Measuring the Welfare Gain from Personal Computers

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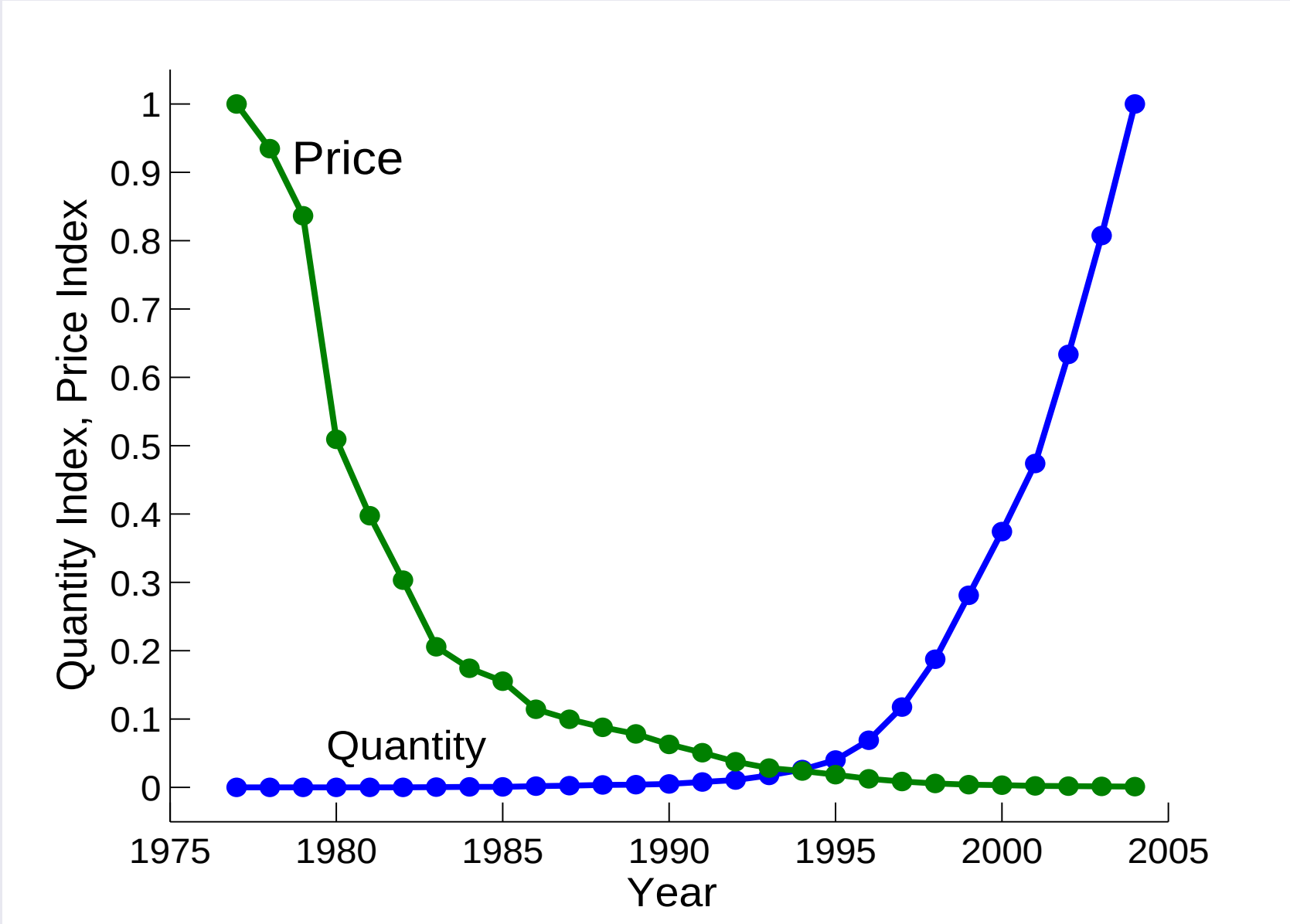
Personal Computers (PCs)

Facts:

- PCs enter the market in 1977.
- First successfully mass produced PC is Apple II.
- Rapid technological progress drives
  - 25 percent per year decline in quality-adjusted price
  - and synonymous rise in demand.

