ME2708 Economic Growth

Lecture 8: Directed Technical Change

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Outline

1. Introduction
2. Directed Technical Change
3. DTC and Income Inequality
4. Applications to the Pharmaceutical Industry

1. Introduction

2. Directed Technical Change

3. DTC and Income Inequality

4. Applications to the Pharmaceutical Industry

Introduction I

- The theories presented in this lecture are based on a series of recent papers by Daron Acemoglu and coauthors
- The literature on directed technical change (DTC) however goes back to the early 1930s
  - Hicks (1932) suggested that technological progress economizes on the more expensive factor
- Other important ideas closely related to DTC were introduced in the 1950s and 1960s
  - Fellner's (1961) idea of factor-saving technologies: labor-saving inventions conditional on wages rising faster than rental prices of capital goods
  - Arrow (1962) studied the optimality of the resource allocation for inventions from the viewpoint of welfare economics
  - Kennedy's (1964) "innovation possibilities frontier": trade-off in the generation of different types of innovation

Introduction II

- Other important ideas closely related to DTC were introduced in the 1950s and 1960s (*cont.*)
  - Kennedy also suggested that induced innovation would push the economy to an equilibrium with constant relative-factor shares
  - Atkinson and Stiglitz's (1969) "localized technical progress": technical change can improve some *but not all* the production techniques for one product
- The *microfounded* theories discussed here emerged in the 1990s and feature the existence of *market-size effects* (mostly absent in previous literature)
  - Some of these ideas were already introduced during last lecture
  - In particular we introduced a model discussing the extent of skill-biased technical change (SBTC) in the economy and market-size effects as its main driver (Acemoglu and Zilibotti, 2001)

Introduction III

- In this lecture we discuss further *market-size* effects and also connect with income inequality, another important macroeconomic topic
    - Acemoglu's (2002) *Directed Technical Change*
    - Autor, Krueger and Kratz's (1998) *Computing Inequality*
    - Acemoglu and Linn's (2004) *Market Size in Innovation*

- Motivation: instead of innovations taking place with the same avg. frequency across sectors (as seen in previous models), some sectors innovate more than others
    - Sector size is likely to be key: *ceteris paribus*, it is more profitable to innovate in larger sectors because successful innovators have larger markets to exploit
    - As a result, technical change tends to be biased toward larger sectors
    - Application: pharmaceutical industry, where innovations are directed toward drugs that are used by wealthier customers

1. Introduction
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Directed Technical Change I

- This section is based on Acemoglu (2002):
  - Large and influential literature on the determinants of technical progress (Romer, 1990; Segerstrom et al., 1990; Grossman and Helpman, 1991; Aghion and Howitt, 1992; Romer, 1995)
  - This literature does not address (extremely relevant) questions related to the *direction* and *bias* of technical change
    - In most situations technical change is not neutral but rather favors some factor of production
    - The amount of R&D directed towards different factors and sectors likely to depend on profit incentives
  - Whether technical change is biased towards particular factors of production is of central importance for several economic literatures (growth, development, labor, international trade. . .)

Directed Technical Change II

- Some historical facts:
  1. Over the past 60 years, the US relative supply of skills have increased rapidly but there's been no tendency for the returns to college to fall (*rather the opposite*!)

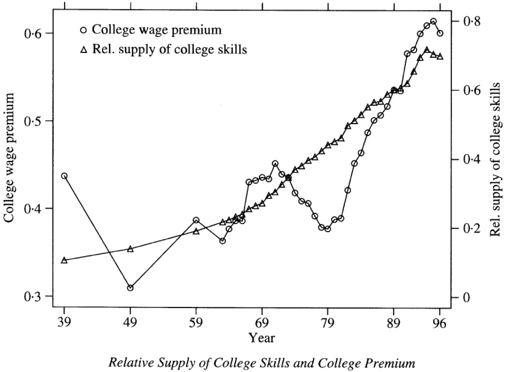

Figure: Skill-biased technical change

Directed Technical Change III

- Some historical facts (*cont.*):
  2. During the late 18th and early 19th centuries, *unskill-biased* or *skill-replacing* technical change
  3. Over the past 150 years, the prices of the two key factors (capital and labor) have behaved very differently
     - wages have increased steadily but rental prices of capital have remained constant

     ...supporting the idea of labor-augmenting technical change!
  4. Blanchard (1997) mentions that, at some points, technical progress could've even been *capital-biased*
- These historical facts further motivate the relevance of studying DTC
- Acemoglu generalizes existing endogenous technical change models to allow for technical change to be biased towards different factors:
  - the relative profitability of technologies determines the direction of technical change

Directed Technical Change IV

Factor-biased Technical Change I

- Aggregate production function of the form,

  $$Y = F[L, Z, A]$$

  where L is labor, Z is skilled labor (or capital or land) and A is an index of technology

- As usual, technical progress is L-augmenting when,

  $$Y = F[AL, Z]$$

  Z-augmenting technological progress can be similarly defined

- Technical change is L-biased when

  $$\frac{\partial \frac{\partial F/\partial L}{\partial F/\partial Z}}{\partial A} > 0$$

  i.e. when technical change increases the marginal product of L more than that of Z

Directed Technical Change V

Factor-biased Technical Change II

- Production occurs according to the more particular form of a constant elasticity of substitution (CES) production function,

$$Y = \left[\gamma(A_L L)^{\frac{\sigma-1}{\sigma}} + (1-\gamma)(A_Z Z)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \tag{1}$$

  where A_L and A_Z are two separate technology parameters, $\gamma \in (0,1)$ is a distribution parameter determining how important each factor is, and $\sigma \in (0,\infty)$ is the elasticity of substitution between the 2 factors

  - $\sigma = \infty$: factors are perfect substitutes and production is linear
  - $\sigma = 1$: production is Cobb-Douglas
  - $\sigma = 0$: no substitution between factors and production is Leontieff
  - $\sigma > 1$: factors are gross substitutes
  - $\sigma < 1$: factors are gross complements

Directed Technical Change VI

Factor-biased Technical Change III

- Whether technical change is L- or Z- biased depends on the elasticity of substitution σ

- To see this calculate the relative marginal product of either factor,

$$\frac{MP_Z}{MP_L} = \frac{1-\gamma}{\gamma}\left(\frac{A_Z}{A_L}\right)^{\frac{\sigma-1}{\sigma}}\left(\frac{Z}{L}\right)^{-\frac{1}{\sigma}} \tag{2}$$

- The relative marginal product of Z is decreasing in the relative abundance of Z, Z/L (*substitution effect*)

- The effect of A_Z on the relative MP of Z depends however on σ
  - $\sigma > 1$: An increase in A_Z, relative to A_L, increases the relative MP of Z
  - $\sigma < 1$: An increase in A_Z decreases the relative MP of Z
  - $\sigma = 1$: neither a change in A_Z nor in A_L is biased towards any factor

