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Accounting for Latent Cropping Management Practices Choices in Crop Production Models: a Random Parameter Hidden Markov Model Approach

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Outline

From the economist point of view on pesticide reduction...

- **Pesticides** are still **abundant** in the European agriculture despite a long-known **pesticide noxiousness** (*e.g.*, Pimentel and Greiner, 1997; Pimentel et al., 1992; Wilson, 1999) ;
- European Directive 2009/128/EC: EU members have to implement **National Action Plans** (NAP) to **reduce** their **pesticide use** ;
- **Pesticide taxation** scheme:
  - Standard economists' answer to **negative externality** (*e.g.*, Aubertot et al., 2005; Lichtenberg, 2004) ;
  - **Limited impact** in Norway, Denmark, Sweden and France (Böcker and Finger, 2016) ;
  - **Low pesticide demand elasticity** (*e.g.*, Böcker and Finger, 2017; Skevas et al., 2013).

...to the agronomist point of view

Cropping management practices (CMP) = *ordered sequence of yield production decisions made by the farmer along the crop season to achieve a targeted yield.*

- Farmers cropping decisions are a **coherent set** ;
- In a given set of CMP, **only small adjustments** of input use are possible ;
- Pesticides are the **keystone** of **conventional practices** (Aubertot et al., 2007).

Pesticide reduction requires a **change in CMP practices** towards low-input production practices → we need to **account for CMPs** in economists' production functions.

An application to the case of French winter wheat producers

- Cost accounting data on **1351 farmers** from 1998 to 2014 situated in la Marne area ;
- Data on observed **yields** and **wheat prices**, on **pesticide and fertilizer expenditures** ;
- No information on cropping management practices $\Rightarrow$ **latent CMPs**.

A double objective:

- **Uncover CMPs**, their characteristics and adoption ;
- Investigate into **policies** to encourage the **adoption of low-input** practices.

A brief literature review

- An abundant literature on **technology adoption**:
  - **Heterogeneous economic returns** (*e.g.*, Griliches, 1957; Michler et al., 2018; Suri, 2011) ;
  - Adoption as a **social process**: information exchanges (*e.g.*, Foster and Rosenzweig, 2010; Ryan and Gross, 1943), imitation (*e.g.*, Rogers, 1962) ;
  - Other factors as technical efficiency (*e.g.*, Kumbhakar et al., 2009), labour-constraints (*e.g.*, Fernandez-Cornejo et al., 2005), risk & uncertainty (*e.g.*, Chavas and Nauges, 2020), **social concerns** (*e.g.*, Mzoughi, 2011).
- A literature on **latent class stochastic frontier models** (Alvarez and Corral, 2010; Dakpo et al., 2021; Greene, 2005; Martinez Cillero et al., 2018; Orea and Kumbhakar, 2004).

Outline

A parametric approach to uncover farmers' CMP choice

- Model for **latent** wheat yield (y) and input uses (x_k, $k \in \{1, ..., K\}$) levels:

$$\text{For } c \in \{1, ..., C\}, \begin{cases} y_{it}^c = b_{y,i}^c + d_{y,t,0} + \boldsymbol{\delta}'_{y,0} \boldsymbol{z}_{it} + \varepsilon_{y,it}^c \\ \boldsymbol{x}_{it}^c = \boldsymbol{b}_{x,i}^c + \boldsymbol{d}_{x,t,0} + \boldsymbol{\Delta}_{x,0} \boldsymbol{z}_{it} + \boldsymbol{\varepsilon}_{x,it}^c \end{cases} ;$$

i = farmer index, t = time index, c = CMP index

- $(b_{y,i}^c, \boldsymbol{b}_{x,i}^c)$ are **random terms** accounting for CMP effects ;
- A **decreasing intensity parametrization**:

$$\text{For } c \in \{2, ..., C\}, \; b_{y,i}^c = b_{y,i}^1 \prod_{d=2}^{c} a_{y,i}^d ,$$

with $b_{y,i}^1 \geq 0$ the targeted yield of the most intensive CMP, and $\forall c > 1$, $a_{y,i}^c \in [0, 1]$.

