United States Department of Agriculture

An Overview of Three Food System Models to Inform Public Policy

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Research Question and Model Framework

Research Question	Model Framework
1. Where do our food dollars go?	Input-Output Model (IO)
2. Are healthy diets sustainable?	Multiregional Environmental-Sustainable IO Model (MEIO) & Mathematical Optimization
3. How do taxes affect food markets?	Multiregional Computable General Equilibrium Model (CGE)

Where do our food dollars go?

- The U.S. Code is a consolidation and codification by subject matter of the general and permanent laws of the United States.
- TITLE 7 > CHAPTER 38 > SUBCHAPTER I > §1622 (b) of the current U.S. Code states:
  - **<u>The Secretary of Agriculture is directed and authorized to determine costs of marketing agricultural products in their various forms and through the various channels</u>** and to foster and assist in the development and establishment of more efficient marketing methods (including analyses of methods and proposed methods), practices, and facilities, **<u>for the purpose of bringing about more efficient and orderly marketing, and reducing the price spread between the producer and the consumer</u>**.

Input-Output Accounting Overview

Industry→	Agriculture, Mining, Construction & Utilities (I)	Manufacturing (II)	Freight & Trade (III)	Services (IV)	GDP	Sales
Commodity↓	*$ million*					
(I)	Interindustry transactions $\mathbf{Z}$				$\mathbf{y}$	1) $\mathbf{x} = \mathbf{Zi} + \mathbf{y}$
(II)						
(III)						
(IV)						
GDI	$\mathbf{v}'$					
Outlays	2) $\mathbf{x}' = \mathbf{i}'\mathbf{Z} + \mathbf{v}'$					

Input-Output Accounting Overview

Normalize elements in transaction and value added (GDI) matrices by column sum:

$$\mathbf{A} = \mathbf{Z}\{\hat{\mathbf{x}}\}^{-1} \qquad \text{(direct requirement multipliers)}$$

$$\mathbf{w}' = \mathbf{v}'\{\hat{\mathbf{x}}\}^{-1} \qquad \text{(unit value added income multipliers)}$$

Equation 1can be restated as:

$$\mathbf{y} = \{\hat{\mathbf{i}} - \mathbf{A}\}\mathbf{x} \;\Leftrightarrow\; \{\hat{\mathbf{i}} - \mathbf{A}\}^{-1}\mathbf{y} = \mathbf{x} \;\Leftrightarrow\; \mathbf{L}\mathbf{y} = \mathbf{x} \qquad \text{(total requirement multipliers)}$$

In IO accounting, total GDP equals total GDI:

$$\mathbf{i}'\mathbf{y} = \mathbf{v}'\mathbf{i} \;\Leftrightarrow\; \mathbf{i}'\mathbf{y} = \mathbf{w}'\hat{\mathbf{x}}\mathbf{i} \;\Leftrightarrow\; \mathbf{i}'\mathbf{y} = \mathbf{w}'\mathbf{x} \qquad \text{(product/income identity)}$$

If *f* denotes the subset of GDP representing personal consumption expenditures on food, linear homogeneity of production means food-related outputs and income can be measured:

$$\mathbf{L}\mathbf{y}^{f} = \mathbf{x}^{f} \;\Leftrightarrow\; \text{(food-related gross output)}$$

$$\mathbf{i}'\mathbf{y}^{f} = \mathbf{w}'\mathbf{x}^{f} \;\Leftrightarrow\; \text{(food-related GDI)}$$

Matrix Reduction for Supply Chain Analysis

$$\begin{bmatrix} \mathbf{x}_1 \\ \cdots \\ \mathbf{x}_2 \end{bmatrix} = \begin{bmatrix} (\mathbf{I}_1 - \mathbf{A}_{11}) & -\mathbf{A}_{12} \\ -\mathbf{A}_{21} & (\mathbf{I}_2 - \mathbf{A}_{22}) \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{y}_1 \\ \cdots \\ \mathbf{y}_2 \end{bmatrix}$$

$$= \begin{bmatrix} \textbf{supply chain industry transactions} & \textbf{non-supply chain industry use of supply chain commodities} \\ \textbf{supply chain use of non-supply chain commodities} & \textbf{non-supply chain industry transactions} \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{y}_{\text{supply chain}} \\ \cdots \\ \mathbf{y}_{\text{non-supply chain}} \end{bmatrix}$$