Directed Technical Change VII

Adapted Model I

- Final output consists of two distinct goods: a labor-intensive good Y_L and a skill-intensive good Y_Z, both produced under perfect comp.
- These two goods have the following production functions,

$$Y_L = \int_0^1 A_{L,i} y_{L,i}^{\alpha} di \cdot L^{1-\alpha} \tag{3}$$

and

$$Y_Z = \int_0^1 A_{Z,i} y_{Z,i}^{\alpha} di \cdot Z^{1-\alpha} \tag{4}$$

- where $\alpha \in (0,1)$, and each good is produced using its factor of production and the corresponding continuum of specialized intermediate products

Directed Technical Change VIII

Adapted Model II

- Assume that the local monopolist in each sector can produce one unit at no cost but cannot produce any more than one unit at any cost
- In equilibrium: $y_{L,i} = y_{Z,i} = 1$, which allows us to rewrite final-output production functions as,

$$Y_L = A_L L^{1-\alpha} \quad \text{and} \quad Y_Z = A_Z Z^{1-\alpha} \tag{5}$$

  where $A_L = \int A_{L,i} di$ and $A_Z = \int A_{Z,i} di$ are the avg. productivity parameters

- Equilibrium in the competitive final markets implies that the wage rate of each type of labor must equal its MP

$$w_L = (1-\alpha) P_L \frac{Y_L}{L} \quad \text{and} \quad w_Z = (1-\alpha) P_Z \frac{Y_Z}{Z} \tag{6}$$

  where P_L and P_Z are the two final-good prices

Directed Technical Change IX

Adapted Model III

- The skill premium is then defined as,

$$\frac{w_Z}{w_L} = \left(\frac{P_Z Y_Z}{P_L Y_L}\right)\left(\frac{Z}{L}\right)^{-1} \tag{7}$$

- In equilibrium, the relative price P_Z/P_L must equal the marginal rate of substitution in demand between the two goods, which we suppose depends on the relative quantity Y_Z/Y_L according to,

$$\frac{P_Z}{P_L} = \left(\frac{Y_Z}{Y_L}\right)^{-\upsilon}, \quad \upsilon > 0 \tag{8}$$

where υ is an inverse measure of substitutability between the two goods (*a common expression that you may see, instead of* υ, *is* $\frac{1}{\sigma}$)

Directed Technical Change X

Adapted Model IV

- The first parenthesis of eq. (7) can now be re-written as,

$$\frac{P_Z Y_Z}{P_L Y_L} = \left(\frac{Y_Z}{Y_L}\right)^{1-\upsilon} \tag{9}$$

- Combining equations (5,7) with eq. (9), we can re-express the skill premium as,

$$\frac{w_Z}{w_L} = \left(\frac{A_Z}{A_L}\right)^{1-\upsilon} \left(\frac{Z}{L}\right)^{-1+(1-\alpha)(1-\upsilon)} \tag{10}$$

  where $-1 + (1-\alpha)(1-\upsilon) < 0$ since $\alpha \in (0, 1)$ and $\upsilon > 0$

- Equation (10) says that anything that raises the relative supply of skilled labor (*e.g. education subsidies*) will reduce the skill premium because it makes skilled labor less scarce (*substitution effect*)

Directed Technical Change XI

Adapted Model V

- What we see in eq. (10), i.e. that the relative abundance of skilled labor reduces its wage premium, is the **immediate, direct effect**. . .

$$\frac{w_Z}{w_L} = \left(\frac{A_Z}{A_L}\right)^{1-\upsilon} \left(\frac{Z}{L}\right)^{-1+(1-\alpha)(1-\upsilon)}$$

- . . . but there are more factors into play!
  - As time goes by there will be an **indirect, market-size effect**
  - This effect is caused by the change in the relative supply of factors of production
  - These changes may induce a reallocation of R&D towards or away from the skill-intensive intermediate inputs
  - Ultimately affecting the relative productivity parameter A_Z/A_L

Directed Technical Change XII

Adapted Model VI: Market-size Effect I

- The profit of the monopolist in one skill-intensive sector is given by,

$$\pi_{Z,i} = p_{Z,i} y_{Z,i} = p_{Z,i}$$

- Recall that we assumed that monopolist had no cost of production and could produce only 1 unit (*the second equality follows from this*)

- Equilibrium in the skill-intensive final good market requires that the price $p_{Z,i}$ be equal to the value of the marginal product of $y_{Z,i}$,

$$\pi_{Z,i} = P_Z \frac{\partial Y_Z}{\partial y_{Z,i}} = \alpha P_Z A_{Z,i} Z^{1-\alpha}$$

- Each period the *unique* entrepreneur in each sector has the opportunity to become the monopolist if she innovates, raising productivity by $\gamma > 1$

Directed Technical Change XIII

Adapted Model VII: Market-size Effect II

- The probability of innovation is $\phi(n_Z)$, where

$$n_Z = \frac{R_{Z,i}}{A^*_{Z,i}}$$

  is the productivity-adjusted R&D expenditure and $A^*_{Z,i}$ is the "targeted" productivity level

- Note that $\phi^{'} > 0$ and $\phi^{''} < 0$

- The entreprenur's problem is to choose n_Z so that her expected payoff is maximized

$$\max_{n_Z} \quad \phi(n_Z)\pi_{Z,i} - A^*_{Z,i} n_Z = A^*_{Z,i}\left[\phi(n_Z)\alpha P_Z Z^{1-\alpha} - n_Z\right]$$

Directed Technical Change XIV

Adapted Model VII: Market-size Effect III

- FOC yields,

  $$\phi^{'}(n_Z)\alpha P_Z Z^{1-\alpha} = 1$$

  which we can rewrite, using production function eq. (5) as,

  $$\phi^{'}(n_Z)\alpha \frac{P_Z Y_Z}{A_Z} = 1 \tag{11}$$

- The same analysis applies to each labor-intensive sector, so that we get an identical (but adapted) condition,

  $$\phi^{'}(n_L)\alpha \frac{P_L Y_L}{A_L} = 1 \tag{12}$$

Directed Technical Change XV

Adapted Model VII: Market-size Effect IV

- The growth rate of each $A_{Z,i}$ will be $(\gamma - 1)$ with probability $\phi(n_Z)$ and zero with probability $1 - \phi(n_Z)$
- Thus, the expected growth rate of the avg. productivity parameter A_Z will be,

  $$g_Z = (\gamma - 1)\phi(n_Z)$$

  which, by the *L.L.N.*, is also the *actual* growth rate of A_Z
- The same reasoning applies to A_L, which grows at,

  $$g_L = (\gamma - 1)\phi(n_L)$$

Directed Technical Change XVI

Adapted Model VII: Market-size Effect V

- In the long run the economy approaches a steady state in which the relative producitivity, A_Z/A_L, is constant, which requires

  $$g_Z = g_L = g$$

  this also implies that $n_Z = n_L$

- From equations (11) and (12) it follows that, in the steady state, relative productivity must equal relative expenditure

  $$\frac{A_Z}{A_L} = \frac{P_Z Y_Z}{P_L Y_L}$$

Directed Technical Change XVII

Adapted Model VII: Market-size Effect VI

- Substituting for the right-hand side using eq. (9) and then substituting for the relative quantity Y_Z/Y_L, using equations in (5), we get the steady-state condition,

$$\frac{A_Z}{A_L} = \left[\frac{A_Z}{A_L}\frac{Z^{1-\alpha}}{L^{1-\alpha}}\right]^{1-\upsilon}$$

