Capital Obsolescence and Agricultural Productivity

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July, 2016
Introduction

• Agricultural productivity growth is key to the development process.
• There are large differences in agricultural productivity across countries

...consider an economy with 1/2 the GDP p/worker of the US

• agricultural value added p/worker is 20 times lower than in the US.
• agricultural TFP growth is 4 times lower than in the US.
Main question

What is the role of capital embodied technology adoption for agricultural productivity?
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• Capital embodied technical change is a key determinant of the price of investment goods. (Solow (1959), Grilliches (1961), Hall (1968), ...)
• We focus on tractors.
  • Detailed equipment’s price and characteristics data across high and middle-income countries.
  • Single cross-section, 2014.
Main question

What is the role of capital embodied technology adoption for agricultural productivity?

• Capital embodied technical change is a key determinant of the price of investment goods. (Solow (1959), Grilliches (1961), Hall (1968), ...)

• We focus on tractors.
  • Detailed equipment’s price and characteristics data across high and middle-income countries.
  • Single cross-section, 2014.

Challenge: Can we identify capital embodied technical change from cross-sectional equipment price data?
Identification

• Price of capital of quality $q$

$$p_{q,t} = \sum_{s=t}^{T} \phi^{s-t} (F(\text{efficiency units}_{q,s, \cdot}) \times \text{return per efficiency unit})$$

Key assumption: quality and quantity are separable.

Gordon (1990), Hulten (1992), Greenwood, et. al. (1997), Cummins & Violante(2002), ...

$F(.)$ is possibly a function of all other qualities.

if goods are perfect substitutes, $F(.)$ linear.
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• Cross-sectional price profile

$$\ln\left(\frac{p_{q}}{p_{\bar{q}}}\right) \simeq \text{age}_q \times \ln\left(\frac{\text{depreciation}}{\text{technical change}}\right) + \text{constant}(\bar{q}, \phi)$$

where $\bar{q}$ is the best adopted quality.
This paper

• **Novel dataset** on second hand prices of agricultural equipment (tractors)
  • construct age-price profiles across 13 countries at different stages of development.

• **Study the link** between equipment price and quality composition of the capital stock
  • vintage capital growth model,
  • endogenous quality adoption.

• **Quantitative exercise**
  • identify the growth and level disparities in capital quality,
  • growth and income accounting exercises (1990-2012).
Main findings

1 Empirics:

- age-price profiles are steeper in more productive countries.
- the price of a 15 years old piece of equipment is
  - 60 cents on the dollar of a new one in the US.
  - 75 cents on the dollar of a new one in Brazil.

2 Quantitative implications:

- adoption patterns ...
  - account for 1/4 of productivity growth, on average.
  - account for 1/3 of disparities in output per worker.
Overview

• Price of equipment: empirical evidence.

• Model: inferring quality from cross-sectional data.

• Growth and income accounting exercises.
Empirical evidence

Dataset

- Tractor quotes gathered by a mayor publisher of retail and auction data.
- For each tractor sold we observe:
  - price
  - age, model, horsepower, use hours, and location.
- We matched data via geolocation with controls for
  - main crops produced within a 20-mile-wide grid around the sale location (EarthStat).
  - wages of repair workers (OWW by NBER).
- 13 countries at different stages of development:
  - agricultural value added per worker relative to US
    - Brazil: 18%  France: 77%  Canada: 87%
Empirical evidence

Dataset
Age-price profiles

• Hedonic pricing with Box-Cox transform

\[
p_{i,c}^{\theta_1} - 1 \over \theta_1 = \gamma_c + \beta_{a,c} a_{i,c} + \frac{X_{i,c}^{\theta_2} - 1}{\theta_2} \beta + \epsilon_{i,c}
\]

- \( p_{i,c} \): price of tractor \( i \) sold in county \( c \)
- \( \gamma_c \): country-specific intercept
- \( a_{i,c} \): years since tractor introduced
- \( X_{i,c} \): tractor’s characteristics
- \( \theta_1 \): shape parameter in pricing
- \( \theta_2 \): shape parameter associated to \( X \)
- \( \beta_{a,c} \) and \( \beta \): characteristics coefficients

