The Diffusion of Process Innovation: The Case of Drip Irrigation in California

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Overview

1. Motivation
2. Overview of adoption and diffusion literature
3. Literature on drip irrigation
4. Drip irrigation in California
5. Conclusions

Our CIMIS study
1. Ben Gordon
2. Interviews
3. Follow up
4. Thanks to Inge Bisconer
Drip: Poster-child of agricultural technology adoption

1. Agricultural economists have made major contributions to the economics of adoption and diffusion.
   - Griliches incorporated economics to diffusion literature.
   - Ag economists expanded and operationalized the threshold model.
   - Alan Olmstead casted an economic history perspective on the diffusion of agricultural technologies, countering and furthering the methods and theories developed by Paul David.

2. Adoption of modern irrigation has been a major area of research.
   - Drip is a process innovation \( \rightarrow \) the implementation of improved production methods that may be embodied in new technologies or processes.
     • Ex. Computer, Dynamo, Mechanical reaper, Drip irrigation.
Why drip in SF and now?

1. California growers are threatened by **chronic water problems**. → Drip is a resource conserving, input-use enhancing technology.

2. Drip irrigation was selected as one of the **major success stories** over the last 100 years by an informal survey of California County Directors.

3. Timely to study a technology whose adoption has been shaped by droughts during a period with a **severe California drought**.

4. Drip has **evolved over time**, with its range of applications expanding across crops and locations.

5. Drip’s **diffusion was non-linear** → It was introduced in California in late 1960s. By 1988, it was used on only 5% of irrigated land. Now over 40% of irrigated land uses drip systems.

6. Spreading fast in **developing countries**.
Economic literature on adoption and diffusion

- Three methodological approaches in literature:
  1. Conceptual—theoretical models with simulations.
  2. Empirical—statistical methods by agronomists and econometricians.
  3. Historical—combining various bodies of data to weave illustrative stories.

- Two major school of thought:
  1. **Imitation model**: Diffusion spread like an infection. Rate is affected by socioeconomic and biophysical factors. Model is especially amenable to be used with data on aggregate adoption.
  2. **Threshold model**: Adoption is an economic choices. Diffusion across agents is a result of individual optimization, heterogeneity, dynamic processes, like learning.

→ Integrative approaches.
Modeling adoption and diffusion of drip

1. Drip as a land quality augmenting technology.
   - Drip increasing water use efficiency (Caswell & Zilberman 1985, 1986).

2. Drip improves timing of application of water.
   - Increase yields, reduce drainage, may save water at field level (Shani et al 2009; Kan et al 2002; Caswell et al 1990).
   - Adopted on lower quality land first, such as steep hills and sandy soil (Schoengold & Zilberman 2007).
   - Distinguish between extensive and intensive margin effect (Shah et al. 1995).
Empirical literature on adoption of drip

1. Profitability was a key factor explaining diffusion of drip in Israel.
   - Weather was a source of heterogeneity affecting timing of diffusion (Fishelson and Rymon 1989).
   - Dinar and Yaron (1992) identify sequences of transition from less advanced to more advanced technologies— influenced by yield effects, water-savings and subsidies.

2. In Spain, adoption of drip started in perennial crops and moved to annuals.
   - Adoption probability increased with water scarcity, credit availability, education, and access to information (Alcon et al. 2011).

3. Adoption of drip in Crete and Greece.
   - Profitability, production risk, and water shortage contribute to adoption in Crete (Koundouri et al. 2006).
   - Better access to information from informal and formal sources enhances likelihood of adoption. Formal and informal information sources are complementary (Genius et al. 2014).
Estimates of impacts of drip

• Netafim analyze 112 studies of drip irrigation versus flood irrigation.
  – Find yield effects range from 18-50% (Durand and Birrell, 2010).

• We compare 31 published studies across 15 crops:
  → Half of the studies report no statistically significant difference in yields.
  → Half of studies report significant and positive yield effects, ranging from 12-66%.
  → **Average yield effect across all studies is 16%.**
  → 11 out of 31 studies also report positive water-savings effects (35% on average when it happens).

• Pesticides and fertilizer use reduction.
### Agronomic Studies Comparing Yields Under Drip to Other Irrigation Methods

<table>
<thead>
<tr>
<th>Crop</th>
<th>Paper</th>
<th>Location</th>
<th>Yield Effect</th>
<th>Comparison</th>
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<tr>
<td>Alfalfa</td>
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<td>furrow</td>
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<tr>
<td>Cotton</td>
<td>Phene et al., 1992</td>
<td>California</td>
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<td>furrow</td>
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<td>Cotton</td>
<td>DeTar et al., 1994</td>
<td>California</td>
<td>-</td>
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<td>Henggeler, 1995</td>
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<td>India</td>
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<td>Lettuce</td>
<td>Sammis, 1980</td>
<td>New Mexico</td>
<td>-</td>
<td>furrow</td>
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<tr>
<td>Lettuce</td>
<td>Hanson et al., 1997</td>
<td>California</td>
<td>-</td>
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<tr>
<td>Okra</td>
<td>Sivanappan et al., 1987</td>
<td>India</td>
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<td>furrow</td>
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<td>Arizona</td>
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<td>furrow</td>
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<td>Colorado</td>
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<td>Virginia</td>
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<td>sprinkler</td>
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<td>New Mexico</td>
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<td>Potato</td>
<td>DeTar et al., 1996</td>
<td>California</td>
<td>27%</td>
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<td>Turkey</td>
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<td>furrow</td>
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<td>Texas</td>
<td>-</td>
<td>furrow</td>
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<td>Sweet corn</td>
<td>Adamsen, 1992</td>
<td>Virginia</td>
<td>-</td>
<td>sprinkler</td>
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<td>Schweers &amp; Grimes, 1976</td>
<td>California</td>
<td>14%</td>
<td>furrow</td>
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<td>Rose et al., 1982</td>
<td>California</td>
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<td>furrow</td>
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<td>California</td>
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<td>Bogle et al., 1989</td>
<td>Texas</td>
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<td>Ethiopia</td>
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<td>California</td>
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<td>Arizona</td>
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<td>furrow</td>
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</table>
Gaps in agricultural economics literature on adoption of drip