- Now we can solve for the equilibrium relative productivity

$$\frac{A_Z}{A_L} = \left(\frac{Z^{1-\alpha}}{L^{1-\alpha}}\right)^{\frac{1-\upsilon}{\upsilon}} \tag{13}$$

Directed Technical Change XVIII

Adapted Model VIII: Market-size Effect VII

- In this equation we can see very interesting things:

$$\frac{A_Z}{A_L} = \left(\frac{Z^{1-\alpha}}{L^{1-\alpha}}\right)^{\frac{1-\upsilon}{\upsilon}}$$

  - If the two final goods are close-enough substitutes ($\upsilon < 1$[1]), then an increase in the relative supply of skilled labor will have the long-run effect of raising the relative productivity of skill-intensive inputs
  - If this effect is large enough then, according to eq. (10), it will override the negative direct effect so that the overall effect is to raise the long-run skill premium
    - As $\upsilon \to 0$, $Z/L \to \infty$ in eq. (13)

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[1] In Acemoglu's original formulation, $\sigma > 1 \Rightarrow \upsilon = \frac{1}{\sigma} < 1$

Directed Technical Change XVIX

- Two important determinants of the direction of technical change:
  1. **Degree of substitution between factors**: when the two factors are more substitutable, the market size effect is stronger and technical change is likely to be biased toward the more abundant factor
  2. **Degree of state dependence in the innov. possibilities frontier** (*not discussed here*)

- The model presented here exhibits the scale effects associated with Romer (1990)

- More complex formulations allow to get rid of these scale effects and to reach results like that of Jones' (1995)

- This model also allows introduction of more realistic phenomena
  - part of scientific progress is profit-driven
  - supplies of L and Z determined by relative prices w_Z/w_L
  - adjusting conveniently the degree of state dependence

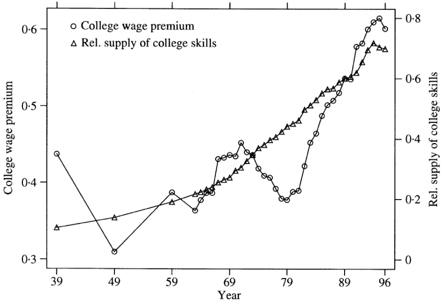
Directed Technical Change XXX

- Important results:
  1. **Weak induced-bias hypothesis**: irrespective of the elasticity of substitution (granted that $\sigma \neq 1$), an increase in the relative abundance of a factor creates some amount of technical change in the direction of that factor
  2. **Strong induced-bias hypothesis**: if the elasticity of substitution is sufficiently large ($\sigma \to \infty$ or $\upsilon \to 0$), the induced bias in technology can overcome the usual substitution effect and increase the relative reward to the factor that has become more abundant

- Applications:
  - Endogenous factor-biased technical change
  - DTC and cross-country income differences (e.g. North vs. South)
  - International trade pushes further the amount of factor-biased technical change and also increases the skill-premium
  - The Habakkuk (1962) hypothesis: direction and intensity of technical change respond to factors of production, i.e. factor-saving techs

Directed Technical Change XXXI

- Predictive power: it can totally account for facts observed in Fig. 1:
  - Increase in the relative abundance of Z, creates a tendency towards skill-biased technologies
  - Greater skill abundance could lead to higher skill premiums
  - Acceleration in the skill-bias of technology explains the *rapidly* increasing skill premiums



Relative Supply of College Skills and College Premium

Directed Technical Change XXXII

- Predictive power (*cont.*):
  - Technical change in 1750-1850 was biased towards unskilled labor because migration flows from little villages to towns introduced incentives for innovators to develop unskilled-biased technologies
- Criticisms:
  - Jones (1995) comment: despite OECD countries have experienced substantial increases in avg. schooling and R&D levels during the past 60 years, there has been no apparent payoff in terms of growth
  - The growth rate, according to this model should've increased following an increase in the relative skill-labor supply
    - Acemoglu's response: decreasing returns in R&D
  - Some economists argue that this approach cannot account for labor-market patterns observed previously

1. Introduction

2. Directed Technical Change

3. DTC and Income Inequality

4. Applications to the Pharmaceutical Industry

DTC and Income Inequality I

- This section is mainly based on Autor, Katz and Krueger (1998)
  - This section can easily be linked to the previous section (based on Acemoglu, 2002) and its implications
  - We now focus more in depth on the evolution of two related factors: the skill premium and the relative supply of skills
  - AKK (1998) is mainly an empirical study aimed at documenting the effects of DTC (measured by computerization) on wage differentials for the US economy in 1940–1996
  - Main results are:
    - Strong and persistent growth in the relative demand for skilled workers
    - Increases in relative demand of skilled workers are greater in computer-intensive industries

DTC and Income Inequality II

- Overall wage inequality and educational wage differentials have expanded in the US since the late 1970s
  - skill-biased technical change
  - rising globalization (e.g. offshoring, etc.)
  - decline in unionization
  - ...
- Empirical evidence suggests some complementary between physical capital and new technologies with more-skilled workers
- Documented increases of nonproduction vs. production workers within industries in the US despite rising wages of the former
- This increased demand for more-educated workers, despite the upward pressure on wages, is interpreted as skill-biased technological change

DTC and Income Inequality III

- AKK focus on the college/high school relative wage as a proxy for the relative price of the "more-skilled" labor
- They studied the relation between the relative price of skilled-labor and the measured changes in the relative supply of and demand for college-educated labor
- Data from the Current Population Survey (CPS)
- Time frame: 1940–1996

DTC and Income Inequality IV

Relative Supply and Demand for Skills 1940–1996

- Dramatic decline in the share of those with less than high school
- Substantial increase in the share of college graduates and those with some college; and also in the wage differential

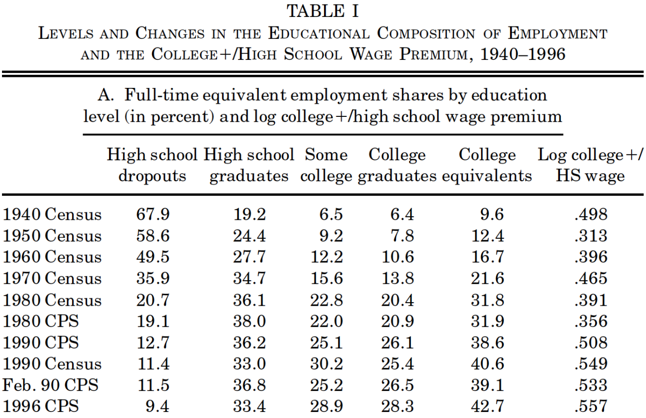


TABLE I

LEVELS AND CHANGES IN THE EDUCATIONAL COMPOSITION OF EMPLOYMENT AND THE COLLEGE+/HIGH SCHOOL WAGE PREMIUM, 1940–1996

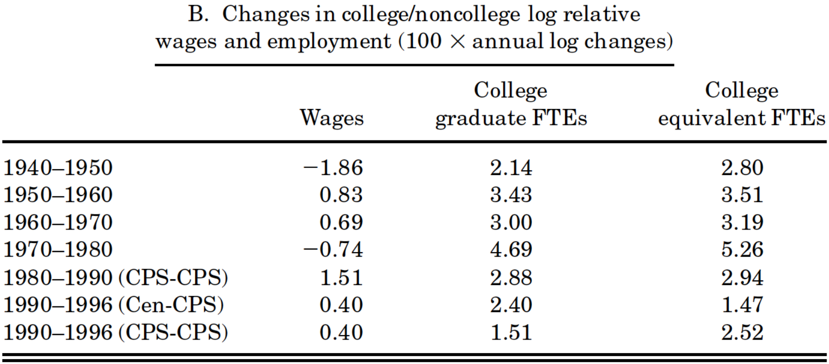
A. Full-time equivalent employment shares by education level (in percent) and log college+/high school wage premium