• Maximum likelihood estimation
Age-price profiles

(a) age-price profile

(b) estimated $\hat{\beta}_a$

normalized age-price profile,

$$\frac{\hat{p}_{a,c}}{\hat{p}_{1,c}} = \frac{(\hat{\gamma}_c + \hat{\theta}_1 \hat{\beta}_{a,c}a + \hat{\theta}_1 \frac{X}{\hat{\theta}_2} - \hat{\beta}_a + 1) \frac{1}{\hat{\theta}_1}}{\hat{p}_{1,c}}$$

Additional controls

Elasticities
Prices
Basic set up

- Continuum of homogeneous farms.
- CRS technology in land, capital and labor.

\[ y_t = \left( \sum_{j \in A_t} q_j k_{j,t} \right)^{\alpha_k} l_t^{\alpha_l} n_t^{\alpha_n}. \]

- Continuum of households, consume and accumulate capital of different vintages.
- Available vintages in the world evolve at rate \( \bar{\mu} \).
Basic set up

- Continuum of homogeneous farms.
- CRS technology in land, capital and labor.

\[ y_t = \left( \sum_{j \in A_t} q_j k_{j,t} \right)^{\alpha_k} l_t^{\alpha_l} n_t^{\alpha_n}. \]

- Continuum of households, consume and accumulate capital of different vintages.
- Available vintages in the world evolve at rate \( \bar{\mu} \).
- To adopt a new vintage there is a country specific cost,

\[ C(q_j, q_{\bar{j}}, \mu) = \begin{cases} 
\frac{q_j}{q_{\bar{j}}} \left( \frac{1+\tau}{1+\bar{\mu}} \right) & \text{if } q_j > q_{\bar{j}}, \\
1 & \text{otherwise}.
\end{cases} \]

- Households rent capital to farms in spot markets.
Prices of new and old equipment

Vintage $j$: $(q_j, a_j)$, $a$ is age

<table>
<thead>
<tr>
<th>Vintage</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t+$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>... 3</td>
</tr>
<tr>
<td>$(q_5, 0)$</td>
<td></td>
</tr>
<tr>
<td>$(q_4, 0)$</td>
<td>$(q_4, 1)$</td>
</tr>
<tr>
<td>$(q_3, 0)$</td>
<td>$(q_3, 1)$</td>
</tr>
<tr>
<td>$(q_2, 1)$</td>
<td>$(q_2, 2)$</td>
</tr>
<tr>
<td>$(q_1, 2)$</td>
<td></td>
</tr>
</tbody>
</table>
Prices of durables

• The price of a tractor of quality $q_j$

$$p_{j,t}(0) = \frac{q_j}{q_{j_t}} \frac{\hat{\Gamma}_t}{1 - \hat{\psi}}$$

• Return $p/\text{efficiency unit}$ $\sim \hat{\Gamma}_t = \alpha_k \frac{y_t}{\hat{q} \delta k}$

• Discounting $\hat{\psi} = \omega \left(\frac{1}{1+\mu}\right)^{1-\alpha_k}$

where $\mu$ is endogenous quality growth.

• Key assumptions:
  • perfect substitutability.
  • separable quality and quantity.

Prices of new and old equipment

Longitudinal age-price profiles
Prices of new and old equipment

• The price of a new tractor at time $t$ of quality $q_j$

$$p_{j,t}(0) = \frac{q_j \hat{\Gamma}_t}{q_{j_t} 1 - \hat{\psi}}$$

• The price of the same tractor $a$ years later

$$\ln(p_{j_{t+a}(a)}) = \text{age} \ln\left( \frac{1 - \delta}{(1 + \mu)^{1 - \alpha_k}} \right) + \ln(p_{j_i,t}(0))$$

**inv. spec. tech. change**
Prices of new and old equipment

Cross-sectional age-price profiles

<table>
<thead>
<tr>
<th>Vintage</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t+</td>
</tr>
<tr>
<td></td>
<td>...</td>
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<tr>
<td></td>
<td>3</td>
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<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>...</td>
</tr>
</tbody>
</table>