A Markov model to describe the dynamics of CMP choice

- **No sunk costs** as for an investment choice as irrigation technology $\rightarrow$ **easy to switch** ;
- Intangible **learning** and **opportunity costs** $\rightarrow$ farmers tend to **keep the same CMP** across year ;
- **Probability** for farmer i at time t **to choose CMP** d given that previous CMP was c:

$$\frac{\exp\left(\rho_i(\pi_{it}^{d} - \mu_i^{d|c})\right)}{\sum_{k \in C} \exp\left(\rho_i(\pi_{it}^{k} - \mu_i^{k|c})\right)},$$

with $\pi_{it}^{c} = w_{y,t-1} b_{y,i}^{c} - \mathrm{w'}_{x,t} \mathrm{b}_{x,i}^{c} + \eta_{it}$;

π_{it}^{d} represents the **expected return** of CMP d, $\mu_i^{d|c}$ represents **farm-specific switching costs**.

Outline

Agronomic characteristics of the three uncovered CMPs

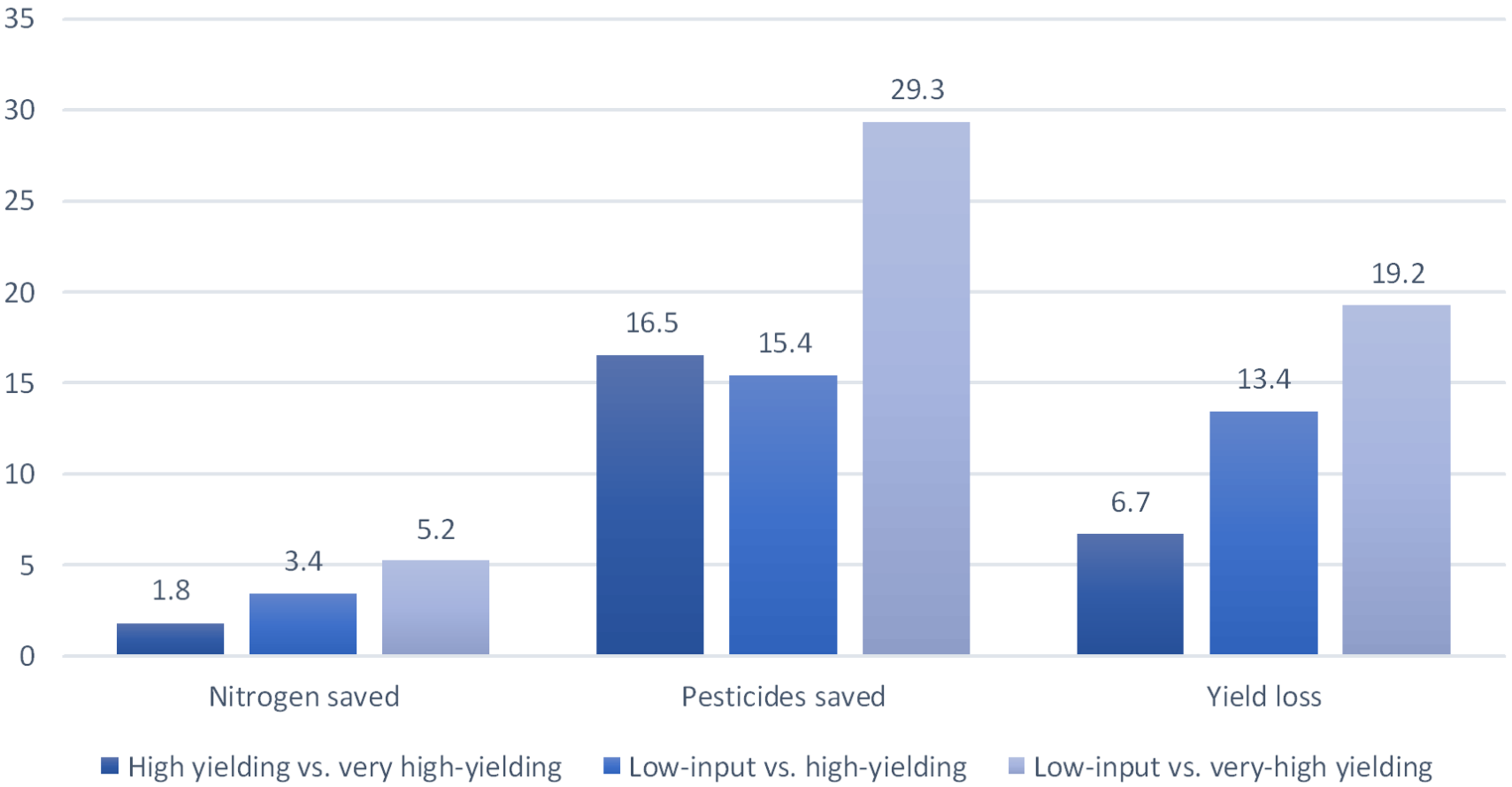

Figure: Mean input uses and yield differences in percentage across CMPs, north eastern France, 1999-2014