	High school dropouts	High school graduates	Some college	College graduates	College equivalents	Log college+/ HS wage
1940 Census	67.9	19.2	6.5	6.4	9.6	.498
1950 Census	58.6	24.4	9.2	7.8	12.4	.313
1960 Census	49.5	27.7	12.2	10.6	16.7	.396
1970 Census	35.9	34.7	15.6	13.8	21.6	.465
1980 Census	20.7	36.1	22.8	20.4	31.8	.391
1980 CPS	19.1	38.0	22.0	20.9	31.9	.356
1990 CPS	12.7	36.2	25.1	26.1	38.6	.508
1990 Census	11.4	33.0	30.2	25.4	40.6	.549
Feb. 90 CPS	11.5	36.8	25.2	26.5	39.1	.533
1996 CPS	9.4	33.4	28.9	28.3	42.7	.557

DTC and Income Inequality V

Relative Supply and Demand for Skills 1940–1996

- Time trends: compression of wage differentials in the 1940s followed by a sharp expansion in the 1950-60s



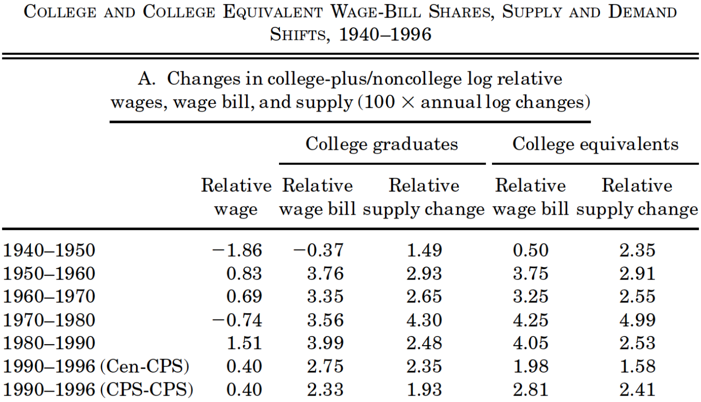
B. Changes in college/noncollege log relative wages and employment (100 × annual log changes)

	Wages	College graduate FTEs	College equivalent FTEs
1940–1950	−1.86	2.14	2.80
1950–1960	0.83	3.43	3.51
1960–1970	0.69	3.00	3.19
1970–1980	−0.74	4.69	5.26
1980–1990 (CPS-CPS)	1.51	2.88	2.94
1990–1996 (Cen-CPS)	0.40	2.40	1.47
1990–1996 (CPS-CPS)	0.40	1.51	2.52

DTC and Income Inequality VI

Relative Supply and Demand for Skills 1940–1996

- The growth rate of the log of relative supply of college workers accelerates dramatically in the 1970s and then decelerates in the 1980s and 1990s



COLLEGE AND COLLEGE EQUIVALENT WAGE-BILL SHARES, SUPPLY AND DEMAND SHIFTS, 1940–1996

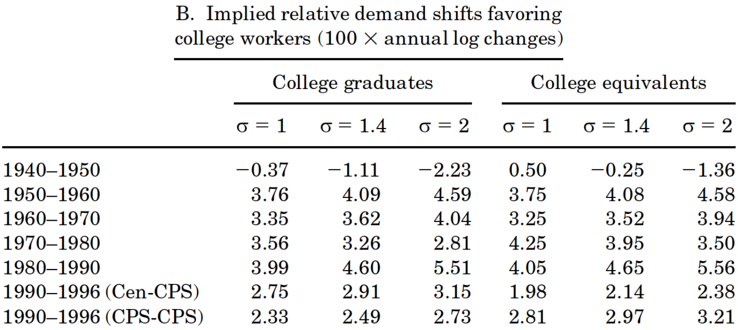
A. Changes in college-plus/noncollege log relative wages, wage bill, and supply (100 × annual log changes)

		College graduates		College equivalents	
	Relative wage	Relative wage bill	Relative supply change	Relative wage bill	Relative supply change
1940–1950	−1.86	−0.37	1.49	0.50	2.35
1950–1960	0.83	3.76	2.93	3.75	2.91
1960–1970	0.69	3.35	2.65	3.25	2.55
1970–1980	−0.74	3.56	4.30	4.25	4.99
1980–1990	1.51	3.99	2.48	4.05	2.53
1990–1996 (Cen-CPS)	0.40	2.75	2.35	1.98	1.58
1990–1996 (CPS-CPS)	0.40	2.33	1.93	2.81	2.41

DTC and Income Inequality VII

Relative Supply and Demand for Skills 1940–1996

- Sensitivity of conclusions concerning the time path of the growth rate of the relative demand for college workers depends on σ
- Overall: strong relative demand growth for college workers since 1950s



B. Implied relative demand shifts favoring college workers (100 × annual log changes)

	College graduates			College equivalents		
	$\sigma = 1$	$\sigma = 1.4$	$\sigma = 2$	$\sigma = 1$	$\sigma = 1.4$	$\sigma = 2$
1940–1950	−0.37	−1.11	−2.23	0.50	−0.25	−1.36
1950–1960	3.76	4.09	4.59	3.75	4.08	4.58
1960–1970	3.35	3.62	4.04	3.25	3.52	3.94
1970–1980	3.56	3.26	2.81	4.25	3.95	3.50
1980–1990	3.99	4.60	5.51	4.05	4.65	5.56
1990–1996 (Cen-CPS)	2.75	2.91	3.15	1.98	2.14	2.38
1990–1996 (CPS-CPS)	2.33	2.49	2.73	2.81	2.97	3.21

DTC and Income Inequality VIII

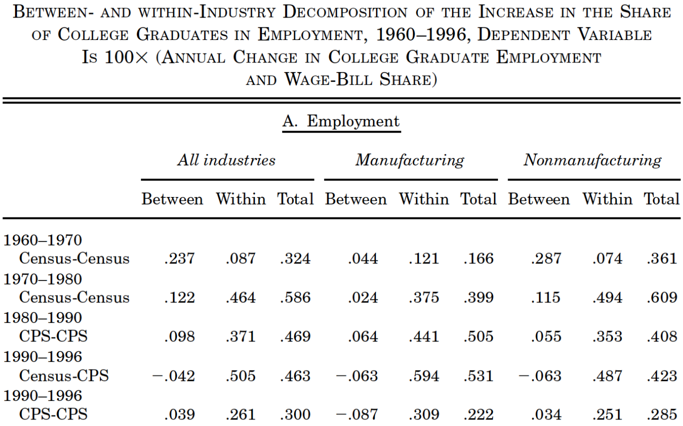
Relative Supply and Demand for Skills 1940–1996

