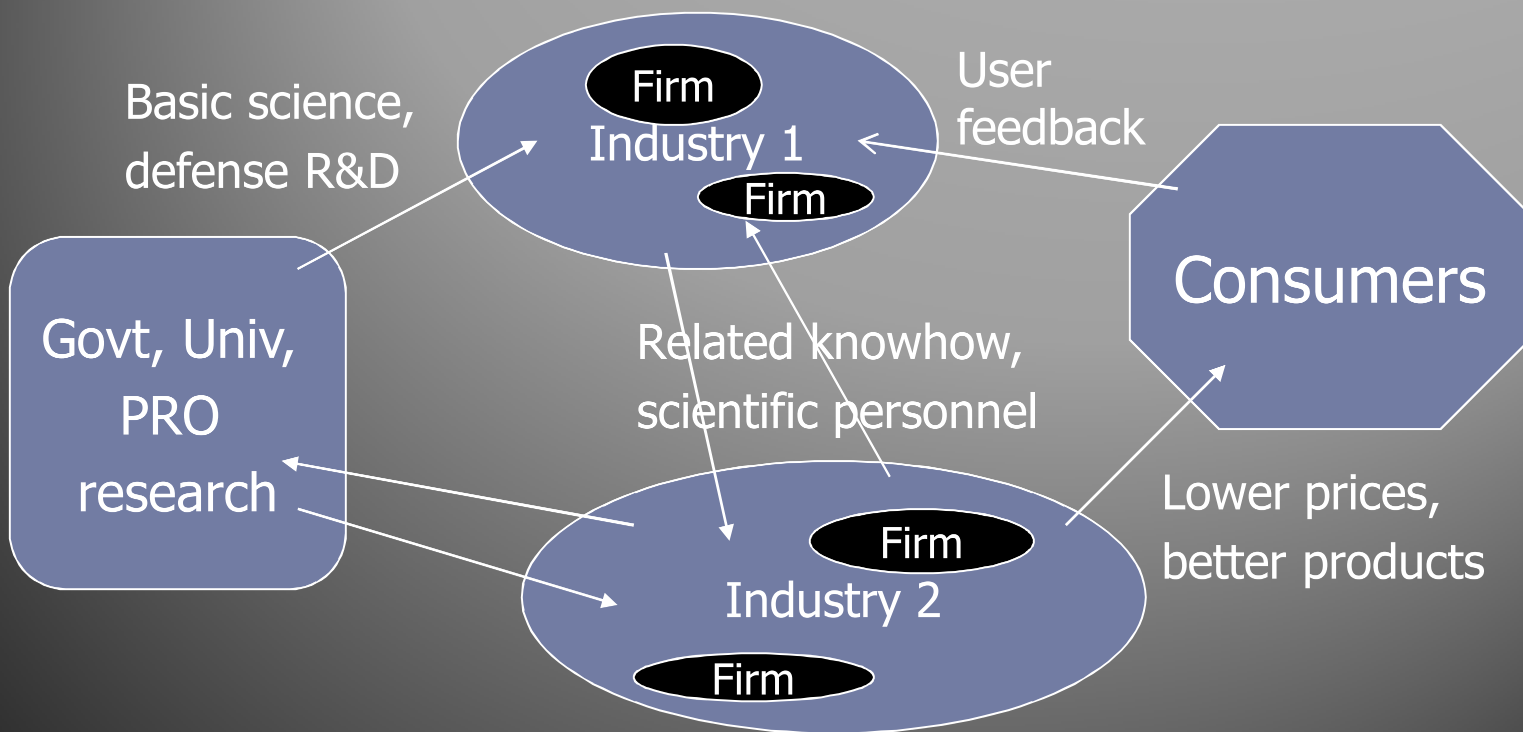
- From firm to firm in the same or related industries.
  - Reverse engineering
  - Migration of scientists and engineers (e.g., within Silicon Valley)
  - Lower cost imitation of innovative products
- From firms to downstream customers
  - Improved capital equipment (e.g., computers in financial services)
  - Consumer electronics, healthcare (e.g., CT scanner)
  - Much of this welfare increase captured by pricing – flows to consumers

R&D Spillovers (cont.)

- From govt. and university research to firms
  - commercial product improvements from defense R&D (e.g., airframes, satellites)
  - scientific base for innovation (e.g., biotech)
- From govt. and university research to consumers
  - via new industrial products
  - directly (environment, healthcare, etc.)

