Planning, consolidation and coordination the keys for small farmers to advance in the fresh produce value chain

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November 2014
http://ilpil.asu.edu/
Agenda

- Background
- Trends in the supply chain of fresh fruits and vegetables
- Planning
- Coordination
- Analytics
- Conclusions
Background

- Per capita consumption of fresh produce has increased over 60% in the last 30 years.
- Demand is driven by demographic changes and health concerns (Let’s move, farm to school programs).

From Harvard School of Public Health: “…average American gets a total of just three servings of fruits and vegetables a day. The latest dietary guidelines call for five to thirteen servings of fruits and vegetables a day (2½ to 6½ cups per day)”
Fresh Supply Chain

- Long cycle times, perishability, high variability and other special conditions (temperature controlled, compatibility, marketing practices) make the fresh supply chain very complex → up to 50% of the product is lost when the product reaches the consumer.

- There are many players in the fresh produce SC.
- This increases costs and lead time, and reduces flexibility.
- The grower has narrow profit margins even though the complete chain doesn’t.
Supply Chain Value in Year 2000

- Consumers: $78.5 Billion
  - Retail Stores: $38.0 Billion (Margin: 33%)
  - Foodservice: $39.2 Billion (Margin: 70%)
  - Wholesale: $51.6 Billion (Margin: 15%)
  - Direct Markets: $1.2 Billion
- Grower/Shipper: $19.7 Billion
- Exports: $3.4 Billion
- Imports: $5.5 Billion

Average Transport as Purchase Cost: 17%-18%

Imports: 5.5/78.5 = 7%

Supply Chain Value in Year 2010

Imports: 12.3/122 =10%

Taken from: http://agecon.ucdavis.edu/people/faculty/roberta-cook/docs/Articles/ValueChainProduce2010.pdf
Trends

- Direct relationships between producers and retailers seek to reduce the "distance" between them in the value chain.
- More direct relationships between the retailers and growers based on year-round supply of products based on contracts.
- Integrated grower-retailer planning.
- Greater control of the distribution chain by the retailers.
- Elimination of non-added value inefficient intermediaries to better control de cost, quality and traceability of the product.
- About to experience some of the trends already experienced in Europe.
Background

For the (small) farmers to advance in the value chain is necessary to have the infrastructure and underlying planning systems necessary to provide services to end customers.

Planning tools are needed at different levels to make the production, consolidation, distribution and marketing of fresh agricultural products more efficient.

For small farmers a key question is how to reach the final consumer with limited resources.
Supply Chain

Locations  Packing  Warehousing  DC’s  Customers

L1  P1  W1  D1  C1  
L2  P1  W1  D1  C2  
L3  P2  W2  D3  C3  

Packing and Warehousing are connected to DC’s, which then connect to Customers.
First Problem*

Objective:

Provide vertically integrated producers of highly perishable products, such as fresh fruits and vegetables, with the planning tools of the supply chain that will allow them to maximize their profits by selling directly to final distributors.

*Omar Ahumada Dissertation
DEVELOPMENT OF PLANNING TOOLS
Levels of Planning

Strategic
- Crop Selection
- Location Analysis
- Technology Selection

Tactical
- Transportation Decisions
- Crop Production
- Scheduling of Activities

Operational
- Harvest Decisions
- Marketing Decisions
- Storage and Transportation
Description of the problem:

Farmers:

- Make critical tactical decisions which will influence their entire season

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<thead>
<tr>
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<th>Production</th>
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<th>December</th>
<th>January</th>
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Models Developed

**Tactical Model**
- How much and when to plant
- Land assigned to each crop
- When to harvest and sale
- Transportation decisions

**Operational Model**
- Harvest schedule
- Schedule of shipments
- Storage and selling decisions
- Transportation decisions

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**Risk Analysis**

**Market Analysis**

**Tactical Decisions**
- Crop selection
- Area assigned to crops
- Planting scheduling

**Tactical Decisions**
- Labor planning
- Harvest plan
- Distribution plan

**Price Estimates**

**Weather Patterns**

**Feedback**

**Phase I: Tactical**

**Phase II: Operational**

**Spot Prices**

**Operational Decisions**
- Harvest schedule
- Shipment schedule
- Selling decisions
Models Developed

Model interaction
- Use tactical model a few times in the season (multiple planting dates).
- Use the operational model every week during the season harvesting season.
- Use estimated costs of harvest and transportation from operational model in tactical planning.
Supply Chain

Locations
L1
L2
L3

Packing
P1
P2

Warehousing
W1
W2

DC’s
D1
D2
D3

Customers
C1
C2
C3

Consolidation Facility
DEVELOPMENT OF COORDINATION TOOLS
Coordination Objective*

Develop tools to coordinate the supply chain such that optimal decisions are made in a decentralized way as if they were taken by centralized decision maker.