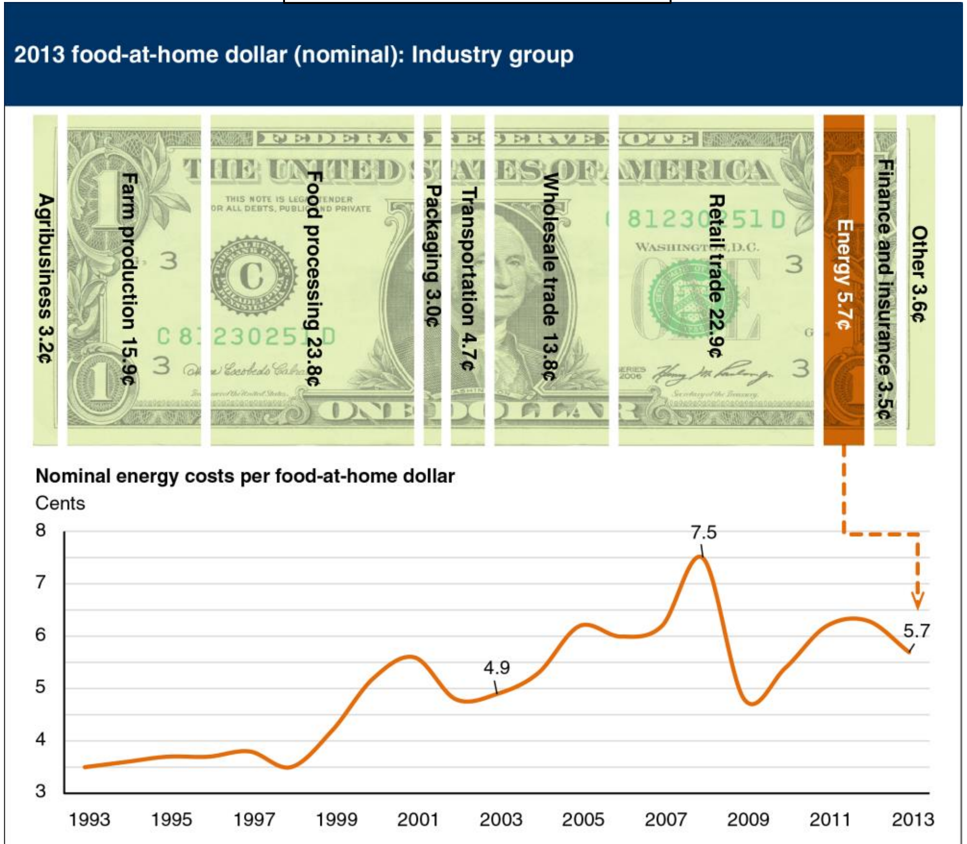
$$\mathbf{A}^{\#}[1,1] = \mathbf{A}[1,1] + \mathbf{A}[1,2] \cdot \{\hat{\mathbf{i}} - \mathbf{A}[2,2]\}^{-1} \cdot \mathbf{A}[2,1]$$ $\Leftrightarrow$ (reduced dimension direct requirements)

$$\mathbf{L}^{\#} = \{\hat{\mathbf{i}}[1] - \mathbf{A}^{\#}\}^{-1}$$ $\Leftrightarrow$ (reduced dimension total requirements)

$$\mathbf{v}^{\#} = \mathbf{v}[1] + \mathbf{L}'[1,1]^{-1} \cdot \mathbf{L}'[2,1] \cdot \mathbf{v}[2]$$ $\Leftrightarrow$ (reduced dimension value-added/GDI)

Where do our food dollars go?

$$\mathbf{v}^{\#f} = \mathbf{w}^{\#} \cdot \mathbf{L}^{\#} \cdot \mathbf{y}^{\mathbf{f}}[1]$$



Note: "Other" includes three industry groups: Advertising, legal and accounting, and foodservices.
Source: USDA, Economic Research Service, Food Dollar Series data product.