- What factors explain the rapid shift of relative labor demand favoring more-educated workers?
  - increased trade: shifts from less-skilled to more-skilled workers
  - SBTC and changes in the organization of work favoring more-skilled workers
  - growth of foreign outsourcing of low-skill tasks
  - ...
- A decomposition of the growth of the share of aggregate employment accounted for by college graduates into between- and within- industry components can help illustrate the importance of these channels

DTC and Income Inequality IX

Relative Supply and Demand for Skills 1940–1996

- Vast majority of growth in the utilization of college graduates can be attributed to within-industry changes



BETWEEN- AND WITHIN-INDUSTRY DECOMPOSITION OF THE INCREASE IN THE SHARE OF COLLEGE GRADUATES IN EMPLOYMENT, 1960–1996, DEPENDENT VARIABLE IS 100× (ANNUAL CHANGE IN COLLEGE GRADUATE EMPLOYMENT AND WAGE-BILL SHARE)

A. Employment

	All industries			*Manufacturing*			*Nonmanufacturing*		
	Between	Within	Total	Between	Within	Total	Between	Within	Total
1960–1970 Census-Census	.237	.087	.324	.044	.121	.166	.287	.074	.361
1970–1980 Census-Census	.122	.464	.586	.024	.375	.399	.115	.494	.609
1980–1990 CPS-CPS	.098	.371	.469	.064	.441	.505	.055	.353	.408
1990–1996 Census-CPS	−.042	.505	.463	−.063	.594	.531	−.063	.487	.423
1990–1996 CPS-CPS	.039	.261	.300	−.087	.309	.222	.034	.251	.285

DTC and Income Inequality X

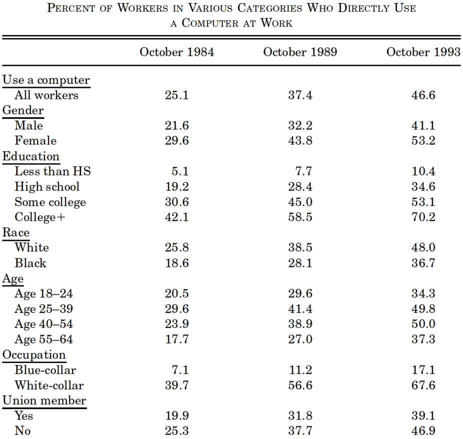
Trends in Computer Technology

- Diffusion of computers and related technologies induce changes in the relative demand for skills if they influence relative labor demand in the following ways:
    - Many tasks performed by less-skilled workers may be routinized
    - Automation of many production processes
    - Computer-based technologies increase the returns to creative use of greater available information
- Direct substitution and organizational complementary channels both predict an increase in the relative demand for highly educated workers
    - ⋆ Bresnahan et al. (1998) partly support this view: greater use of IT associated with higher employment of skilled workers

DTC and Income Inequality XI

Trends in Computer Technology

- Computer use at work increased from 1/4 in 1984 to 1/2 in 1993
- Women, highly educated, whites, white-color, and full-time workers are more likely to use computers



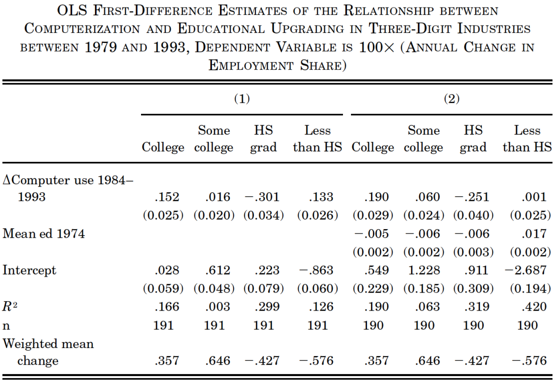
PERCENT OF WORKERS IN VARIOUS CATEGORIES WHO DIRECTLY USE A COMPUTER AT WORK

	October 1984	October 1989	October 1993
Use a computer			
All workers	25.1	37.4	46.6
Gender			
Male	21.6	32.2	41.1
Female	29.6	43.8	53.2
Education			
Less than HS	5.1	7.7	10.4
High school	19.2	28.4	34.6
Some college	30.6	45.0	53.1
College+	42.1	58.5	70.2
Race			
White	25.8	38.5	48.0
Black	18.6	28.1	36.7
Age			
Age 18–24	20.5	29.6	34.3
Age 25–39	29.6	41.4	49.8
Age 40–54	23.9	38.9	50.0
Age 55–64	17.7	27.0	37.3
Occupation			
Blue-collar	7.1	11.2	17.1
White-collar	39.7	56.6	67.6
Union member			
Yes	19.9	31.8	39.1
No	25.3	37.7	46.9

DTC and Income Inequality XII

Computers and Skill Upgrading

- Shift toward college-educated workers, and away from high school-educated workers, greatest in industries with greatest rises in computer use
- Surprisingly, faster growth in computer use associated with a relative rise in the share of less-than-high school workers



OLS FIRST-DIFFERENCE ESTIMATES OF THE RELATIONSHIP BETWEEN COMPUTERIZATION AND EDUCATIONAL UPGRADING IN THREE-DIGIT INDUSTRIES BETWEEN 1979 AND 1993, DEPENDENT VARIABLE IS 100× (ANNUAL CHANGE IN EMPLOYMENT SHARE)

	(1)				(2)			
	College	Some college	HS grad	Less than HS	College	Some college	HS grad	Less than HS
ΔComputer use 1984–1993	.152	.016	−.301	.133	.190	.060	−.251	.001
	(0.025)	(0.020)	(0.034)	(0.026)	(0.029)	(0.024)	(0.040)	(0.025)
Mean ed 1974					−.005	−.006	−.006	.017
					(0.002)	(0.002)	(0.003)	(0.002)
Intercept	.028	.612	.223	−.863	.549	1.228	.911	−2.687
	(0.059)	(0.048)	(0.079)	(0.060)	(0.229)	(0.185)	(0.309)	(0.194)
R^2	.166	.003	.299	.126	.190	.063	.319	.420
n	191	191	191	191	190	190	190	190
Weighted mean change	.357	.646	−.427	−.576	.357	.646	−.427	−.576