- (q₅, 0)
- (q₄, 0), (q₄, 1)
- (q₃, 0), (q₃, 1), (q₃, 2)
- (q₂, 1), (q₂, 2)
- (q₁, 2)
Prices of new and old equipment

- The price of a new tractor at time $t$ of quality $q_j$

$$p_{j,t}(0) = \frac{q_j}{q_j^*} \frac{\hat{\Gamma}_t}{1 - \hat{\psi}}$$

- The price of the same tractor $a$ years later

$$\ln(p_{\bar{j},t+a}(a)) = \text{age} \ln \left( \frac{(1 - \delta)}{(1 + \mu)^{1-\alpha_k}} \right) + \ln(p_{\bar{j},t}(0))$$

- Age-price profiles in a cross-section (+ BGP)

$$\ln(p_{\bar{j},t-a}(a)) = \text{age} \ln \left( \frac{(1 - \delta)}{(1 + \mu)} \right) + \ln(p_{\bar{j},t}(0))$$
Identification
Main relationship for identification

\[
\ln p_c \ (\text{age}) = \text{age} \ \ln \left( \frac{1 - \delta_c}{1 + \mu_c} \right) + \ln \left( \frac{\Gamma_c}{1 - \psi_c} \right)
\]

for: \( \psi_c = \frac{\omega}{(1 + \mu_c)^{1 - \alpha_k}} < 1, \) and \( \Gamma_c \simeq \alpha_{k_c} \frac{y(q_{jt,c})}{(\hat{q}_c \delta \hat{k}_c)} \)

- Country-specific path of capital quality: \( \mu \) and \( q_{jt} \)
Identification: adoption rate

\[
\ln p_{c,i}(\text{age}) = \text{age}_i \ln \left( \frac{1 - \delta_c}{1 + \mu_c} \right) + \ln \left( \frac{\Gamma_c}{1 - \psi_c} \right) + \gamma \frac{X_i^{\theta} - 1}{\theta_2} + \epsilon_i
\]

for: \( \psi_c = \frac{\omega}{(1 + \mu_c)^{1-\alpha_k}} < 1 \), and \( \Gamma_c \simeq \alpha_k \frac{y(q_{j_t,c})}{\hat{q}_c \hat{\delta}_c \hat{k}_c} \)

• Country-specific path of capital quality: \( \mu \) and \( q_{j_t} \)
• Identify \( \mu \) given \( \delta_c \)
  • measure \( \delta_c \) from the price decay of a synthetic piece of equipment with hours of usage
Inferred quality improvement, $\mu$

![Graph showing inferred quality improvement](image)
Identification: average quality

\[
\ln p_{c,i}(\text{age}) = \text{age}_i \ln \left( \frac{1 - \delta_c}{1 + \mu_c} \right) + \ln \left( \frac{\Gamma_c}{1 - \psi_c} \right) + \gamma \frac{X_i^\theta - 1}{\theta_2} + \epsilon_i
\]

for: \( \psi_c = \frac{\omega}{(1 + \mu_c)^{1 - \alpha_k}} < 1 \), and \( \Gamma_c \simeq \alpha_k^c \frac{y(q_{jt,c})}{(\hat{q}_c \delta \hat{k}_c)} \)

- Country-specific path of capital quality: \( \mu \) and \( q_{jt} \)
- Identify the top quality \( q_{jt} \) given USDA-ERS data for
  - factor shares, \( \alpha_k, \alpha_l \) and \( \alpha_n \)
  - endowments of land per worker \( \tilde{l} \)
Inferred average quality, $q_{jt} \times \hat{q}$
Model predictions and the data

• Quality improvement as inferred from the equipment price time series (Krusell et.al. (2000)) for the US,

\[
\Delta \left( \frac{p_{con}}{p_{inv}} \right) \left( \frac{1}{1 - \alpha_k} \right) \simeq 1.2\%, \quad \text{if tractors only} \quad \simeq 2.5\%
\]

\[
\mu = 2.3\%
\]

• Data and model-predicted steady state capital stocks,

\[
\rho(k_{data}, k_{model}) = 0.58
\]
Accounting exercises
Accounting exercises

What is the role of capital embodied technology adoption for agricultural productivity?