Would adherence to the Dietary Guidelines for Americans reduce food-system energy use?

To specify a multiregional IO model with R regions, redefine **y, x** and **A** as follows:

$$\mathbf{y} = [\mathbf{y}'^{1} \ldots \mathbf{y}'^{R}]' \qquad \mathbf{A} = \begin{bmatrix} \mathbf{A}_1 & \cdots & \mathbf{0} \\ \vdots & \mathbf{A}_r & \vdots \\ \mathbf{0} & \cdots & \mathbf{A}_R \end{bmatrix}$$
$$\mathbf{x} = [\mathbf{x}'^{1} \ldots \mathbf{x}'^{R}]' ,$$

Denote **T** a bilateral commodity trade coefficient matrix, summarizing all commodity (M) trade flows between origin (O) and destination (D) regions:

$$\mathbf{T} = \begin{bmatrix} \mathbf{T}_{11} & \cdots & \mathbf{T}_{1D} \\ \vdots & \mathbf{T}_{o,d} & \vdots \\ \mathbf{T}_{O1} & \cdots & \mathbf{T}_{O,D} \end{bmatrix}, \text{where } \mathbf{T}_{\boldsymbol{o},\boldsymbol{d}} = \hat{\boldsymbol{t}}_{M}^{o,d} \ \forall\, o, d \in R \qquad \text{(trade coefficient matrix)}$$

Would adherence to the Dietary Guidelines for Americans (DGA) reduce food-system energy use?

Denote **S** a sustainable indicators coefficient matrix of dimension $N \times R \times M$:

$$\mathbf{S} = \begin{bmatrix} \mathbf{S}_{1,1} & \cdots & \mathbf{S}_{1,R\times M} \\ \vdots & \mathbf{S}_{n,r\times m} & \vdots \\ \mathbf{S}_{N,1} & \cdots & \mathbf{S}_{N,R\times M} \end{bmatrix},$$

(material flow coefficient matrix)

where $\mathbf{S}_{n,r\times m}$ represents average *material* units of indicator "*n*" embodied in each *$mil.* of commodity "*m*" gross output in region '*r*'.

If ξ denotes the subset of each matrix element representing a primary energy source (*Btu/$mil.*), change in embodied energy (Btu) from a transition to the DGA is measured as:

$$\mathbf{E}^{\xi} = \mathbf{S}^{\xi} \times \mathbf{L} \times \mathbf{T} \times (\mathbf{y}^{f1} - \mathbf{y}^{f0})$$

Mathematical Programming Estimates of Diet Change

Annual food expenditures represent the product of annual quantities purchased and annual average prices:

$$\mathbf{y}^{f} = \hat{\mathbf{p}}^{f} \times \mathbf{q}^{f}$$

Denote:

$\mathbf{q}^{f0} = \{\mathrm{q}_m^{f0}\}$	observed average "Baseline Diet" (BD)
$\boldsymbol{\Sigma} = \{\mathrm{s}_m^2\}$	variance of observed BD
$\mathbf{q}^{f1} = \{\mathrm{q}_m^{f1}\}$	unobserved average "Healthy Diet"
$\mathbf{H} = \{\mathrm{h}_{d,m}\}$	nutrition attribute "*d*" content per commodity unit "*m*"

Mathematical Programming Estimates of Diet Change

When survey data measuring current average diets are normally distributed, the maximum likelihood equation is used to test the following:

Hypothesis: $\mathbf{q}^{f1} = \mathbf{q}^{f0}$

Maximize

i) $$Z = -0.5 \times (\mathbf{q^1} - \mathbf{q^0})' \times \widehat{\sum}^{-1} \times (\mathbf{q^1} - \mathbf{q^0})$$

subject to:

ii)

a) $\mathbf{H} \times \mathbf{q}^{f1} \geq \mathbf{h}^{G}$	(DGA goal constraints)
b) $\mathbf{H} \times \mathbf{q}^{f1} \leq \mathbf{h}^{L}$	(DGA limit constraints)
c) $q_m^{f0}, q_m^{f1} \geq 0 \ \forall \ m \in M$	(non-negative consumption constraint)
d) $\mathbf{p'}^{f} \times \mathbf{q}^{1} \leq \mathbf{p'}^{f} \times \mathbf{q}^{0}$	(budget limit constraint)

Representative Diets

Baseline Diet

- NHANES 2007-2008

Realistic Healthy Diet

- Minimize

$$(\mathbf{q}^1 - \mathbf{q}^0)'\widehat{\Sigma}^{-1}(\mathbf{q}^1 - \mathbf{q}^0)$$

subject to

  - Calories
  - Nutrient targets
  - Food Patterns components
  - Cost

Energy Efficient Diet

- Minimize

$$\mathbf{E}^{\xi}$$

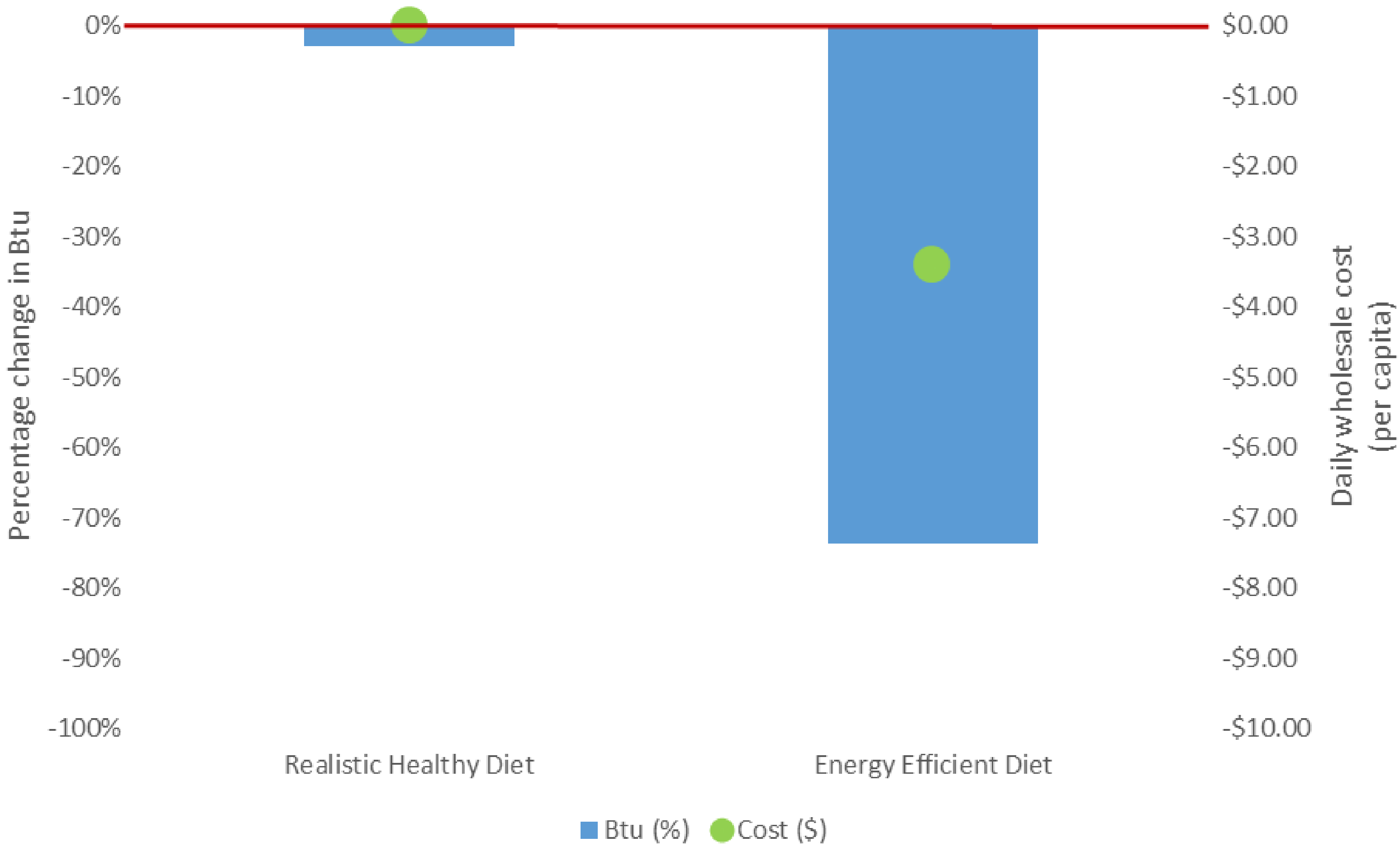
subject to

  - Calories
  - Nutrient targets
  - Cost

Percentage Change From Baseline Diet

	Realistic Healthy		Energy Efficient	
	Calories	BTUs	Calories	BTUs
Milk and milk products	59%	49%	62%	-42%
Meat, poultry, fish, and mixtures	-27%	8%	-96%	-95%
Eggs and egg products	19%	22%	-20%	-41%
Legumes, nuts, and seeds	131%	69%	728%	212%
Grain products	-12%	-26%	-31%	-72%
Fruits	100%	68%	-71%	-19%
Vegetables	101%	73%	-89%	-92%
Fats, oils, and salad dressings	-99%	-94%	233%	11%
Sugar, sweets, and beverages	-68%	-51%	7%	-96%

Results Relative to Baseline Diet