DTC and Income Inequality XIII

Computers and Skill Upgrading

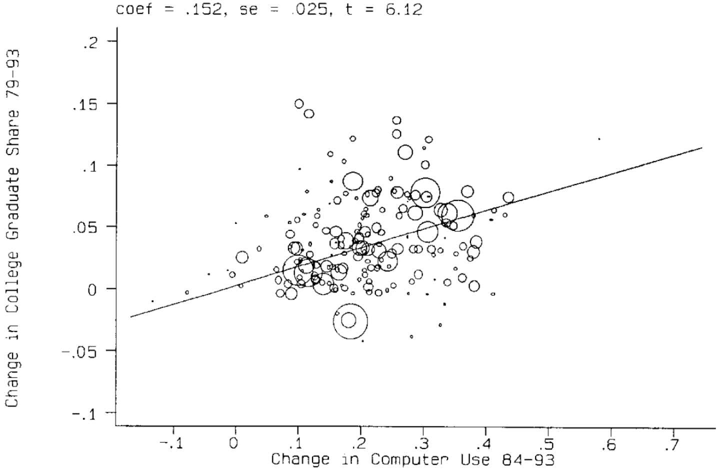


Figure: College graduates and computer use

DTC and Income Inequality XIV

Computers and Skill Upgrading

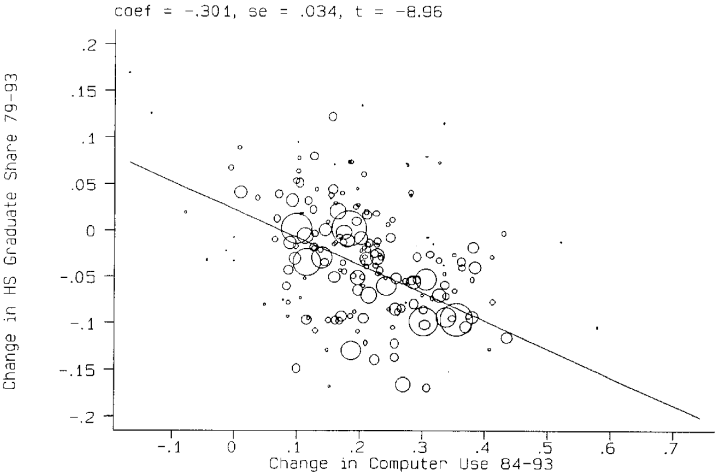
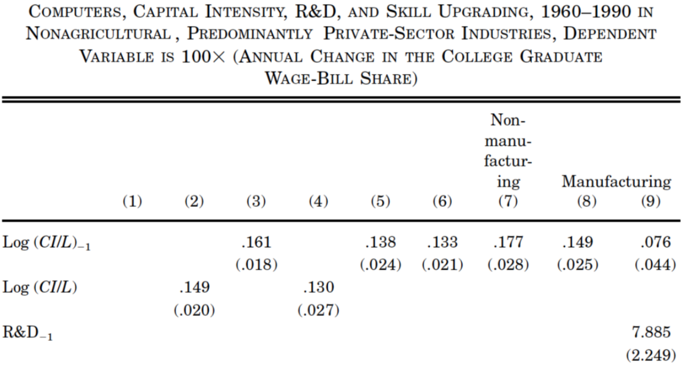


Figure: High-school graduates and computer use

DTC and Income Inequality XV

Computers, Capital Intensity, R&D and Skill Upgrading

- Increased rate of computer investment per worker positively associated with skill upgrading and the wage bill
- R&D intensity has a substantial positive impact on skill upgrading

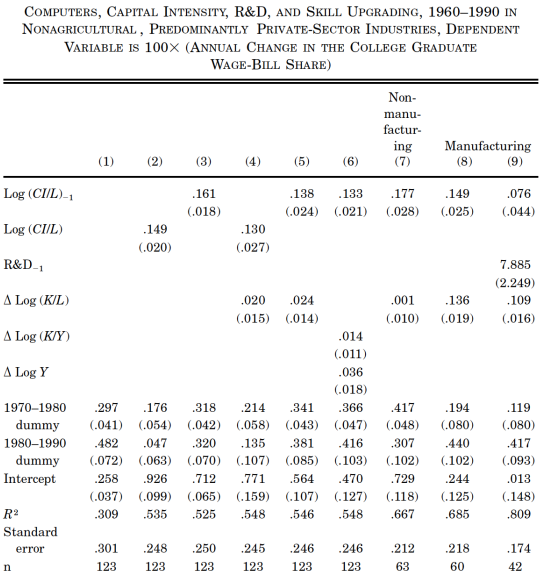


COMPUTERS, CAPITAL INTENSITY, R&D, AND SKILL UPGRADING, 1960–1990 IN NONAGRICULTURAL, PREDOMINANTLY PRIVATE-SECTOR INDUSTRIES, DEPENDENT VARIABLE IS 100× (ANNUAL CHANGE IN THE COLLEGE GRADUATE WAGE-BILL SHARE)

							Non-manufacturing	Manufacturing	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log $(CI/L)_{-1}$			.161		.138	.133	.177	.149	.076
			(.018)		(.024)	(.021)	(.028)	(.025)	(.044)
Log (CI/L)		.149		.130					
		(.020)		(.027)					
$\text{R\&D}_{-1}$									7.885
									(2.249)

DTC and Income Inequality XVI

Computers, Capital Intensity, R&D and Skill Upgrading



COMPUTERS, CAPITAL INTENSITY, R&D, AND SKILL UPGRADING, 1960–1990 IN NONAGRICULTURAL, PREDOMINANTLY PRIVATE-SECTOR INDUSTRIES, DEPENDENT VARIABLE IS 100× (ANNUAL CHANGE IN THE COLLEGE GRADUATE WAGE-BILL SHARE)

							Non-manufacturing	Manufacturing	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log $(CI/L)_{-1}$			.161		.138	.133	.177	.149	.076
			(.018)		(.024)	(.021)	(.028)	(.025)	(.044)
Log (CI/L)		.149		.130					
		(.020)		(.027)					
R&D$_{-1}$									7.885
									(2.249)
Δ Log (K/L)				.020	.024		.001	.136	.109
				(.015)	(.014)		(.010)	(.019)	(.016)
Δ Log (K/Y)						.014			
						(.011)			
Δ Log Y						.036			
						(.018)			
1970–1980	.297	.176	.318	.214	.341	.366	.417	.194	.119
dummy	(.041)	(.054)	(.042)	(.058)	(.043)	(.047)	(.048)	(.080)	(.080)
1980–1990	.482	.047	.320	.135	.381	.416	.307	.440	.417
dummy	(.072)	(.063)	(.070)	(.107)	(.085)	(.103)	(.102)	(.102)	(.093)
Intercept	.258	.926	.712	.771	.564	.470	.729	.244	.013
	(.037)	(.099)	(.065)	(.159)	(.107)	(.127)	(.118)	(.125)	(.148)
R^2	.309	.535	.525	.548	.546	.548	.667	.685	.809
Standard error	.301	.248	.250	.245	.246	.246	.212	.218	.174
n	123	123	123	123	123	123	63	60	42

DTC and Income Inequality XVII

Conclusions

- Strong relative demand growth favoring highly educated workers that has persisted throughout 1950-2000s (most likely until now, if updated)
- Increases in relative demand of skilled workers are greater in computer-intensive industries
- The pace of within-industry skill upgrading not homogenous across industries
- Capital intensity and R%D positively associated with skill upgrading
- SBTC and organizational changes that accompanied the computer revolution have contributed to faster growth in the relative skill demand