Economic characteristics of the three uncovered CMPs

Figure: Estimated annual mean expected return per CMP type, north eastern France, 1999–2014

Expected return variations are mainly attributed to wheat price variations

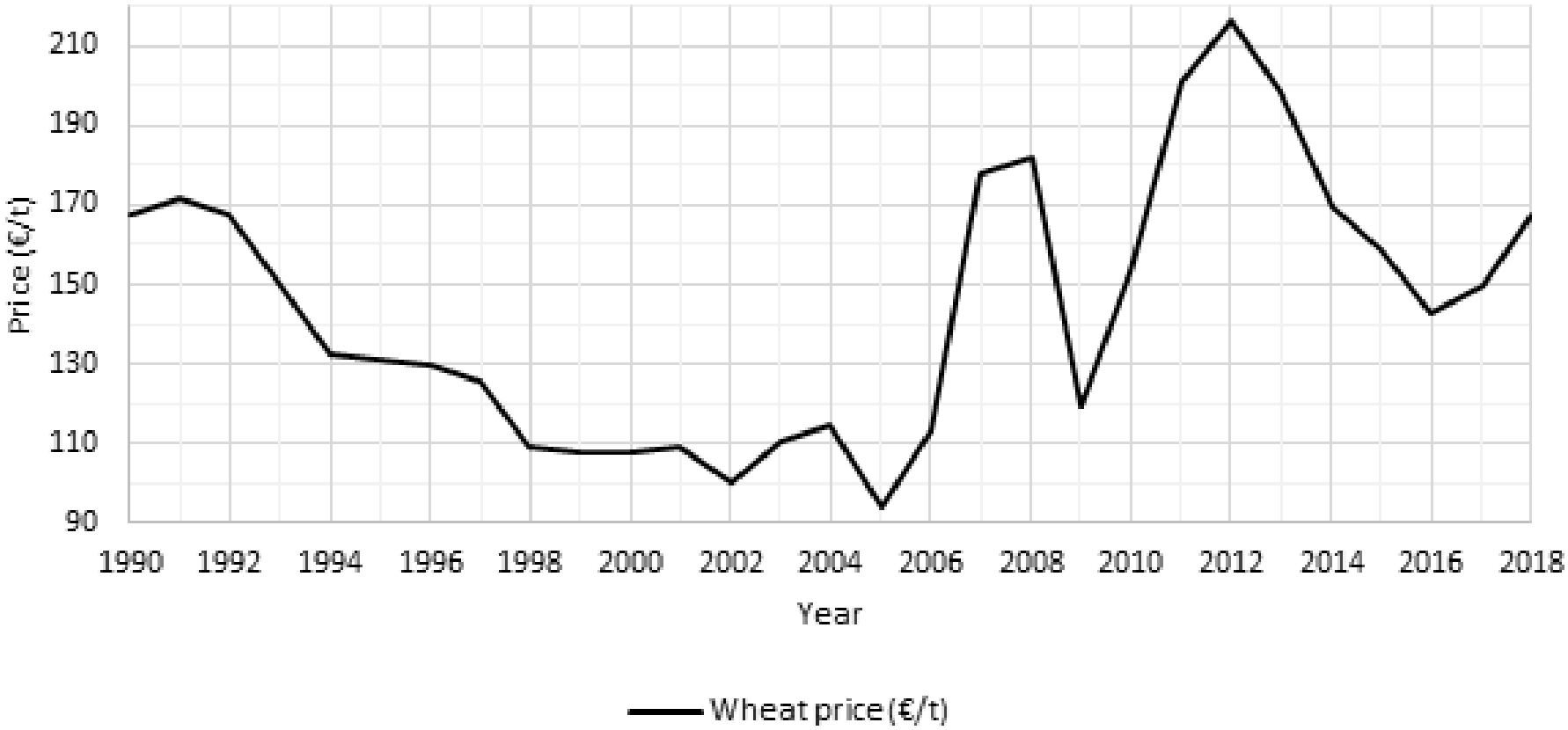