1. Literature emphasizes demand side factors in adoption.  
   → Lacks analysis of transition among locations and crops.

1. Economic historians found that supply side factors are very important in adoption and evolution of other technologies. (Is it true in California?)
2. Agronomists found that the introduction of drip failed in many countries, despite its successes in Israel and US.
3. They attributed the successes to the:
   1. Co-evolution of the drip technology and other agronomical practices.
   2. Introduction of a network to support the technology and its adoption.
   → How did these factors play in California?

4. Economic history analysis of adoption of drip can fill some of the gaps.
Background: The importance of irrigation in California

- California grows more than **200 different commercial crops**, with a net farm income of approximately $16 billion in 2012 (USDA 2014).

- Of the 9.6 million acres of cropland in California, 7.4 million acres (77%) are irrigated.

- On average, irrigated cropland in California is valued at more than 3 times that of non-irrigated cropland—$12,000 per irrigated acre vs. $3,550 per non-irrigated acre (USDA 2012).

- There are wide differences in water productivity across locations.
Early Development and Adoption: 1965-1980

• Extension specialist in San Diego introduced drip to California after trip to Israel.

• Extension arranged demonstration of technology.
  – Early adoption in Avocados grown on foothills.

• Extension specialist helped in developing drip tapes for annual crops.
  – Led to adoption of drip in fresh-market vegetables and fruits.

• The drought of 1977 → main impetus for adoption.
  – From 75,000 acres in 1976 to 305,000 acres in 1980.
Slow down and build up: 1980-1989

- Very little increase in drip acreage between 1980-1989.

- Poor designs gave the technology bad name.

- State university established center for irrigation technology (1980).

- Technology has been improved as Netafim entered California (1987).

- CIMIS (California Irrigation Management Information System) was introduced to provide irrigation advice.

- Decreased water delivery costs and higher pumping cost provided incentive to adopt.
- The water bank allowed trading.
- During the drought, drip adoption drastically shot up:
  - In fruits and vegetables (where adoption had already begun),
  - In tomatoes for processing (where adoption was new).
- Conservation efforts during drought assessed to have countered 1/3 of the impacts of the water delivery reductions.
- The achievements during the drought were preserved:
  - After drought, CVPIA was introduced → it allowed federal contractor to trade water.
  - Water bank continued for few years.
Diffusion of Drip in California

Figure 1: Trends in irrigated area (%) by irrigation system category

Source: Tindula, Orang, and Snyder (2013)
Figure 2: % of irrigated acres using drip by crop in Monterey County

Source: Monterey County Water Resources Board, *Ground Water Summary Reports.*
Diffusion of Drip in California

(a) 1975 Drip Irrigation (% of Irrigated Acres)

Figure 3: Drip Irrigation by County and Year

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Vine Crops

Figure 4: Drip Irrigation by Crop, County and Year

Figure 4: Drip Irrigation by Crop, County and Year

Truck Crops

Figure 4: Drip Irrigation by Crop, County and Year

Process Tomato

Figure 4: Drip Irrigation by Crop, County and Year

Water Cost and High Value Crop Acreage

Figure 5: 2001 Water Cost by Acre and % High Value Crop Acreage

Adapting Drip to Other Crops & Regions: 1992-Present

- Extension developed new management practices enabling drip use in lower-value crops.
- Companies focused on innovations to improve their equipment and to reduce its price.
- Consulting software introduced to optimize drip use.
- Broad use of chemigation.
- Drip use intensified during the drought of 2011-2015.
Conclusions

• Predictions of theories (threshold/imitation) seem to work.
  – Profitability was crucial factor in adoption of drip.
  – As technology advanced and got more affordable, its use has spread.
  – Has increased yield and saved water, reduced chemical use and drainage.
  – Was adopted first in high-value crops and on lands with low water-holding capacity.
  – Adoption was triggered by extreme events.
  – Word of mouth can enhance and slow adoption (retreat of the technology in 1980s).

• Technology evolved over time.
  – Private sector mostly improved the technology.
  – Public efforts adapted crop systems to optimize its use.

• Historical analysis provides essential knowledge not available with modeling and standard econometric methods.
Impacts of drip—Order of magnitude

- 40% water use in drip
- 20% saving of water = 8% water saved* 25 MAF = 2 MAF
- 2 MAF * $250/AF = $500 million/year
- 10% revenue increase (adjusted for elasticity) consideration) – 10 billion net farm income = 1 billion
- Add
  - Consumer surplus effect’ HUGE
  - Fertilizer & pesticides effect quite big
- Subtract – R&D cost rebound effect etc
  - - we work on the details
- Conservation pays
Future work

• Continue documentation of the evolution of conservation technologies in California → There are gains from continued historical analysis.
• Estimate yield and water saving effects econometrically.
• Estimate welfare effects—including impact on the environment.
• Assess rate of return to public investment.
• Study the evolution of the technology elsewhere—conduct comparative analyses.
• Study of water supply chains- of water and ag inputs
California Israel collaboration

• Precision ag and water use
  – Broad definition
  – Understanding adoption
• Desalinization and solar
• Adaptation to climate change
THANK YOU