Conclusion: some of the benefits to R&D go to individuals and firms that do not bear its cost.

R&D spillover schematic



Estimating spillover returns

- Usually estimate social = private + spillover
- Construct measures of flows from other sectors or countries based on trade, patent citations, inter-industry investments, etc.
- Weight external R&D measure using these flows
- Include in a productivity regression along with own R&D

Industry estimates of returns

Authors	*Sample*	*Years*	*Private returns*	*Social returns*
Griliches-Lichtenberg (1984a)	US industries	1959-78	11% to 31% (8%)	50% to 90% (36%)
Odagiri (1985)	Japan industries	1960-77	157% to 315%	-606% to 734%
Sterlacchini (1989)	UK industries	1945-83	12% to 20%	15% to 35%
Goto-Suzuki (1989)	Japan industries	1978-83	26%	80%
Bernstein (1989)	Canada industries	1963-83	24% to 47%	29% to 94%
Bernstein-Nadiri (1989)	US industries	1965-78	7%	9% to 13%
Mohnen-Lepine (1991)	Canada industries	1975, 77, 79, 81-83	56% (5% to 275%)	30% (2% to 90%)
Wolff-Nadiri (1993)	US industries	1947, 58, 63, 67, 72,77	11%-19%	0%-14%
Bernstein-Yan (1997)	Canada industries	1964-82	17.2%	62% to 183%
	Japan industries	1964-82	17.4%	9% to 56%
Bernstein (1998)	Canada industries	1962-89	12.8%	19% to 145%
	US industries	1962-89	16.4%	28% to 167%
Bernstein-Mohnen (1998)	Canada industries	1962-86	44.0%	47%
	Japan industries	1962-86	47%	0%
Griffith-Redding-van Reenen (2004)	12 OECD countries/ 11 industries	1974-90	47% to 67%	57% to 105%

Conclusions from this literature

- In general, the social returns to most R&D investments are greater than the private returns.
  - Gap varies by industry and type of research
  - some R&D investments have high private returns and do not need to be subsidized.
- Some kinds of public research spending (academic science; advanced training) have very high social returns, some of them geographically concentrated.
- R&D process is highly uncertain; probability of success not sensitive to fine financial tuning; project choice is difficult, for firms or government agencies.

Some remaining questions

- Quality-adjusted price deflators and their effect on measured R&D contribution.
- How do we target the marginal project? If we are going to subsidize some (pre-)commercial projects, how should we choose and evaluate them?
- Conflict between the goals of the firm (product differentiation) and those of society.
- Short run response to R&D subsidies is an increase in the wage of R&D workers (elasticity ~.2). How does the long run play out?

Growth accounting intro

Supplementary slides

Introduction – Growth Accounting

- In developed economies, over half of output growth cannot be explained by growth in conventional inputs.
- Correcting the inputs (labor and capital) for quality improvement leaves about a third unexplained.
- Presumption: unexplained growth AND quality improvements are a result of research and technological activity, broadly defined.
- Thus our interest in the R&D-Growth relationship.

Basic growth accounting (1)

Assume the economy can be described by a "production function" with technical progress *A(t)* and two inputs, capital *C(t)* and labor *L(t)*:

$$Q(t) = A(t)F[C(t), L(t)]$$

Q(t) is aggregate output (GDP) in year *t*

Labor *L(t)* is measured in person-hours or number of workers.

Other inputs such as energy or materials can be included

Productivity level *A(t)* grows over time

=> more output for a given level of capital and labor

Basic growth accounting (2)

What is the growth of output as a function of the growth of labor and capital?

Differentiate output Q(t) with respect to time t, using the chain rule. Express the result in terms of growth rates:

$$G_Q = G_A + \varepsilon_C G_C + \varepsilon_L G_L$$

where elasticity is defined as $\varepsilon_X = \dfrac{d \log Q}{d \log X}$

in competitive markets, $\epsilon_X =$ share of X in output; competitive assumption can be relaxed somewhat

How do we measure this?