Figure: Wheat annual prices, France, 1999-2014

Adoption of low-input CMP driven by non-economic factors

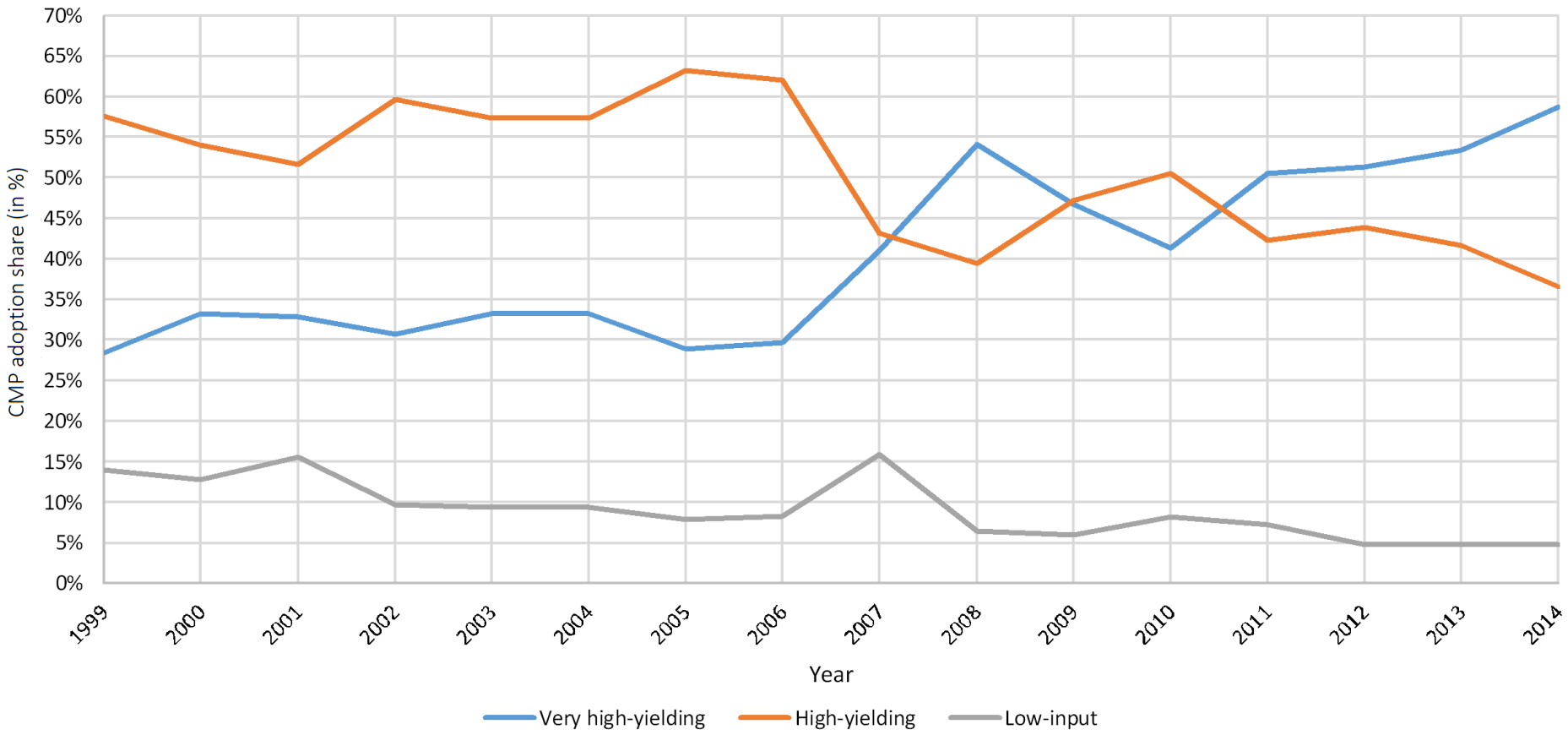

Figure: Estimated annual share of farmers per CMP type, north eastern France, 1999-2014