Must create the right incentives, decision support technologies and collaboration frameworks.

*Nicholas Mason’ Dissertation
Description of the problem:

Farmers:
- Make critical tactical decisions which will influence their entire season

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Harvest by week:
- March
- April
- May
- June
- November
- December
- January
- February
Description of the problem:

Consolidation Facility:

- Role of CF is to pool variance of production, achieve economies of scale and allow year-round availability of products
- Entry point to the cold-chain
Description of the problem:

- First echelon of the supply chain
  - Producers and consolidation points
- Tactical decisions
- There should be transparency and fairness on contract allocation
- **Must achieve coordination despite internal competition and asymmetric information**
Solution Approach:

Non-traditional auction for agricultural goods

- Allocates contracts before any production has been materialized
- Auctions multiple products/units simultaneously
- Agricultural planning is "specially well suited" for such a mechanism

Flowchart:

1. Initialize Auction prices
2. Farmers: Respond with a production schedule
3. CF: Computes difference between planned and contracted demand
4. CF: Define a new price schedule to announce
5. Demand schedule met? (NO → 3, YES → 6)
6. Terminate Auction

Flowchart steps:

- Initialize Auction prices
- Farmers: Respond with a production schedule
- CF: Computes difference between planned and contracted demand
- CF: Define a new price schedule to announce
- Demand schedule met? (NO → 3, YES → 6)
- Terminate Auction
Solution Approach:

Decentralized optimization with auctions:

![Projected Demand schedule]

- **Iteration 1**
- **Iteration 2**
- **Iteration 3**

- Raise prices in periods 8 - 10
- Raise prices further in periods 8 - 12
- Terminate Auction
Models Proposed:

Centralized and decentralized models:

- **Centralized Model**
  - Growers Input: Production Cost, Yields, Resources
  - Customer Input: Demand, Retail Prices
  - Market Input: Transportation costs, Open Market Prices
  - Output: Optimal production, sourcing and marketing

- **Master Problem**
  - Customer Input: Demand, Retail Prices
  - Market Input: Transportation costs, Open Market Prices
  - Negotiated prices, Contracts, Quantity harvested
  - Output: Sourcing and marketing solutions

- **Sub-prob 1, Sub-prob 2, ..., Sub-prob N**
  - Input: Production Cost, Yields, Resources
  - Output: Quantity harvested
Convergence and Efficiency:

Convergence of formulation for various problem sizes

- **Auction – Obj**: Current auction objective function value
- **Planning Mismatch**: Difference between CF request and farmers' plans
- **Optimal**: Centralized, optimal solution
- **WD–Obj**: Solution obtained through WD-decomposition
Convergence and Efficiency:

Convergence of formulation for various problem sizes

Auction Convergence (5 Farmers)
Convergence and Efficiency:

Convergence of formulation for various problem sizes

Auction Convergence (20 Farmers)
Convergence and Efficiency:

Convergence of formulation for various problem sizes

Auction Convergence (50 Farmers)

Number of Iterations

Auction - Obj  Planning Mismatch  Optimal  WD - Obj
Convergence and Efficiency:

Convergence of formulation for various problem sizes

Auction Convergence (125 Farmers)
Convergence and Efficiency:

Convergence Summary:

- Convergence is faster at larger problem instances
- Smaller optimality gap is achieved with more players
- A reduced number of players leads to high supply elasticity
  - Few players have more control over relative supply/demand equilibrium
- Consistent with economic theory

<table>
<thead>
<tr>
<th>Number of participants</th>
<th>Optimal Solution</th>
<th>Best Auction Solution</th>
<th>% Planning Mismatch</th>
<th>% Optimality</th>
<th>Iteration #</th>
<th>Iterations to 80%</th>
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<td>$ 324,269</td>
<td>$(1,161,669)</td>
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<td>-358%</td>
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<td>$ 1,020,037</td>
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<td>48%</td>
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<td>85%</td>
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<td>92%</td>
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<td>10</td>
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<td>$ 50,863,300</td>
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<td>92%</td>
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Convergence and Efficiency:
Comparison of optimal and auction production

Production for 20 farmers auction outcome

Production for 20 farmers (optimal)
Final Considerations:

- There should be transparency and fairness on contract allocation.
- Reasonable convergence.
- **Agents may act strategically** and attempt to influence allocation decisions.
- **Incentive Compatibility:** No agent can be made better off by misrepresenting its information.
- **Individual Rationality:** Agents cannot be forced to participate.
DEVELOPMENT OF MARKET ANALYTICS TOOLS
Mexican Farmer Case Study

- **Observation Period**
  - January 2000 – December 2009 (Daily prices)