- output:
  - sum over sales of all final goods and services in the economy
  - sum value added in each sector
- capital:
  - sum over plant and equipment
  - sum over imputed rental cost (depreciation plus interest rate or required net rate of return)
- labor:
  - number of workers
  - number of worker hours

Measurement issues

- input utilization
- price deflation
  - Values from National Income Accounts = *P*Q*
  - Choice of deflator *P* affects measurement of real output *Q*
  - similarly for real capitals *C,K*
- quality change
  - Capital, output, labor today not the same quality as that in earlier years
- aggregation
  - Can sum values (in the same units)
  - ……but cannot sum different kinds of output or capital types – must convert to real value

Growth accounting example

Aggregate US Data 1900–1949 (Solow, with elasticities equal to shares):

$$G_A = G_Q - s_C G_C - s_L G_L$$

$= 2.75\% - (.35)\ 1.75\% - (.65)\ 1.00\%$

$= 2.75\% - 0.61\% - 0.65\%$

$= 1.49\%$

Implication: slightly more than half of output growth is not explained by growth in capital and labor inputs. This quantity (G_A) is often called the "residual" or "total factor productivity growth."

Growth Accounting for the US 1960-2001

	Growth rate	Growth due to			Growth rate
Period	of GDP	Capital	Labor	TFP (A)	of GDP/worker
1960-1970	4.0	0.8	1.2	1.9	2.2
1970-1980	2.7	0.9	1.5	0.2	0.4
1980-1990	3.5	1.5	1.3	0.6	1.7
1989-1995	2.5	1.2	1.0	0.3	1.5
1995-2001	4.2	2.1	1.1	1.0	2.7

Source: Jorgenson (2004)

These estimates have been corrected for changes in capital and labor quality.

Contribution of R&D & ICT to growth – France

	1980-1990	1990-1995	1995-2000	2000-2002
Growth in VA	2.63	0.48	2.55	1.61
Contribution from:				
R&D	0.08	0.10	0.05	0.06
ICT	0.08	0.03	0.12	0.25
Adjusted for quality improvement, using social deprec. rate:				
R&D	0.34	0.42	0.32	0.33
ICT	0.14	0.11	0.22	0.38

Scope: Business Sector
Source: Kocoglu and Mairesse (2004) – calculations based on National Accounts and OECD (for R&D)

Contribution of R&D & ICT to growth – United States

	1980-1990	1990-1995	1995-2000	2000-2002
Growth in VA	3.09	2.41	4.28	1.13
Contribution from:				
R&D	0.11	0.07	0.10	0.14
ICT	0.21	0.14	0.37	0.41
Adjusted for spillovers, quality improvement:				
R&D	0.47	0.41	0.46	0.57
ICT	0.33	0.30	0.60	0.67

Scope: Business Sector
Sources: Koceglu and Mairesse (2004) – calculations based on National Accounts and OECD (for R&D)

Private returns to public R&D (1)

- Measured returns to govt.-funded R&D performed by private firms (contract R&D for defense, space, etc.):
  - zero at the firm or industry level in the U.S. (Bartelsman, Griliches, Lichtenberg, Nadiri and Mamuneas, etc.)
  - zero using cross-country data (Lichtenberg 1993)
  - zero for Canada (Hanel 1994), Norway (Klette 1991, 1997), Germany (Harhoff 1993), but positive for France (Hall and Mairesse 1995), Israel (Griliches and Regev)
- most studies use TFP methodology with measures of govt. funded R&D together with private R&D
  - Due to high correlation between private & govt R&D across industry, identification often weak

Private returns to public R&D (2)

- Individual case study evidence shows that contribution can be large
  - Mowery (1985) on commercial aircraft spillovers
  - Hertzfeld (1985) on communications satellites
  - Etc……
- Why the difference?
  - long and variable lags
  - diffuse benefits outside the industry of origin
  - measurement difficulties (deflators again)
  - problems defining and measuring the appropriate R&D input cost
  - focus on successes

Social returns to public R&D

- Defense, space, environment, etc. – output not measured.
- Science and basic research – some earlier work
  - Adams (1990) – stocks of scientific articles enter into related industry productivity with long (20 year) lags. Social returns average 70-80%, but very disperse.
  - Mansfield (1995) – direct traceable returns to academic R&D about 20-30 percent, ignoring longer lags, other spillovers, spillovers outside U.S., etc.
  - Griliches (1986); Lichtenberg & Siegel (1991) – basic research has higher returns than ordinary R&D at firm level in US.
  - Hall & Mairesse (1995) – French firms with a large share of basic research have lower productivity.