Impact of a 100% chemical inputs tax on CMP adoption

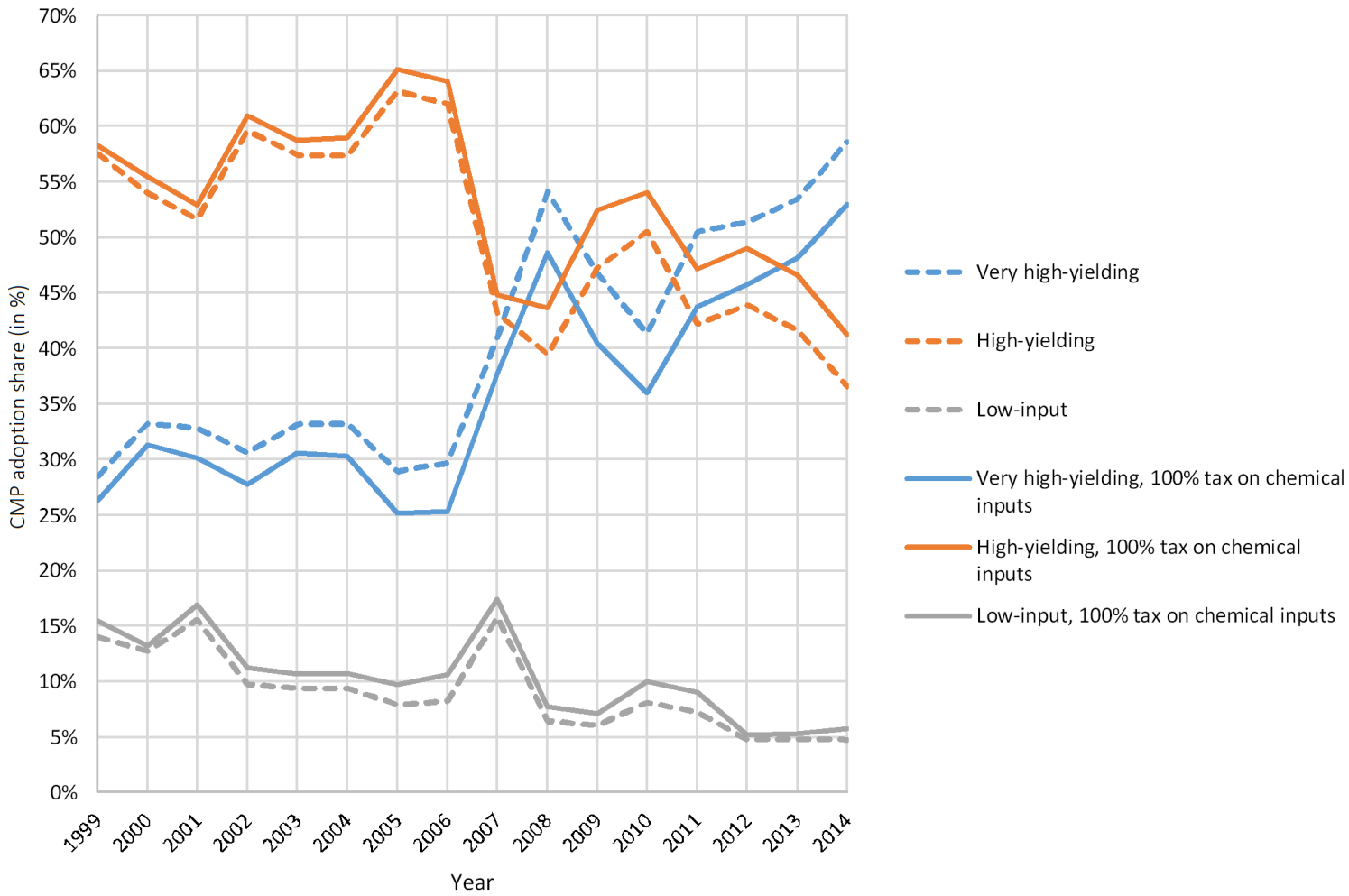

Figure: Mean annual change in the CMP adoption share after simulating a 100% tax on chemical inputs, north eastern France, 1999-2014

Outline

Main results and potential extensions

- Uncovered CMPs have similar characteristics to **agronomists' CMPs** (Loyce et al., 2012; Rolland et al., 2003) ;
- Compared to the **revenue loss** associated to yield losses, the **input savings** are **too small** so that a taxation scheme encourage low-input adoption ;
- **Investigate** into the **non-economic motives** that are impacting low-input adoption to design **more efficient public policies**.