How do taxes affect food markets?

Comparison of Input Output (IO) and Computable General Equilibrium (CGE) models: (a simple closed economy, no government example)

IO	CGE

Household problem (utility maximization)

IO

Max U($\mathbf{q}$), s.t. I - $\mathbf{p}'\mathbf{q}$ = 0

Consumer demand:

$q_m^d = \alpha_m \times I/p_m^0, \qquad \sum_m \alpha_m = 1$

$p_m^0 = 1 \;\; \forall\, m \in M$ (units = \$1 of output)

I = $\mathbf{r}'\mathbf{k}$ (factor payments flow to household as income)

Notes: $\mathbf{v} = \hat{\mathbf{r}}\mathbf{k}$, where $\mathbf{k}$ represents a composite quantity of all primary factors (capital, labor, resources) and $\mathbf{r}$ the composite price. Commodity prices ($\mathbf{p}$) are **exogenous** in the basic IO model (see producer problem).

CGE

Max U($\mathbf{q}$), s.t. I - $\mathbf{p}'\mathbf{q}$ = 0

consumer demand:

$\mathbf{q} = g(\mathbf{p}, I)$ (Marshallian)

$\mathbf{q}^h = h(\mathbf{p}, U)$ (Hicksian)

Notes: Primary factor prices ($\mathbf{r}$) and commodity output prices ($\mathbf{p}$) are **endogenous** in the basic CGE model. Demand properties include additivity ($\mathbf{p}'\mathbf{q}$=I), homogeneity($g(\mathbf{p},I)=g(\varepsilon\mathbf{p},\varepsilon I)$ & $h(\mathbf{p},U)=h(\varepsilon\mathbf{p},U)$), negativity ($dq_m^h/dpm < 0$) , and symmetry

$$\left(\frac{dq_m^h/dp_{\tilde{m}}}{q_m^h/p_{\tilde{m}}} = \frac{dq_{\tilde{m}}^h/dp_m}{q_{\tilde{m}}^h/p_m} \;\; \forall m, \tilde{m} \in M\right)$$

How do taxes affect food markets?

