# Impact of CO2 Emission Policies on Food Supply Chain:

## Application to the U.S. Apple Sector

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# Impact of CO2 Emission Policies on Food Supply Chain: Application to the U.S. Apple Sector*

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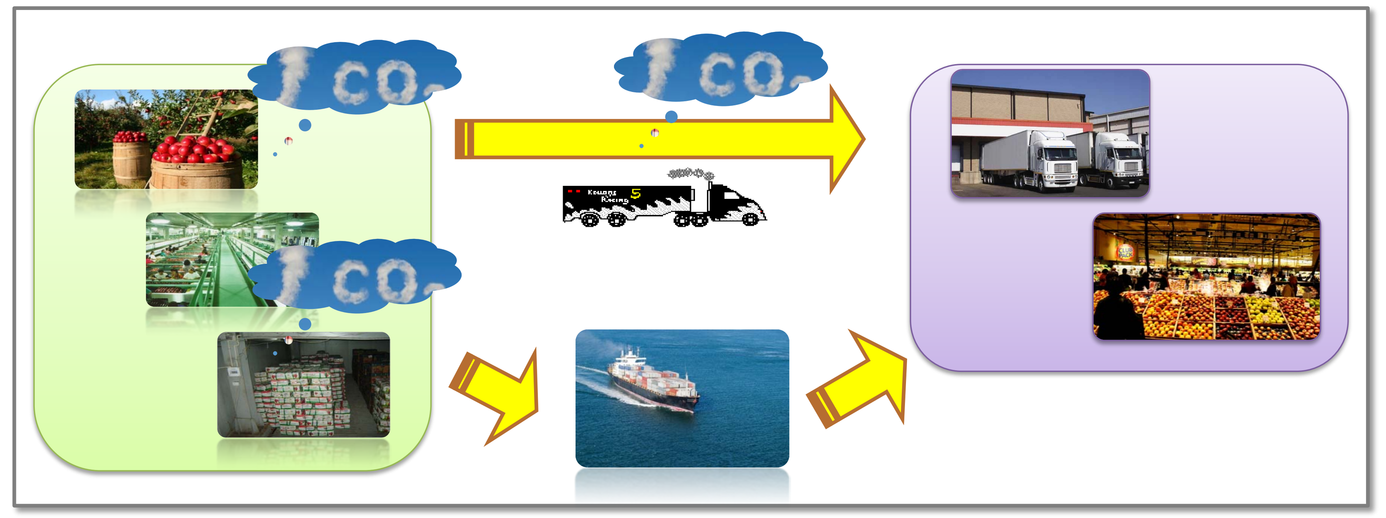
## Introduction

Food supply chains (FSCs) are an important source of CO2 emissions in their production, processing, distribution and consumption activities. Such policy instruments as a carbon tax and a cap-and-trade program have been considered to reduce CO2 emissions in FSCs. At the same time, some argue that production agriculture may be an important source of CO2 offsets. However, little is known about the potential impacts of these policies (i.e. carbon tax, cap-and-trade, and offset credits) on the structure of FSCs as well as on the welfare implications for supply chain participants.