Personal Computers (PCs)

Price and Quantity Indices for Computers: 1977 to 2004



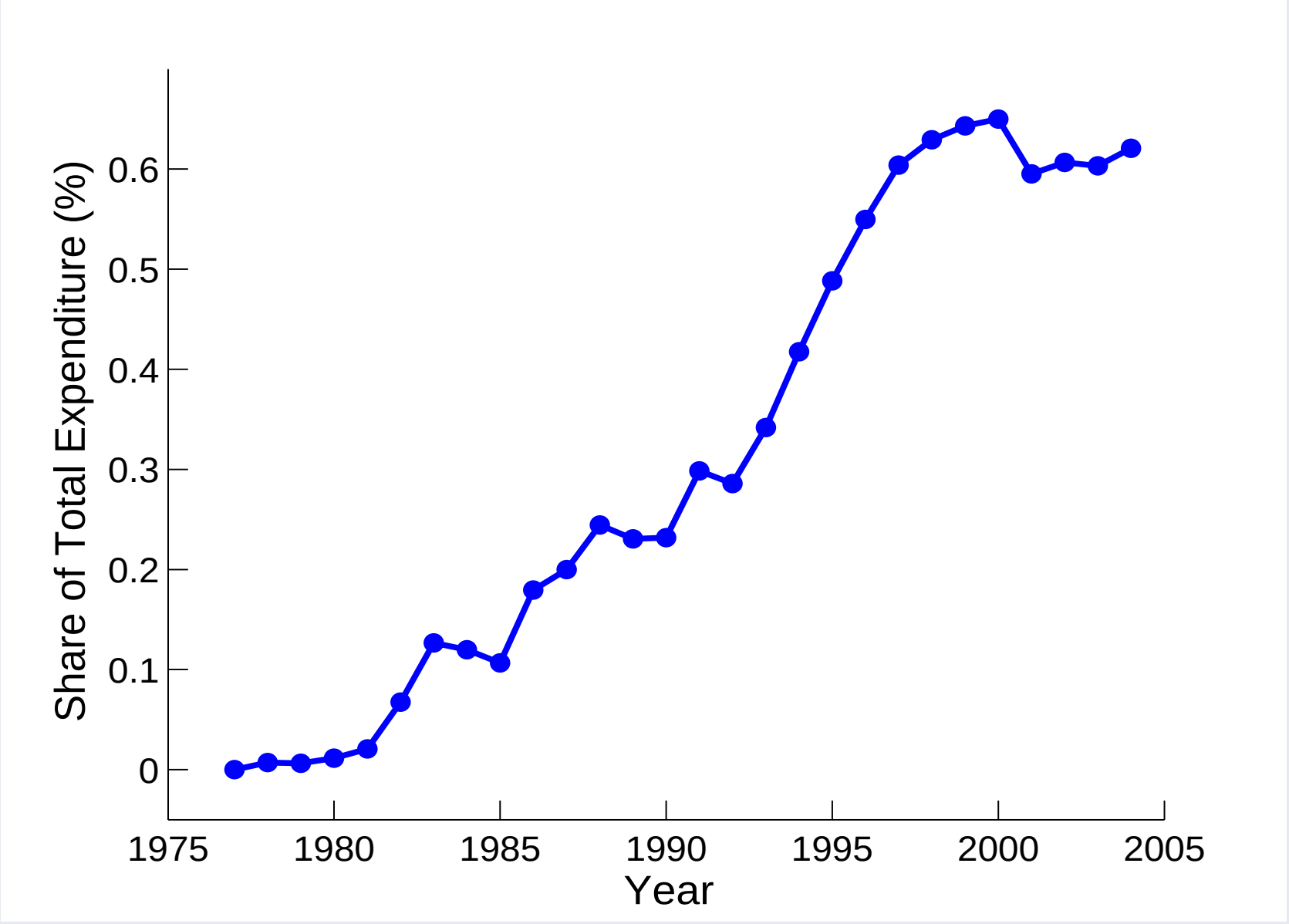
Source: U.S. National Income and Product Accounts, Tables 2.4.4 and 2.4.5