Supplementary material

Sketch of the estimation procedure

- A **fully parametric** **random parameter hidden Markov model**
  Maximum Likelihood Stochastic Approximation of Expectation-Maximization

  $\Rightarrow$ **SAEM** algorithm (Delyon et al., 1999) ;

- **Hidden Markov model** consists in solving "three basic problems" (Lavielle, 2018; Rabiner, 1989):
  1. **Training** problem: estimate the vector of model parameters to maximize the likelihood ;
  2. **Evaluation** problem: evaluate the likelihood of the data given the model $\Rightarrow$ **Forward-Backward** algorithm ;
  3. **Decoding** problem: estimate the most probable sequence of hidden state corresponding to the observed data $\Rightarrow$ **Viterbi** algorithm.

Annual mean yields for the three CMP categories

Figure: Annual mean yield per CMP type, north eastern France, 1999-2014

Annual mean nitrogen use for the three CMP categories

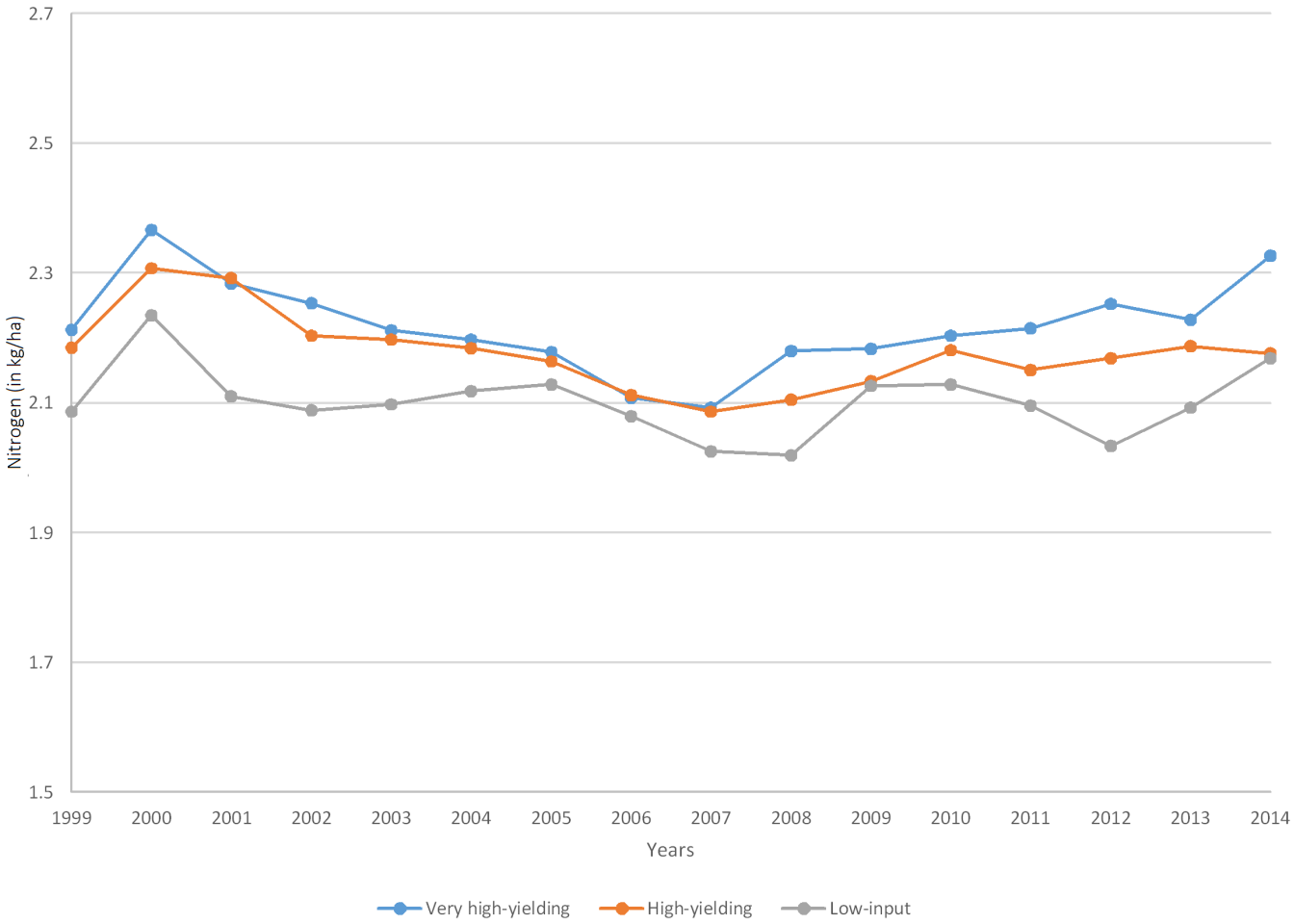