1. Growth accounting exercise
   - cross-country disparities in productivity growth between 1990 and 2012.
   - on average, capital quality explains 26% of productivity growth.

2. Development accounting exercise
   - cross-country disparities in value added per worker in 2012
   - capital quality explains 38% of differences in agricultural income per worker.
Conclusion

• We use a cross-section of second-hand prices to identify adoption patterns of capital-embodied technology.

• Age-price profiles are steeper in richer countries.

• Disparities in quality adoption patterns are quantitatively relevant for the path of agricultural productivity.
Conclusion

• We use a cross-section of second-hand prices to identify adoption patterns of capital-embodied technology.

  The same methodology can be applied to other capital goods for which catalog data is available.

• Age-price profiles are steeper in richer countries.

  Characteristics of second hand markets?

• Disparities in quality adoption patterns are quantitatively relevant for the path of agricultural productivity.

  Feedbacks between human capital and capital embodied technology adoption?
Growth accounting

• Growth in TFP:

\[ g_{TFP,c} = \alpha_{k,c} g_{q,c} + g_{Res,c} \]

• Fraction of \( g_{TFP} \) explained by capital quality

\[ \frac{\alpha_{k,c} \mu_{q,c}}{g_{TFP,c}} \]

• Capital quality explains 26% of productivity growth
• Larger role in richer, more capital intensive, countries.
  • 1/3 in US, Canada and France
  • 1/10 in Brazil
Quality improvement, % of TFP growth

agri. productivity growth explained by capital quality, %

AUSBGR
BRA
CAN
ESP
FRA
GBR
DEU
ITA
MEX
NLD
SWE USA

agricultural VA in 2012, US=1 (data)

Back
Development accounting

• How much of the cross-country agricultural income differences are accounted for by ...?
Development accounting

• How much of the cross-country agricultural income differences are accounted for by ...?
  • Model:
    \[ S^2(\tilde{y}_{2012}, \tilde{y}^d_{2012}) = 87\% \]
    \[ S^2 = 1 - \frac{(x - \hat{x})'(x - \hat{x})}{x'x} \]
Development accounting

• How much of the cross-country agricultural income differences are accounted for by ...?
  • Model:
    \[ S^2(\tilde{y}_{2012}, \tilde{y}^d_{2012}) = 87\% \]

• Average capital quality:
  \[ S^2(\tilde{y}_{2012}, \tilde{y}^d_{2012}) - S^2(\tilde{y}_{2012}|q_j\hat{q} = 1), \tilde{y}^d_{2012} = 38\%. \]

\[ S^2 = 1 - \frac{(x - \hat{x})'(x - \hat{x})}{x'x} \]
Age-price profiles
Controls for observable characteristics
• Measure of quality: R&D content in imports and local production.

\[ \rho(q_j \hat{q}, q_{R&D}) = 0.52 \]

• Both measures generate analogous ranking of countries by quality.

• Disparities in quality are larger under our benchmark measure.
Age-price profiles
Price age elasticity across countries

Relative price, with (black) and without (blue) controls for characteristics
Notation and basic set up

- **CRS technology**

$$y_t = \left( \sum_{j \in A_t} q_j k_{j,t} \right)^{\alpha_k} l_t^{\alpha_l} n_t^{\alpha_n}$$

- $A_t = \left[ j_t, \tilde{j}_t \right]$: set of vintages currently used in production.
- Capital services for the stock of vintage $j$ at time $t$.

$$q_j k_{j,t}$$

- $k_{j,t}$ units of capital of vintage $j$ at time $t$.
- $q_j$ quality/efficiency of vintage $j$.
- Depreciation rate $\delta$.
- Vintage retirement rate $\lambda$.

- Costly adoption, $C\left( \frac{q_j}{q_{j,t}}, \tau \right)$ country specific cost $\tau$. 

Along the BGP

• Effective adoption rate in each country is

$$\mu(\tau) = \frac{1 + \bar{\mu}}{1 + \tau}$$

where $\bar{\mu}$ is the frontier rate.