Personal Computers (PCs)

- Since 1977 computers' share of total expenditure has been rising...

Personal Computers (PCs)

Computers' Share of Personal Consumption Expenditure: 1977 to 2004



Source: U.S. National Income and Product Accounts, Tables 2.4.4 and 2.4.5

Overview

Question:

- What is the welfare gain to consumers in 2004 from the invention of the PC and the fall in its quality-adjusted price since 1977?

Findings:

- Welfare gain is approximately 4% of total consumption expenditure in 2004.

Overview

Approach:

- Calibrate/estimate a simple model of PC demand using the aggregate NIPA data.
- Calculate model's prediction of welfare gain.

Overview

Issue:

- Need to know what utility is in the absence of the good.
- However for a standard isoelastic utility function:

$$U(x) = \frac{x^{1-\rho}}{1-\rho},$$

1. $\lim_{x \to 0} U'(x) = \infty$

   $\Rightarrow$ demand for x always positive regardless of price.

2. $\lim_{x \to 0} U(x) = -\infty$ when $1/\rho \leq 1$

   $\Rightarrow$ welfare gain from new good is infinite.

Overview

Resolution:

- Modify preferences such that utility and marginal utility of zero consumption are always finite then
  1. when price is high enough demand is zero,
  2. non-trivial welfare gain regardless of elasticity of substitution.

Overview

Related Literature:

- Hausman (1996), Petrin (2002), Goolsbee and Petrin (2004),
- Hausman (1999): cell phones,
- Goolsbee and Klenow (2006): internet.

Our Contribution:

- Simple method for estimating the welfare gain from an innovative new good using aggregate data.

Model

Consumer solves

$$W(y,p) = \max_{c,n}[\theta U(c) + (1-\theta)V(n)]$$

subject to

$$c + pn = y,$$

and

$$c, n \geq 0,$$

where

$y =$ income,
$p =$ relative price of computers,
$c =$ general consumption,
$n =$ standardized units of computer consumption.

Model

- Utility function for consumption of general good is standard:

$$U(c) = \frac{c^{1-\rho}}{1-\rho}, \quad \rho \geq 0$$

so has standard properties:

$$U_1(c) > 0, \quad U_{11}(c) < 0, \quad \lim_{c \to \infty} U_1(c) = 0, \quad \lim_{c \to 0} U_1(c) = \infty$$