Figure: Annual mean nitrogen use per CMP type, north eastern France, 1999-2014

Annual mean pesticide use for the three CMP categories

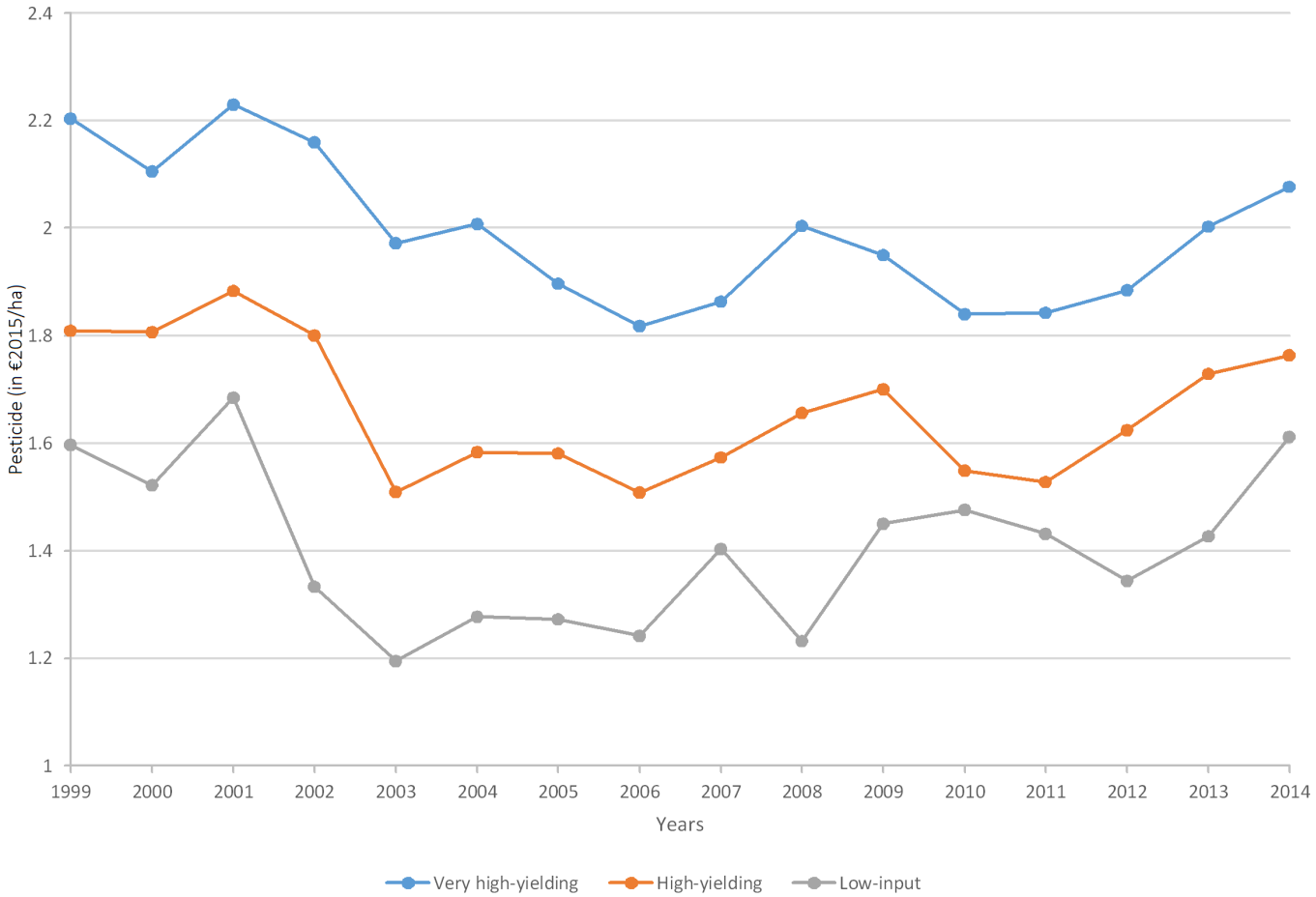

Figure: Annual mean pesticide use per CMP type, north eastern France, 1999-2014

Simulation results: a 10% price premium

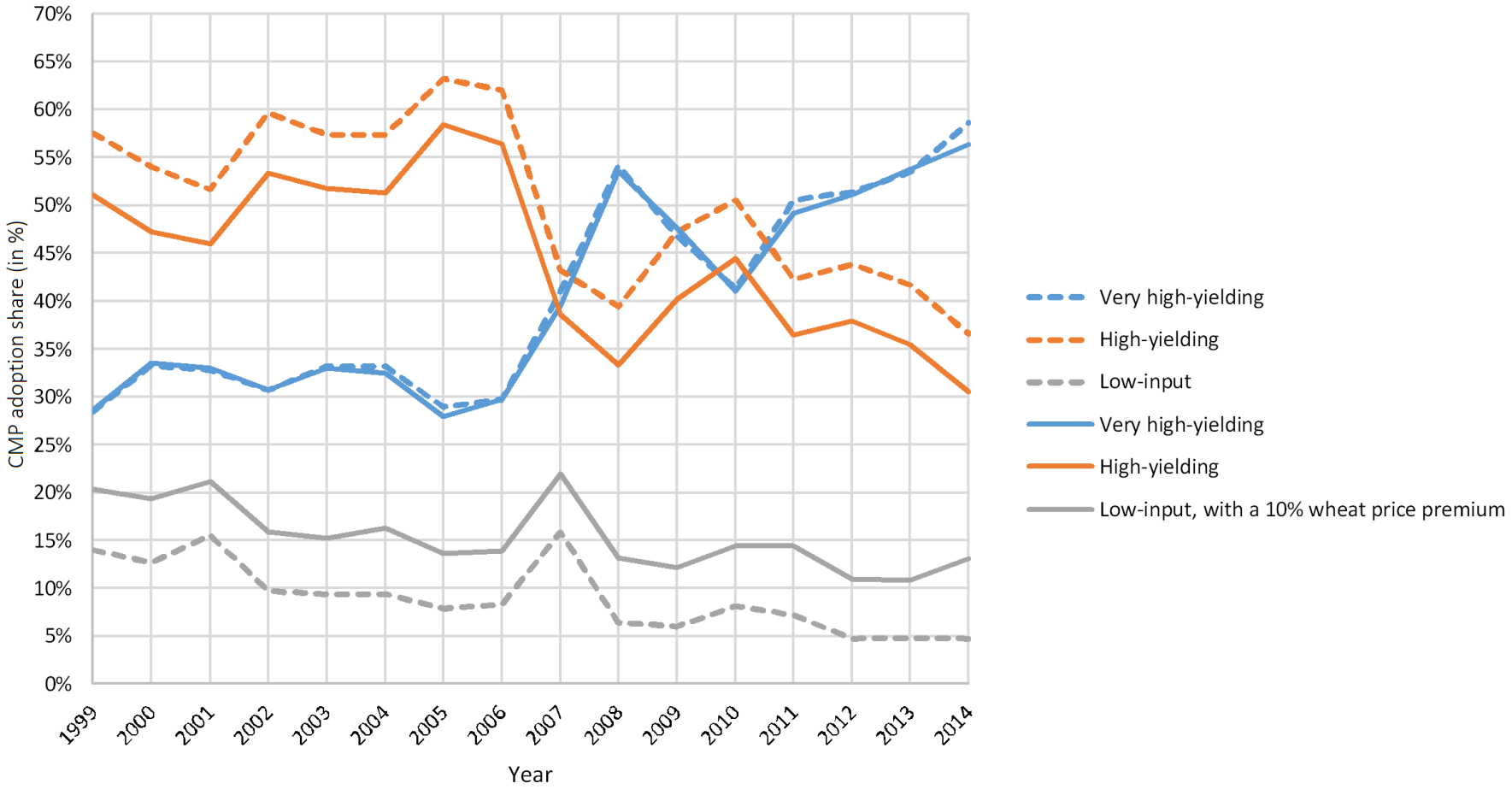

Figure: Mean annual change in the CMP adoption share after simulating a 10% premium on wheat prices, north eastern France, 1999-2014

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