- **Product Basket**
  - Tomato (Plum Type)
  - Cucumber
  - Eggplant
  - Squash
  - Bell Pepper

- **Transportation Mode**
  - Truck

### Table: Price Comparison for Different Markets

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<th>Chicago</th>
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<td>$0.70</td>
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<td>Cucumber</td>
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Potential Market Opportunities
Shipment Policy (Pragmatic)

- Dallas – Boston (10 years) iterative summary of historical profits under varying values of threshold

\[ \mu \text{ and } \sigma \text{ per threshold value is equal to the mean profit and standard deviation per pound of product shipped} \]
## Shipment Policy (Theoretical)

### Total Profits and Average Profits vs. Threshold

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<th>Threshold + Cij</th>
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<td>0.1002</td>
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0.0502 < K < 0.0602
Conclusions

- The research presented is only the start of a plan to develop better planning tools for small farmers of fresh agricultural products to capture a larger share of the value chain.

- Work in progress.

- Other work:
  - Farm to school
  - Labor force planning and immigration
Some Publications


Our Vision

- Tackle the issues of agricultural supply chains using industrial engineering tools
  - Optimization tools
  - Statistical analysis and inference
  - Risk management
- Identify opportunities with large impact (Farm to School, foreign labor force, climate change)
- Design a suite of decision support tools
- Form partnership with farmers to refine tools and implement results
Questions?
Mechanism design and auctions:

- Auctions for price discovery and efficient allocation (Vickrey, 1961)

- Auction mechanisms have been proposed as viable tools to achieve coordination (Vohra, 2011)

- For horizontal coordination, *a marriage between auction mechanisms and supply contracts* may be promising (Chen, 2003)

- (Ausubel & Cramton, 2004) Provide guidelines for designing auctions of divisible goods and details benefits/challenges of iterative auctions
Expected Changes in Agriculture PS’s

- Climate change will no doubt impact agricultural production systems (PS) for decades to come
  - Frequency and strength of “abnormal” weather activities is expected to increase
  - Greater climate uncertainty translates to higher variability in production, as well as mark-up in market prices
- Global population is expected to cross the 9 billion mark within the new few decades, which adds urgency to for current PS’s to increase productivity
  - Estimating the difference between current and the potential agricultural production (i.e. yield gap) is a difficult task, especially at a global level
  - Incorporating marginalized farmers into this assessment is also a difficult task due to information insufficiency and lack of market access

Ability to estimate and close agricultural yield gaps in order to meet future demand is a grand challenge
Latest Research Advances in the Area

- Development of *Integrated Assessment models* that assess the impact of future climate changes on productivity, land-use patterns, and agricultural markets for major crops (on a regional and global, macro-level)
  - Consider future climate conditions, vegetation and crop growth patterns, and socio-economic factors by simulation
  - Integrate these components dynamically with land-use models that attempt to meet future demand with regional production
  - Provide scenario-based assessments of global and regional agricultural production systems

- Development of models that can estimate crop yield potentials based on environmental and technological characteristics
  - Provide data collection and estimation methodologies aimed at determining current and potential production of different regions of the world
  - Identify methods to close yield gaps through technological investments, such as genome advances and better production planning at the farm
Identified Gaps in Literature Work

- Current assessment models are great tools to estimate future patterns in agricultural productivity at a macro-level.

- However, as an individual (more sophisticated) farmer, there are little to no tools available to:
  - Determine needed infrastructure technologies specific to the climate variability and production characteristics of his/her region.
  - Identify demand growth opportunities for particular products in markets.

- Lack of tools that could incentivize “larger farmers” in incorporating marginalized farmers into their own supply chains:
  - Identify geographical regions with the “almost” right production characteristics that could:
    - Produce products with identified growth opportunities.
    - Help diversify production and mitigate risk from climate variability.
    - Develop supply chain and production strategies to connect production potential with demand growth opportunities.
Current Work in the Research Area

- Development of optimization-based modeling tools geared towards farmers with some stake in agricultural production and that may seek to:
  - Protect his/her current production from climate variability by investing in specific technologies or identified regions with identified production potential
  - Maximize profits by taking advantage of demand growth opportunities
  - Diversify his/her investment risk by cooperating with other farmers and sharing resources

E.g.

```
Zone_1
  Products
  - Environmental
  - Resources
  - Capacity

$ for infrastructure
$ for products

Zone_2
  Products
  - Environmental
  - Resources
  - Capacity

$ for pool resources and infrastructure

Market
  Products
  - Price
  - Import/Exports

To wholesale:
  - DV: Quantity to send
  - Limited entrance

Contracted Supply:
  - DV: Quantity to send
  - Penalty for not meeting contract
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\[ \text{equation} \]