Model

- Utility function for personal computers is

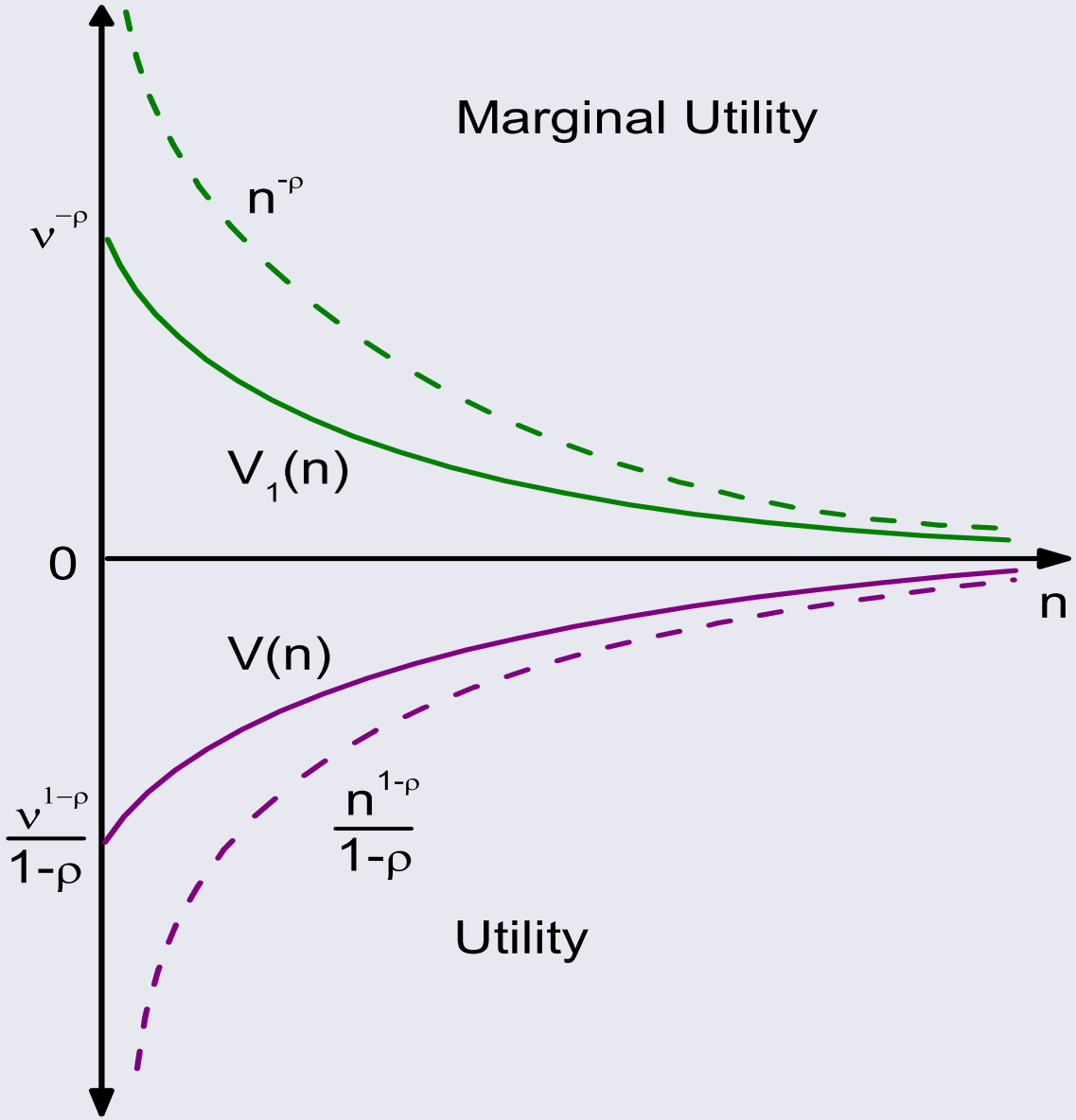
$$V(n) = \frac{(n+\nu)^{1-\rho}}{1-\rho}, \quad 0 < \nu < \infty$$

also standard except that

$$V(0) = \frac{\nu^{1-\rho}}{1-\rho} > -\infty \quad \text{and} \quad V_1(0) = \nu^{-\rho}.$$

Model

Tastes for Computers, $\rho \geq 1$ – Model and Conventional Formulation



Model

- Demand function for general consumption is

$$c = \mathbf{C}(y,p) = \begin{cases} y, & \text{if } p \geq \widehat{P}(y) \equiv \frac{1-\theta}{\theta}\nu^{-\rho}y^{\rho}, \\ \frac{y+p\nu}{1+\left(\frac{1-\theta}{\theta}\right)^{\frac{1}{\rho}}p^{\frac{\rho-1}{\rho}}}, & \text{if } p < \widehat{P}(y). \end{cases}$$