• Capital services in terms of the best technology adoption $q_{\tilde{j}_t}$

$$\sum_{j \in A_t} q_j k_{j,t} = q_{\tilde{j}_t} \hat{\delta}(\delta, \lambda) k $$

where $\hat{\delta}(\delta, \lambda)$ is the effective retirement rate.
Quantitative exercise
Estimated age-price profiles

Coefficients on age

Country-specific intercepts
Main relationship for identification

**Table: Inferred physical depreciation**

<table>
<thead>
<tr>
<th>Physical depreciation: $\delta$</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AUS</td>
<td>2.35%</td>
</tr>
<tr>
<td>BGR</td>
<td>2.62%</td>
</tr>
<tr>
<td>BRA</td>
<td>2.59%</td>
</tr>
<tr>
<td>CAN</td>
<td>2.20%</td>
</tr>
<tr>
<td>ESP</td>
<td>2.40%</td>
</tr>
<tr>
<td>FRA</td>
<td>2.31%</td>
</tr>
<tr>
<td>GBR</td>
<td>2.40%</td>
</tr>
<tr>
<td>DEU</td>
<td>2.40%</td>
</tr>
<tr>
<td>ITA</td>
<td>2.28%</td>
</tr>
<tr>
<td>MEX</td>
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<td>2.32%</td>
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<tr>
<td>SWE</td>
<td>2.26%</td>
</tr>
<tr>
<td>USA</td>
<td>2.18%</td>
</tr>
</tbody>
</table>
Inferred quality improvement

corr: -0.31

quality growth, % (model)

agricultural TFP growth, %, 1990-2012 (data)
Model predictions and the data

Capital stock

![Graph showing model predictions and data for capital stock across different countries. The x-axis represents the number of tractors per worker, US=1 (data), and the y-axis represents steady state capital, US=1 (model). The graph includes points for various countries such as AUS, BGR, BRA, CAN, ESP, FRA, DEU, SWE, USA, MEX, NLD, GBR, and ITA. The blue line indicates the trend.]
Quantitative exercise
Production shares

<table>
<thead>
<tr>
<th>Country</th>
<th>$\alpha_n$</th>
<th>$\alpha_l$</th>
<th>$\alpha_k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUS</td>
<td>18%</td>
<td>68%</td>
<td>14%</td>
</tr>
<tr>
<td>BGR</td>
<td>31%</td>
<td>56%</td>
<td>14%</td>
</tr>
<tr>
<td>BRA</td>
<td>57%</td>
<td>26%</td>
<td>17%</td>
</tr>
<tr>
<td>CAN</td>
<td>72%</td>
<td>4%</td>
<td>24%</td>
</tr>
<tr>
<td>ESP</td>
<td>70%</td>
<td>15%</td>
<td>15%</td>
</tr>
<tr>
<td>FRA</td>
<td>61%</td>
<td>15%</td>
<td>24%</td>
</tr>
<tr>
<td>GBR</td>
<td>32%</td>
<td>31%</td>
<td>37%</td>
</tr>
<tr>
<td>DEU</td>
<td>61%</td>
<td>15%</td>
<td>24%</td>
</tr>
<tr>
<td>ITA</td>
<td>70%</td>
<td>15%</td>
<td>15%</td>
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<tr>
<td>MEX</td>
<td>24%</td>
<td>42%</td>
<td>34%</td>
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<tr>
<td>NLD</td>
<td>61%</td>
<td>15%</td>
<td>24%</td>
</tr>
<tr>
<td>SWE</td>
<td>61%</td>
<td>15%</td>
<td>24%</td>
</tr>
<tr>
<td>USA</td>
<td>38%</td>
<td>37%</td>
<td>25%</td>
</tr>
</tbody>
</table>
Inferred top quality
Age distribution

![Age distribution diagram](chart.png)
Age distribution

USA

Density

0  0.05  0.1  0.15

0  5  10  15  20

age
Age distribution

The diagram shows the age distribution for a group labeled 'BRA', with the x-axis representing age and the y-axis representing density. The distribution peaks around the age of 10.
Age distribution

![Age distribution chart](chart.png)
Age distribution