1. Introduction

2. Directed Technical Change

3. DTC and Income Inequality

4. Applications to the Pharmaceutical Industry

DTC and the Pharmaceutical Industry I

- This section is mainly based on Acemoglu and Linn (2004)
  - Investigation of the effect of *potential* market size on entry of new drugs and pharmaceutical innovation
  - Main results: large effect of potential market size on the entry of nongeneric drugs and new molecular entities
    - Results are robust to controlling for supply-side factors and changes in the technology of pharmaceutical research
  - We here introduce an adapted model of Acemoglu and Linn (2004) that links innovation to market size
  - Then discuss their empirical findings on the pharmaceutical industry

DTC and the Pharmaceutical Industry II

- Many historical accounts of important innovations focus on the autonomous progress of science

- Economists however emphasize profit incentives and size of potential market as innovation drivers
    - Schmookler (1966): "*The amount of innovation is governed by the extent of the market*"

- Role of profit incentives and market size in innovation is crucial for
    - Endogenous technological change models
    - DTC models investigating the influence of profit incentives on the types and biases of new technologies

DTC and the Pharmaceutical Industry III

- Related studies:
  - Griliches' (1957) hybrid corn study: technological change and technology adoption linked to profitability and market size
  - Schmookler (1966): correlation between sales and innovation
  - Newell et al. (1999): cheaper air conditioners1960–1980; more energy-efficient air conditioners 1980–1990
  - Popp (2002): positive association between patents for energy-saving techs and energy prices
  - Kremmer (2002): insufficient R&D funds for the development of third-world diseases' cures because of potential markets' inability to pay
  - Other studies on the pharmaceutical industry: Henderson and Cockburn (1996), Lichtenberg and Waldfogel (2003), Cerda (2003), Finkelstein (2004), DellaVigna and Poller (2004)

DTC and the Pharmaceutical Industry IV

Adapted Model I

- Small, open economy populated by one-period-lived individuals
- Two groups of people each period, indexed by $j \in \{1, 2\}$
- Three-goods economy: a basic good everyone needs to consume to survive and two drugs, also indexed by $j \in \{1, 2\}$
- Each drug is produced one for one using the basic good
- Group j only cares about drug j
- Let A_{jt} and x_{jt} denote the quality and quantity of drug j at time t, respectively

DTC and the Pharmaceutical Industry V

Adapted Model II

- An individual i who belongs to group j derives utility from consuming the final good and the drug according to,

  $$U = (c_{it})^{1-\alpha}(A_{jt}x_{ijt})^{\alpha}$$

  where c_{it} is consumption of the final good and x_{jt} is consumption of drug j

- The consumer is constrained by her income,

  $$c_{it} + p_{jt}x_{ijt} \leq y_{it}$$

- Utility maximization under the budget constraint implies that the consumer always spends fraction α of her income on drug j

  $$x_{ijt} = \alpha \frac{y_{it}}{p_{jt}} \tag{14}$$

DTC and the Pharmaceutical Industry VI

Adapted Model III

- Summing over individuals,

$$x_{jt} = \alpha \frac{Y_{jt}}{p_{jt}} \tag{15}$$

  where $Y_{jt} = \sum_{i \in \text{group } j} y_{it}$

- Drug producers may invest R&D targeted at drug j in hopes of capturing the market for that drug
- Each innovation in drug j increases its quality A_{jt} by $\gamma > 1$
- It takes

$$R_{jt} = \frac{\psi_j \mu_{jt}^2}{2}$$

  units of basic good invested in R&D targeted at drug j to generate an innovation with probability μ_{jt}, where $\psi_j > 0$ is an inverse measure of the productivity of the innovation technology in drug j

DTC and the Pharmaceutical Industry VII

Adapted Model IV

- A successful innovator will charge the maximum price that avoids competition
- Assume that every innovation is copied after one period
- The maximum price the successful innovator will charge is γ, which is the cost at which an imitator could produce and sell next version of the drug
- The profit from innovating in drug j at date t is,

$$\pi_{jt} = (p_{jt} - 1)\frac{\alpha Y_{jt}}{p_{jt}} = \left(\frac{\gamma - 1}{\gamma}\right)\alpha Y_{jt}$$

DTC and the Pharmaceutical Industry VIII

Adapted Model V

- The equilibrium number of innovations in drug j results from the maximization by a potential innovator of her expected payoff

$$\max_{\mu_{jt}} \quad \left\{ \mu_{jt} \left(\frac{\gamma - 1}{\gamma} \right) \alpha Y_{jt} - \frac{\psi_j \mu_{jt}^2}{2} \right\}$$

- which yields

$$\mu_{jt} = \frac{\left(\frac{\gamma - 1}{\gamma} \right) \alpha Y_{jt}}{\psi_j}$$

- This equation says that:
  - the higher the market size for drug j, the higher the flow of innovations
  - the higher the returns to R&D on drug j (measured inversely by ψ_j), the higher the flow of innovations

DTC and the Pharmaceutical Industry IX

Empirical Evidence I

- Acemoglu and Linn (2004) estimate the following Poisson model

$$\mathbf{E}\left[N_{ct}|Z_c X_{ct}\right] = \exp(\beta_1 \ln M_{ct} + \beta_2 X_{ct} + Z_c + u_t) \tag{16}$$

  where N_{ct} is the count of new approvals by the FDA, M_{ct} captures potential market size, X_{ct} is a vector of relevant control, Z_c controls for drug-category fixed effects and u_t controls for time trends

- **Major concern** in this sort of models is the potential endogeneity of market size: better products will have larger markets
  - ⋆ Solution: to exploit the exogenous component of market size associated with demographic trends
  - ⋆ Estimate potential market size for each drug category controlling for age- and income- profile

DTC and the Pharmaceutical Industry X

Empirical Evidence II

- Market size computed as,

$$M_{ct} = \sum_{a} w_{ca} i_{at} \tag{17}$$

where w_{ca} is the avg. expenditure share on drugs of category c of individuals in age group a, and i_{at} is the income of individuals in age group a at time t

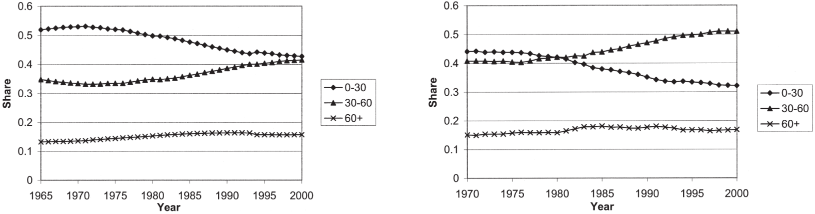
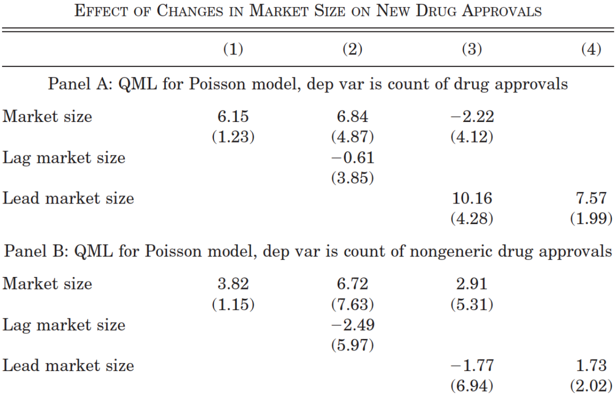