Comparison of Input Output (IO) and Computable General Equilibrium (CGE) models:
(a simple closed economy, no government example)

Producer problem (cost minimization)

IO

Min $\mathbf{r'k}$ **,** s.t., $\mathbf{Lq} - \boldsymbol{\chi}(\mathbf{k}) = 0$

commodity supply and price:

$$\boldsymbol{\chi} = \mathbf{Lq}$$
$$\mathbf{p} = \mathbf{L'\hat{r}w}$$

derived factor demand and price:

$$\mathbf{k} = \mathbf{\hat{w}x}$$
$$\mathbf{r} = (\mathbf{\hat{w}L'})^{-1}\mathbf{p}$$

Notes: Primary factors (**k**) are assumed perfectly mobile between industries and in **excess supply**. This implies the factor rental rate is exogenous, and since **L** and **w** are also fixed, commodity prices are exogenous.

CGE

Min $\mathbf{r'k}$ **,** s.t., $\mathbf{Lq} - \boldsymbol{\chi}(\mathbf{k}) = 0$

commodity supply and price:

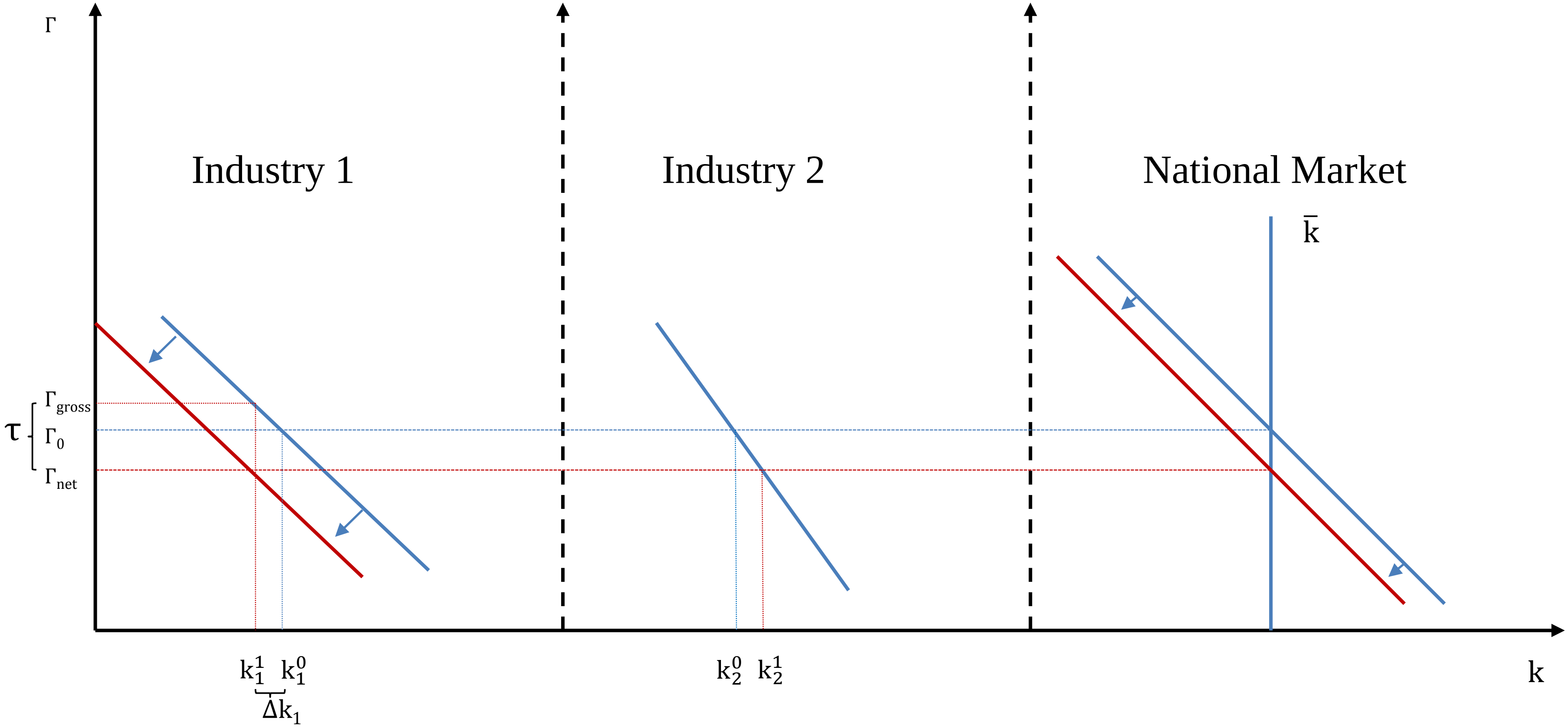
$$\boldsymbol{\chi} = \mathbf{Lq}$$
$$\mathbf{p} = \mathbf{g}^{-1}(\mathbf{q}, \mathrm{I})$$