- Demand function for computers is

$$n = \mathbf{N}(y,p) = \begin{cases} 0, & \text{if } p \geq \widehat{P}(y), \\ \frac{y+p\nu}{p+(\frac{1-\theta}{\theta})^{-\frac{1}{\rho}}p^{\frac{1}{\rho}}} - \nu, & \text{if } p < \widehat{P}(y). \end{cases}$$

Model

- Computer production technology

$$n = zo,$$

where

$o =$ share of total output in computer production,

$z =$ productivity in computer sector,

- then

$$p = 1/z.$$

Model

- BEA quality-adjusts computer price indices using hedonic methods.
- Quality-adjustment accounts for a large fraction of price decline.

Average annual change in PC prices, 2001 to 2005

	percent
unit value	-4.9
quality-adjusted	-16.5
difference	-11.5

Source: Wasshausen and Moulton (2006).

Welfare Gain

Measure 1: **Equivalent variation**

- additional income, $\lambda_{\mathbf{EV}}$, needed to satisfy

$$W((1+\lambda_{\mathbf{EV}})y_{2004}, \infty) = W(y_{2004}, p_{2004}),$$

where

$$W((1+\lambda_{\mathbf{EV}})y_{2004}, \infty) = \theta\frac{\left[(1+\lambda_{\mathbf{EV}})y_{2004}\right]^{1-\rho}}{1-\rho} + (1-\theta)\frac{\nu^{1-\rho}}{1-\rho}.$$

Welfare Gain

Measure 2: **Compensating variation**

- reduction in income, $\lambda_{\mathbf{CV}}$, required to satisfy

$$W((1-\lambda_{\mathbf{CV}})y_{2004}, p_{2004}) = W(y_{2004}, \infty),$$

where

$$W(y_{2004}, \infty) = \theta \frac{y_{2004}^{1-\rho}}{1-\rho} + (1-\theta)\frac{\nu^{1-\rho}}{1-\rho}.$$

Quantitative Experiment

Goal:

- Compute the welfare gain in 2004 from invention of PC in 1977 and subsequent price decline.

Steps:

- Pin–down preference parameters.
- Calculate compensating and equivalent variations.

Quantitative Experiment

Parameters to pin-down:

- ρ: *determines the elasticity of substitution between computers and general consumption*
- θ: *weight on utility from general consumption net of computers*
- ν: *determines marginal utility of zero computer consumption*

Calibration Strategy

For each year t from 1977 to 2004 let

- $\mathbf{p}_t =$ quality-adjusted price of PCs relative to aggregate market consumption net of PCs,
- $\mathbf{y}_t =$ total expenditure,
- $\mathbf{n}_t =$ quantity of standardized units of computers purchased,

in the data.

Calibration Strategy

Given ρ, θ, and ν the model's prediction for $\mathbf{n}_t$ is

$$\widehat{\mathbf{n}}_t = \mathbf{N}(\mathbf{y}_t, \mathbf{p}_t).$$

Denote this mapping by

$$\widehat{\mathbf{n}}_t = \mathfrak{N}(\rho, \theta, \nu; \mathbf{y}_t, \mathbf{p}_t).$$

Calibration Strategy

Preference parameters are chosen by solving

$$\min_{\rho,\theta,\nu} \sum_{t=1977}^{2004} \left[\mathbf{n}_t - \mathfrak{N}(\rho, \theta, \nu; \mathbf{y}_t, \mathbf{p}_t)\right]^2,$$

subject to $\mathfrak{N}(\rho, \theta, \nu; \mathbf{y}_{1977}, \mathbf{p}_{1977}) = 0.$

