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# Estimating crop rotation effects with farm accountancy panel data

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# Motivations

- Crop rotations : sequences of crops grown on a plot

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- Measurements of the effects of crop rotations on yields and input uses
  - Design of chemical input saving agricultural production systems
  - Essential information for agri-environmental policies

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- Measurements of the effects of crop rotations on yields and input uses
  - Design of chemical input saving agricultural production systems
  - Essential information for agri-environmental policies
- Crop rotation effects rarely quantified
  - Only available for a few pairs of major crops in specific area (Meynard et al, 2013)
  - Cost of suitable experiments

## Our contribution

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- Objective : Simultaneous estimation of unobserved crop sequence acreages and crop rotation effects
- Original approach based on :
  - Statistical models of yield and input uses at the crop sequence level
  - Mathematical programming equilibrium constraints (MPEC) problem
  - Use of expert knowledge information to guide the estimation

# Modeling the effects of crop rotations on yield and input use levels

- Assumptions
  - Farmers mostly account for crop rotation effects of order 1
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$$x_{j,k,it} = \alpha_{j,k,i}^x + \beta_{j,k,t}^x + \sum_{m \in K_{i,t-1}} z_{mk,it} \delta_{j,mk}^x + \epsilon_{j,k,it}^x$$

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$\delta_{j,mk}^x$  : impact of preceding crop m on input use for crop k

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- Gross margin of crop  $k$  grown after crop  $m$

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- Constraint 1 : Acreage share constraints

$$\sum_{m \in K_{it-1}} z_{mk,it} = 1, \forall k \in K_{it}$$

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$$\sum_{m \in K_{i,t-1}} z_{mk,it} = 1, \forall k \in K_{i,t}$$

- Constraint 2 : Total demand for  $m$  as preceding crop equals acreage of  $m$  at previous period

$$\sum_{k \in K_{i,t}} z_{mk,it} a_{k,it} = a_{m,it-1}, \forall m \in K_{i,t-1}$$

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- Perturbation of the problem with entropic perturbation (Fang et al. 1997)
- Unique optimal solution, smooth in its parameters

$$z_{mk,it}^*(\delta; \mu_{it}) = \frac{\exp(\pi_{mk,it}(\delta) - \mu_{m,it})^\rho}{\sum_{n \in K_{i,t-1}} \exp(\pi_{nk,it}(\delta) - \mu_{n,it})^\rho}$$

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- $\mu_{it}$  : Lagrange multipliers associated to Constraint 2

$$\sum_{k \in K_{i,t}} z_{mk,it} a_{k,it} = a_{m,it-1}, \forall m \in K_{i,t-1}$$

# Estimating crop rotation effects as solutions to a smooth MPEC problem



# Estimating crop rotation effects as solutions to a smooth MPEC problem

$$\min_{\alpha\beta\delta\mu} \left\{ \begin{array}{l} \sum_t \sum_i \sum_{k \in K_{it}} (\epsilon_{k,it}^y)^2 + \sum_t \sum_i \sum_{k \in K_{it}} \sum_j (\epsilon_{jk,it}^x)^2 \\ \text{s.t.} \\ y_{k,it} = \alpha_{k,i}^y + \beta_{k,t}^y + \sum_{m \in K_{i,t-1}} z_{mk,it}^* \delta_{mk}^y + \epsilon_{k,it}^y \\ x_{j,k,it} = \alpha_{j,k,i}^x + \beta_{j,k,t}^x + \sum_{m \in K_{i,t-1}} z_{mk,it}^* \delta_{j,mk}^x + \epsilon_{j,k,it}^x \end{array} \right.$$

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 \text{s.t.} \\
 y_{k,it} = \alpha_{k,i}^y + \beta_{k,t}^y + \sum_{m \in K_{i,t-1}} z_{mk,it}^* \delta_{mk}^y + \epsilon_{k,it}^y \\
 x_{j,k,it} = \alpha_{j,k,i}^x + \beta_{j,k,t}^x + \sum_{m \in K_{i,t-1}} z_{mk,it}^* \delta_{j,mk}^x + \epsilon_{j,k,it}^x \\
 z_{mk,it}^*(\delta; \mu_{it}) = \frac{\exp(\pi_{mk,it}(\delta) - \mu_{m,it})^\rho}{\sum_{n \in K_{i,t-1}} \exp(\pi_{nk,it}(\delta) - \mu_{n,it})^\rho} \\
 \sum_{k \in K_{i,t}} z_{mk,it}^* a_{k,it} = a_{m,it-1}, \forall m \in K_{i,t-1}^{-r}; \mu_{r,i,t} = 0
 \end{array} \right.$$

# Data

- Accounting data : 378 French farms specialized in grain production in the north of France, 2008-2014
- Unbalanced panel data set, at least 4 years of observations per farm (6 years on average)

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- Accounting data : 378 French farms specialized in grain production in the north of France, 2008-2014
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- 8 crops representing at least 90% of farms' acreages :
  - Wheat, barley, rapeseed, corn, peas, alfalfa, sugarbeet and potato
- Additional data : information based on expert knowledge
  - Interviews with agricultural scientists
  - Introduced in the optimization program to reduce the number of parameters to be estimated and guide the optimization
  - Impose forbidden crop sequences and ranking of crop rotation effects

## Ranking of the impacts of preceding crops on yields

		Crops							
		wheat	barley	rape-seed	corn	peas	alfalfa	sugar-beet	potato
Preceding crops	wheat	5	2	2	1	1	1	1	1
	barley	6	3	2	1	1	2	1	1
	rapeseed	2	1		1	2		2	3
	corn	4	1		1	2		2	3
	peas	1	3	1	1				3
	alfalfa	1	3		1		1	3	3
	sugarbeet	3	2		2	2		3	3
	potato	3	2					2	2

- 1 : Highest yield, 2 : second highest yield, ...