derived factor demands:

$$\mathbf{k} = \mathbf{\hat{w}x}$$
$$\mathbf{r} = (\mathbf{\hat{w}L'})^{-1}\mathbf{g}^{-1}(\mathbf{q}, \mathrm{I})$$

Notes: Primary factors (**k**) are assumed perfectly mobile between industries and in **fixed supply**. In equilibrium, **r** is equal to the value of marginal product.

Harberger General Equilibrium Tax Model



Social efficiency cost of tax ≈ $-0.5\tau\Delta k_1$

How do taxes affect food markets?

Table 2—Impacts of Federal tax flattening on U.S. and regional food markets[1]

Economic indicator/Industry	U.S.	North-east	South-east	Cornbelt	Lake	Delta	Appala-chia	No. Plains	So. Plains	Moun-tain	Pacific
						Percentage change					
Producer price index:											
Farm	1.3	1.9	1.6	1.3	0.8	1.5	1.9	0.9	0.6	0.8	1.6
Food	-0.2	-0.4	-0.2	-0.2	-0.1	-0.2	-0.1	0.0	-0.1	-0.2	-0.5
Consumer price index:											
Farm	1.2	1.2	1.4	0.9	0.8	0.7	1.4	0.7	0.7	0.9	1.4
Food	-0.3	-0.4	-0.3	-0.3	-0.3	-0.3	-0.4	-0.3	-0.3	-0.3	-0.3
Industrial output:											
Farm	-0.4	-5.1	-1.9	-0.1	2.4	-1.3	-4.1	1.9	2.9	1.4	-2.8
Food	0.7	2.1	-0.3	0.2	-0.2	0.5	0.5	-0.6	0.0	-0.8	2.5
Net investment:											
All industries	2.3	2.8	0.8	3.0	2.9	0.3	5.8	1.5	0.3	1.5	1.2
Farm	1.3	-1.3	-0.6	2.0	4.1	-1.2	2.7	2.2	1.4	1.9	0.2
Food	2.6	4.4	-0.1	2.4	3.2	1.0	3.2	1.8	0.9	-1.0	1.7
Net foreign trade:[2]											
Farm	-3.5	-20.3	11.7	-0.6	-7.0	1.4	-2.4	-13.7	0.2	-21.4	-2.6
Food	(14.2)	(3.2)	(4.4)	(10.3)	(10.0)	21.6	(38.9)	17.9	(13.1)	(3.4)	(22.5)

[1] To infer the impact of current tax policy, divide the percentage changes reported by 1 minus this reported change and reverse the sign.

[2] Value of exports minus value of imports. Where impacts are given in parentheses, it indicates a region was a net importer in the benchmark equilibrium. For example, a positive number in parentheses suggests a decline in net imports.

Table 3—Impacts of harmonized Federal and State tax reform on retail food prices

Economic indicator	U.S.	North-east	South-east	Cornbelt	Lake	Delta	Appala-chia	No. Plains	So. Plains	Moun-tain	Pacific
						Percentage change					
Consumer food price index	-2.2	-0.8	-5.0	-1.7	-0.7	-5.3	-5.1	-3.3	-1.4	-2.2	-0.9

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Slides 3 to 7:

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