Figure: Share of population (*left*) and income (*right*) by age group, 1970–2000

DTC and the Pharmaceutical Industry XI

Empirical Evidence III

- Market size positively associated with overall drug approvals and nongeneric drug approvals



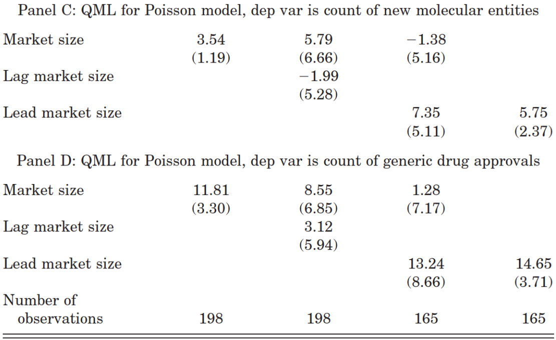
Effect of Changes in Market Size on New Drug Approvals

	(1)	(2)	(3)	(4)
Panel A: QML for Poisson model, dep var is count of drug approvals				
Market size	6.15 (1.23)	6.84 (4.87)	−2.22 (4.12)	
Lag market size		−0.61 (3.85)		
Lead market size			10.16 (4.28)	7.57 (1.99)
Panel B: QML for Poisson model, dep var is count of nongeneric drug approvals				
Market size	3.82 (1.15)	6.72 (7.63)	2.91 (5.31)	
Lag market size		−2.49 (5.97)		
Lead market size			−1.77 (6.94)	1.73 (2.02)

DTC and the Pharmaceutical Industry XII

Empirical Evidence IV

- Market size positively associated with approvals of new molecular entities and generic drugs[2]



Panel C: QML for Poisson model, dep var is count of new molecular entities				
Market size	3.54	5.79	−1.38	
	(1.19)	(6.66)	(5.16)	
Lag market size		−1.99		
		(5.28)		
Lead market size			7.35	5.75
			(5.11)	(2.37)
Panel D: QML for Poisson model, dep var is count of generic drug approvals				
Market size	11.81	8.55	1.28	
	(3.30)	(6.85)	(7.17)	
Lag market size		3.12		
		(5.94)		
Lead market size			13.24	14.65
			(8.66)	(3.71)
Number of observations	198	198	165	165

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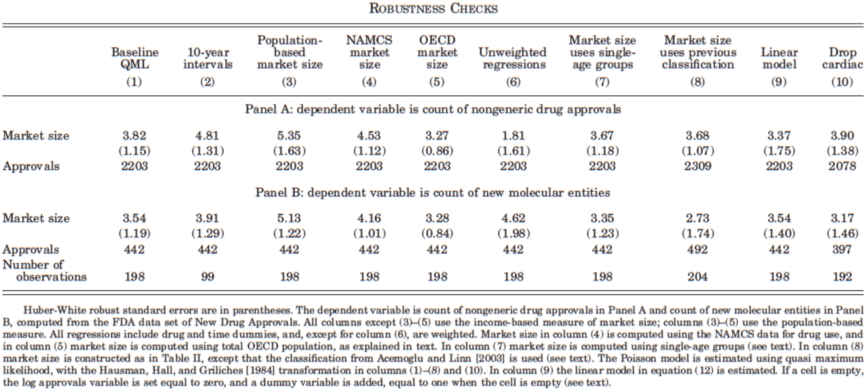
[2] Copies of brand-name drugs that have exactly the same dosage, intended use, effects, side effects, etc. (e.g. Omeprazole vs. losec/prilosec)

DTC and the Pharmaceutical Industry XIII

Empirical Evidence V

- Results are robust to usage of different proxies for market size



ROBUSTNESS CHECKS

	Baseline QML (1)	10-year intervals (2)	Population-based market size (3)	NAMCS market size (4)	OECD market size (5)	Unweighted regressions (6)	Market size uses single-age groups (7)	Market size uses previous classification (8)	Linear model (9)	Drop cardiac (10)
Panel A: dependent variable is count of nongeneric drug approvals										
Market size	3.82	4.81	5.35	4.53	3.27	1.81	3.67	3.68	3.37	3.90
	(1.15)	(1.31)	(1.63)	(1.12)	(0.86)	(1.61)	(1.18)	(1.07)	(1.75)	(1.38)
Approvals	2203	2203	2203	2203	2203	2203	2203	2309	2203	2078
Panel B: dependent variable is count of new molecular entities										
Market size	3.54	3.91	5.13	4.16	3.28	4.62	3.35	2.73	3.54	3.17
	(1.19)	(1.29)	(1.22)	(1.01)	(0.84)	(1.98)	(1.23)	(1.74)	(1.40)	(1.46)
Approvals	442	442	442	442	442	442	442	492	442	397
Number of observations	198	99	198	198	198	198	198	204	198	192

Huber-White robust standard errors are in parentheses. The dependent variable is count of nongeneric drug approvals in Panel A and count of new molecular entities in Panel B, computed from the FDA data set of New Drug Approvals. All columns except (3)–(5) use the income-based measure of market size; columns (3)–(5) use the population-based measure. All regressions include drug and time dummies, and, except for column (6), are weighted. Market size in column (4) is computed using the NAMCS data for drug use, and in column (5) market size is computed using total OECD population, as explained in text. In column (7) market size is computed using single-age groups (see text). In column (8) market size is constructed as in Table II, except that the classification from Acemoglu and Linn [2003] is used (see text). The Poisson model is estimated using quasi maximum likelihood, with the Hausman, Hall, and Griliches [1984] transformation in columns (1)–(8) and (10). In column (9) the linear model in equation (12) is estimated. If a cell is empty, the log approvals variable is set equal to zero, and a dummy variable is added, equal to one when the cell is empty (see text).

DTC and the Pharmaceutical Industry XIV

Conclusions I

- Economically and statistically significant response of the entry of new drugs to market size
    - pharmaceutical innovations in the US seem to have followed the demographic profile of the baby-boom generation
    - 1% increase in the size of potential market for a drug category associated with a 6% increase in the number of new drug approvals
    - 1% increase in the size of potential market size leads to approx. a 4% increase in the number of nongeneric and new molecular entities approvals (*"most innovative" drugs*)
- Pharmaceutical research does also respond to anticipated changes in market size

DTC and the Pharmaceutical Industry XV

Conclusions II

- Results are robust to several measures of market sizes
- Evidence that, as posited by DTC models, R&D is directed towards more profitable areas
- This paper raise awareness of the potential importance of governments' role
    - E.g. relevant drugs will not be developed either if the potential market is not large enough or lacks purchasing power

Thank you for your attention!