## Ranking of the impacts of preceding crops on input uses

## ● Fertilizers

		Crops							
		wheat	barley	rape-seed	corn	peas	alfalfa	sugar-beet	potato
Preceding crops	wheat	1	1	1	1	1	1	1	3
	barley	1	1	1	1	1	1	1	3
	rapeseed	2	2		2	1		1	1
	corn	1	1		1	1		1	1
	peas	3	3	2	3				1
	alfalfa	3	3		3		2	2	1
	sugarbeet	2	2		2	1		1	1
	potato	2	2					1	2

- 1 : Highest fertilizer use, 2 : second highest fertilizer use, ...

## Ranking of the impacts of preceding crops on input uses

## ● Pesticides

		Crops							
		wheat	barley	rape-seed	corn	peas	alfalfa	sugar-beet	potato
Preceding crops	wheat	1	1	1	2	1	2	1	3
	barley	1	1	2	2	1	2	1	3
	rapeseed	2	2		2	1		1	1
	corn	2	1		1	1		1	1
	peas	2	2	2	2				1
	alfalfa	2	2		2		1	1	1
	sugarbeet	2	2		2	1		1	1
	potato	2	2					1	2

- 1 : Highest pesticide use, 2 : second highest pesticide use, ...



# Estimated preceding crop acreage shares

- Averages crop sequence acreage shares ( $z_{mk,it}$ )

		Crops							
		wheat	barley	rape- seed	corn	peas	alfalfa	sugar- beet	potato
Preceding crops	wheat	0.23	0.59	0.52	0.49	0.64	0.18	0.61	0.24
	barley	0.02	0.09	0.45	0.06	0.35	0.23	0.24	0.50
	rapeseed	0.35	0.05		0.02	0.00		0.02	0.00
	corn	0.05	0.05		0.41	0.00		0.01	0.01
	peas	0.04	0.00	0.04	0.01				0.00
	alfalfa	0.08	0.01		0.01		0.60	0.00	0.00
	sugarbeet	0.18	0.18		0.01	0.01		0.12	0.07
	potato	0.04	0.04					0.00	0.18

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	corn	0.05	0.05		0.41	0.00		0.01	0.01
	peas	0.04	0.00	0.04	0.01				0.00
	alfalfa	0.08	0.01		0.01		0.60	0.00	0.00
	sugarbeet	0.18	0.18		0.01	0.01		0.12	0.07
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# Estimated crop rotation effects

- Percentage change in yields compared to 'reference' preceding crops ( $\delta_{mk}^y$ )

		Crops							
		wheat	barley	rape-seed	corn	peas	alfalfa	sugar-beet	potato
Preceding crops	wheat	-0.03	ref	ref	ref	ref	ref	ref	ref
	barley	-0.03	0.00	0.00	-0.21	-0.02	-0.12	0.00	0.10
	rapeseed	ref	0.06		-0.21	-		-0.06	-
	corn	-0.03	0.06		-0.10	-		-0.06	0.00
	peas	0.00	-	0.00	-0.19				-
	alfalfa	0.14	0.00		-0.23		-0.12	-	-
	sugarbeet	-0.03	0.06		-0.24	-0.45		0.00	0.00
	potato	-0.03	0.06					-	0.00

# Estimated crop rotation effects

- Percentage change in fertilizer uses compared to 'reference' preceding crops ( $\delta_{j,mk}^x$ )

		Crops							
		wheat	barley	rape-seed	corn	peas	alfalfa	sugar-beet	potato
Preceding crops	wheat	0.00	ref	ref	ref	ref	ref	ref	ref
	barley	0.03	0.02	0.01	-0.03	0.41	-0.15	-0.06	-0.04
	rapeseed	ref	-0.07		-0.10	-		-0.09	-
	corn	0.00	-0.07		-0.10	-		-0.34	0.02
	peas	-0.08	-	-0.10	-0.10				-
	alfalfa	-0.08	-0.07		-0.87		-0.15	-	-
	sugarbeet	-0.08	-0.07		-0.10	12.16		-0.11	0.02
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- Legumes : Increase nitrogen content in soils
- Root crops : positive impact on soil structure
- Cereals : high nitrogen absorption



## Estimated crop rotation effects

- Percentage change in pesticide uses compared to 'reference' preceding crop ( $\delta_{j,mk}^x$ )

		Crops							
		wheat	barley	rape-seed	corn	peas	alfalfa	sugar-beet	potato
Preceding crops	wheat	0.00	ref	ref	ref	ref	ref	ref	ref
	barley	0.00	-	-0.04	0.06	0.07	-0.11	-0.15	3.34
	rapeseed	ref	-0.12		-0.46	-		-0.05	-
	corn	-0.11	-0.01		0.06	-		-0.48	9.82
	peas	-0.02	-0.01	-0.06	-0.66				-
	alfalfa	0.00	-0.01		0.06		0.00	-	-
	sugarbeet	0.00	-0.11		0.06	1.26		-0.19	3.34
	potato	0.00	-0.01					-	3.34

## Conclusion

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  - Cannot be matched directly with our farm accountancy data
  - Indirect matching approach based on crop acreage variables common to both datasets
    - Compare results obtained with and without observed crop sequence acreages
    - Use of better crop sequences references

Thank you