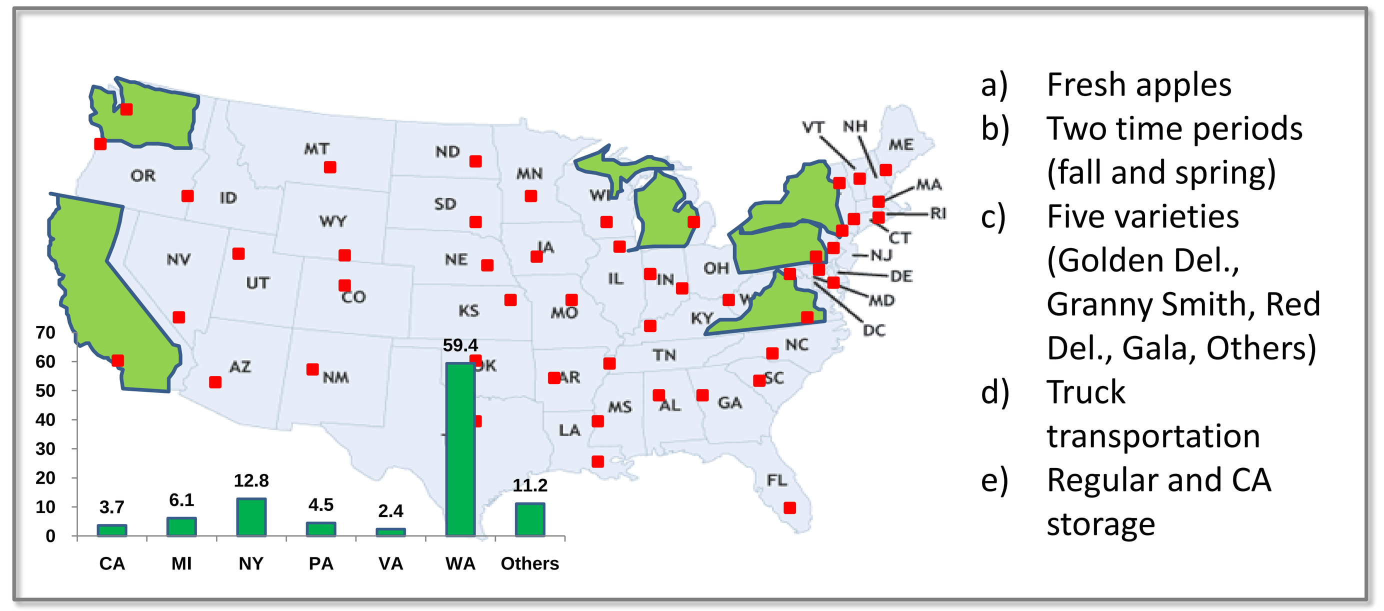
## Objectives

Develop an optimization model of the U.S. apple supply chain to measure the impact of alternative CO2 emission policies on supply chain structure as well as on social welfare of supply chain segments.

Apple Supply Chain




Apple Supply Chain Model: Key Features




## Model

**1. Spatial equilibrium model***

$$\textbf{Max} \quad \sum_t\sum_k\sum_j \delta^{t-1}\int_0^{qd^t_{k,j}} pd^t_{k,j}(qd^t_{k,j})dqd^t_{k,j} - \sum_k\sum_i \int_0^{qs_{k,i}} ps_{k,i}(qs_{k,i})dqs_{k,i} + \sum_t \delta^{t-1}\int_0^{qim^t} ppim^t(qim^t)dqim^t - \sum_t \delta^{t-1}\int_0^{qex^t} ppex^t(qex^t)dqex^t$$

*Social surplus from supply and demand*

$$-\sum_k\sum_i pc_{k,i}\cdot qs_{k,i} - \sum_t\sum_s\sum_i \delta^{t-1}\left[sc^t_{s,i}\cdot\left\{\sum_k sa^t_{k,s,i}\right\}\right] - \sum_t\sum_i\sum_j \delta^{t-1}\left[tc^t_{i,j}\cdot\left\{\sum_k\sum_s tfa^t_{k,s,i,j}\right\}\right] - \sum_t\sum_m\sum_j \delta^{t-1}\left[tc^t_{m,j}\cdot\left\{\sum_k tfam^t_{k,m,j}\right\}\right]$$

*Costs from supply chain's activities*

***Constraints***

1) Capacity constraints (production and storage)
2) Technical constraints
3) Supply and Demand balances
4) Non-negativity constraints

** See supplementary pages for details*

**2. Demand price elasticities**

1) LA-AIDS model using Nielsen Homescan data (2005-2006)
2) Heckman's two step procedures to deal with zero consumption problems

| Apple Variety | Northeast | | Midwest | | South | | West | |
|---|---|---|---|---|---|---|---|---|
| | *Spring* | *fall* | *spring* | *fall* | *spring* | *fall* | *spring* | *fall* |
| Golden Del. | -2.00 | -1.54 | -2.71 | -1.17 | -1.71 | -0.97 | -3.22 | -0.61 |
| Granny Smith | -2.56 | -3.35 | -4.68 | -1.49 | -1.96 | -2.00 | -2.69 | -2.08 |
| Red Delicious | -1.00 | -0.98 | -1.11 | -1.02 | -0.99 | -0.99 | -0.90 | -0.93 |
| Gala | -0.71 | -1.52 | -1.27 | -0.69 | -0.72 | -0.79 | -0.96 | -1.12 |
| Others | -1.06 | -1.05 | -1.08 | -1.08 | -1.10 | -1.08 | -1.06 | -1.09 |

**3. Price elasticities of supply**

1) Nerlove's model

| California | Michigan | New York | Pennsylvania | Virginia | Washington |
|---|---|---|---|---|---|
| 0.57 | 0.36 | 0.36 | 0.50 | 0.55 | 0.12 |

**4. Costs**

1) Production costs
2) Storage costs
3) Transportation costs

## Emission Policies*

**1. Carbon Tax**

1) Carbon tax $\tau$ on the ton of CO2 emissions is applied to production and storage activities

**2. Cap-and-Trade (without Offsets)**

1) Emission allowances (permit) are distributed to each supply region by $A_i = (1\text{-}\Phi)E_i = \mu_i * qs_{k,i}$, where $\Phi$ is emission reduction plan and $\mu_i$ is emission rate.