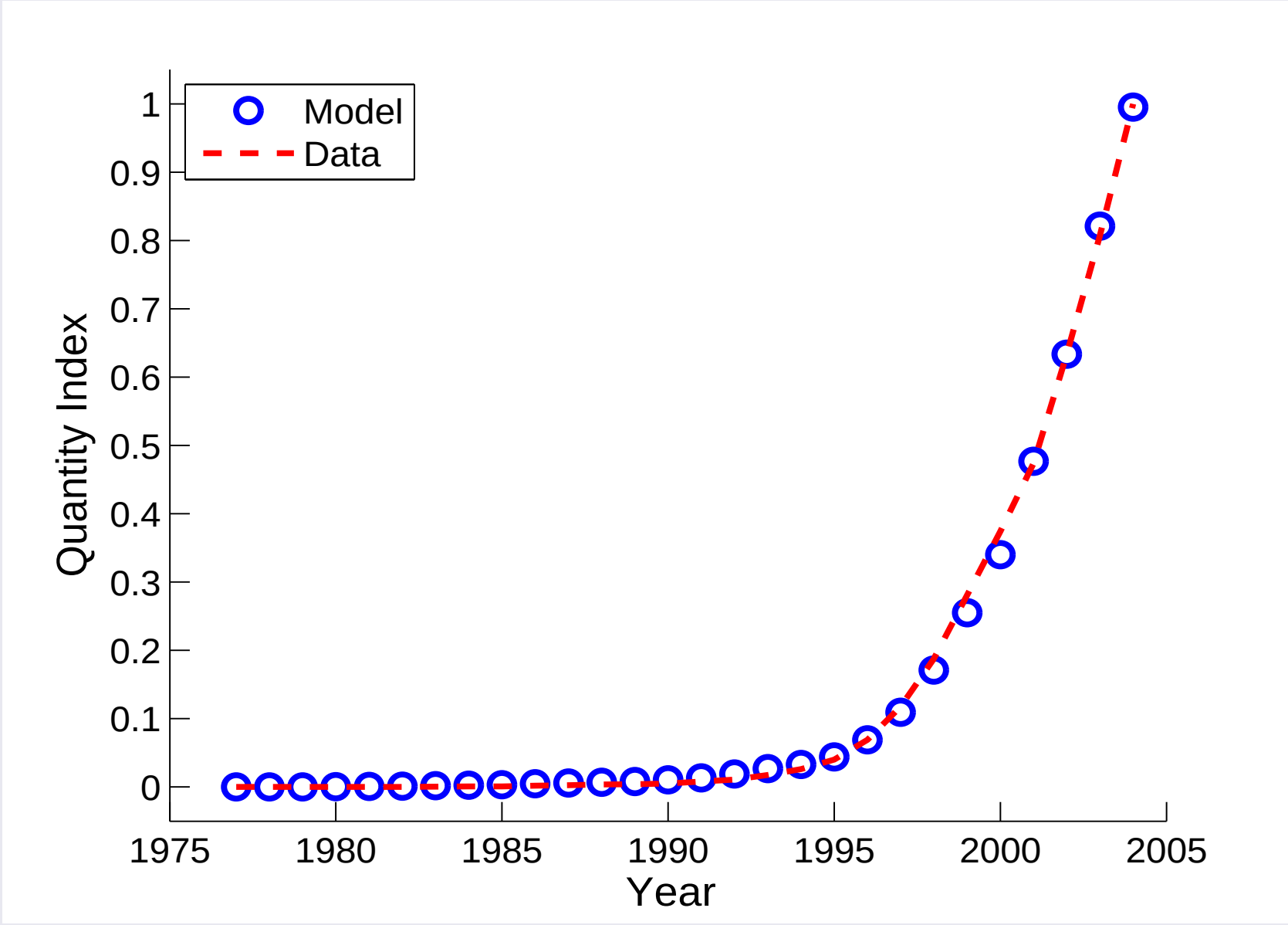
Results

Parameter values resulting from minimization:

Parameter		Value
ρ	*determines elasticity of substitution between computers and consumption*	0.993
θ	*weight on utility from general consumption net of computers*	0.994
ν	*determines marginal utility of zero computer consumption*	5×10^{-4}

Results

Quantity Indexes for Computers: 1977 to 2004–Data and Model



Results

Welfare gain from PCs as percent of total consumption expenditure:

Measure	Percent
equivalent variation	4.00
compensating variation	3.82

Results

If instead utility is

$$U(c, n) = [\theta c^{\rho} + (1 - \theta)(n + \nu)^{\rho}]^{1/\rho},$$

then

$$\rho = 0.007, \qquad \theta = 0.994, \qquad \nu = 5 \times 10^{-4},$$

and welfare gain is

Measure	Percent
equivalent variation	4.00
compensating variation	3.82

Results

Welfare gain from various new goods as a percent of total consumption expenditure:

Product	Percent	Ratio	Source
PCs	3.91		
Apple-Cinnamon Cheerios	0.002	1955	Hausman (1996)
Minivans	0.029	135	Petrin (2002)
Satellite TV	0.035	117	Goolsbee & Petrin (2004)
Internet	26.8	0.15	Goolsbee & Klenow (2006)

Results

Welfare gain based on alternative methods:

- Hausman's (1999) approximate demand measure:

$$\text{Welfare Gain} = 0.5 \times \left(\begin{array}{c} \text{share of new good} \\ \text{in expenditure} \end{array} \right) / \left(\begin{array}{c} \text{price elasticity} \\ \text{of demand} \end{array} \right)$$

share of computers in expenditure in 2004 = 0.6%

price elasticity of demand = 1.83

$$\text{Welfare Gain} = 0.5 \times (0.006) / (1.83) = 0.16\%$$

Results

Welfare Gain based on alternative methods:

- Simple Tornqvist index:

$$\ln(T_{2004}) = \frac{1}{2}\left(\begin{array}{c}\text{2004 exp.}\\ \text{share}\end{array} + \begin{array}{c}\text{1977 exp.}\\ \text{share}\end{array}\right)\ln\left(\frac{p_{2004}}{p_{1977}}\right)$$

$$\text{Welfare Gain} = \frac{1}{T_{2004}} - 1 = 2.07\%$$

Results

Welfare gain from PCs as percent of total consumption expenditure using various measurements:

Measure	Percent
equivalent variation	4.00
compensating variation	3.82
Hausman's approximate demand measure	0.16
Tornqvist index	2.07

Results

For electricity the same exercise yields

- Separable utility

ρ	θ	ν
9.18	$<< 1$	0.0347

compensating variation $= 95.4\%$

- Non-separable utility

ρ	θ	ν
-8.8	$<< 1$	0.0364

compensating variation $= 95.3\%$

Results

For electricity Hausman's (1999) approximate demand measure yields

- welfare gain $= 1.9\%$

  using

  share of expenditure in 2001$^* = 1.5\%$
  price elasticity of demand$^* = 0.39$

- welfare gain $= 8.0\%$

  using

  share of expenditure in 1984$^* = 2.4\%$
  price elasticity of demand$^* = 0.15$

$*$ Source: Reiss and White (2002)

Conclusion

- Simple method for computing welfare gain from innovative new goods.
- Standard model of consumer demand with slightly modified preferences.
- Calibrated using aggregate data.
- Welfare gain from PCs approximately 4 percent of total consumption expenditure.

Apple II

Kopecky – 2008

Hausman's Approximate Demand Measure

1. Assume demand curve is

$$\ln q = \alpha \ln p$$

   then $\alpha = -\frac{dq}{dp}\frac{p}{q}$ is price elasticity of demand.

2. Approximate demand curve by tangent line at observed price and quantity: (p_1, q_1),

$$q = -\alpha \frac{q_1}{p_1}(p - p_1) + q_1.$$

3. Compute compensating variation

$$CV = \frac{1}{2}\frac{p_1 q_1}{\alpha}.$$