**3. Cap-and-Trade (with Offsets)**

1) Allow each supply region to purchase offset credits ($CR_i$)by δ percents of required emission reductions

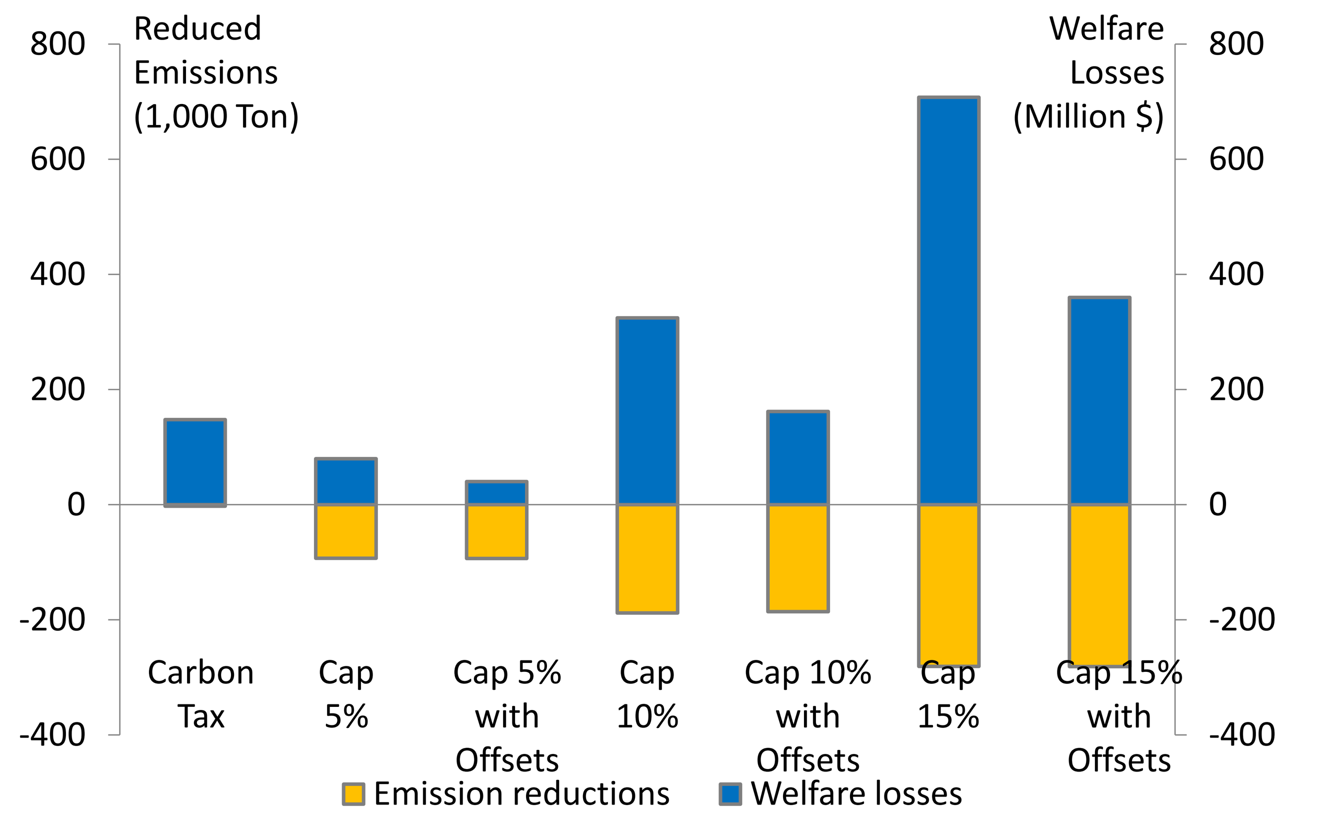
** See supplementary pages for details*

## Simulations

*Assumptions:*

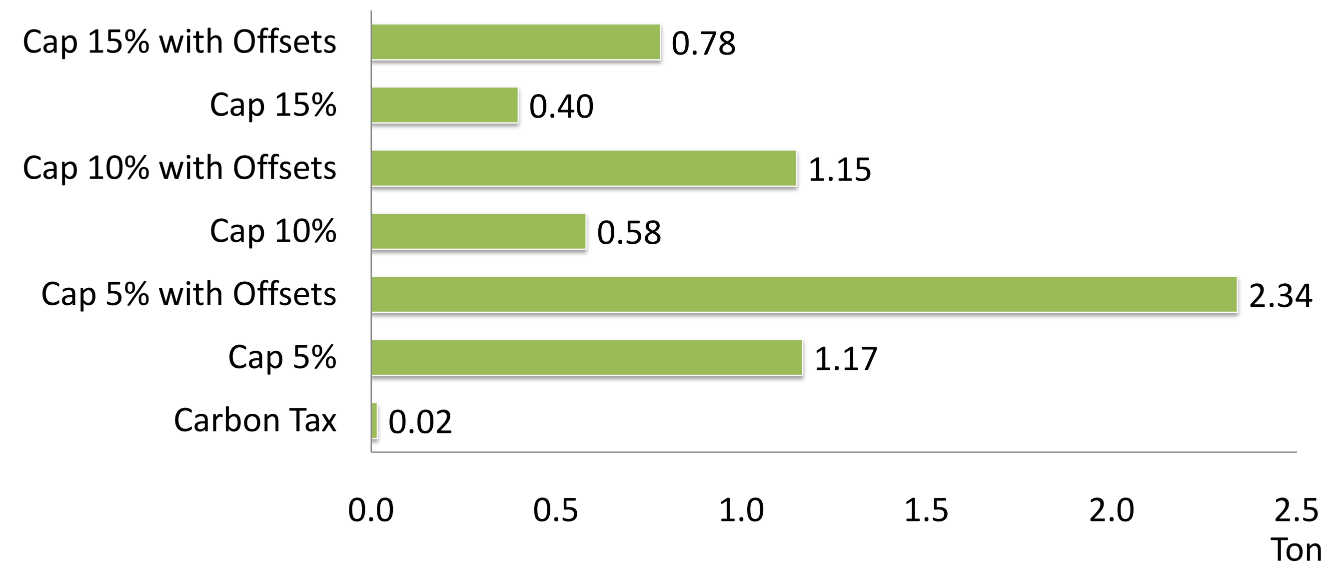
1. Permit price = Emission tax = Offset Credits = $20
2. Maximum Offset: 30% of emission cuts

Annual Emission Reductions and Welfare Losses




## Simulations (continued)

Annual Per-dollar Emission Reduction




Production Changes from Alternative Policies (million lbs.)

| State | Baseline | Carbon Tax | Cap-and-Trade without Offsets | | | Cap-and-Trade with Offsets | | |
|---|---|---|---|---|---|---|---|---|
| | | | 5% | 10% | 15% | 5% | 10% | 15% |
| California | 117 | 115 | 93 | 61 | 46 | 95 | 91 | 57 |
| Michigan | 269 | 269 | 246 | 24 | 202 | 253 | 243 | 241 |
| New York | 675 | 674 | 659 | 646 | 645 | 666 | 646 | 645 |
| Pennsylvania | 128 | 128 | 120 | 119 | 118 | 121 | 119 | 119 |
| Virginia | 32 | 32 | 30 | 30 | 29 | 30 | 30 | 30 |
| Washington | 4,119 | 4,117 | 3,965 | 3,807 | 3,670 | 4,015 | 3,893 | 3,794 |

## Conclusions

1. A carbon tax may have modest impacts on emission reductions and on supply chain structure (e.g. production decisions)
2. Cap-and-Trade schemes with offsets appear to be more effective than Cap-and-Trade schemes without offsets
3. The impacts of emission policies may be largest in California due to its higher production costs

*References*

1. Canal et al. 2007. "Comparing Domestic versus Imported Apples: A Focus on Energy Use," *Env. Sci. Poll. Res* 14(5): 338-344
2. Guajardo, R.G.,and H.A. Elizondo. 2003. "North America Tomato Market: A Spatial Equilibrium Perspective," *Applied Economics* 35: 315-322