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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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 - Impacts on pest and weed populations and on the structure and nutrient content of soils
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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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 - Impacts on yield levels
- 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

- Estimation of crop rotation effects based on existing economic data sets

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- Estimation of crop rotation effects based on existing economic data sets
- Use of large farm accountancy panel data
 - Yields, acreages and input uses per crop at the farm level
 - But no information on farmers' **crop sequence acreages**
- 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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$z_{mk,it}$: share of crop k grown after crop m

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- Input use equation

$$x_{j,k,it} = \alpha_{j,k,i}^x + \beta_{j,k,t}^x + \sum_{m \in K_{i,t-1}} z_{mk,it} \delta_{j,mk}^x + \epsilon_{j,k,it}^x$$

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$z_{mk,it}$: share of crop k grown after crop m

δ_{mk}^y : impact of preceding crop m on yield of crop k

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

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- Gross margin of crop k grown after crop m

$$\pi_{mk,it} = p_{k,it}(\alpha_{k,i}^y + \delta_{mk}^y) - \sum_j w_{j,k,it}(\alpha_{j,k,i}^x + \delta_{j,mk}^x)$$

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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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- Constraint 1 : Acreage share constraints

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

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

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

Recovering crop sequence acreage choices

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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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- μ_{it} : Lagrange multipliers associated to Constraint 2

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

Estimating crop rotation effects as solutions to a smooth MPEC problem

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

Estimating crop rotation effects as solutions to a smooth MPEC problem

$$\begin{aligned}
 & \min_{\alpha\beta\delta\mu} \left\{ \sum_t \sum_i \sum_{k \in K_{it}} (\epsilon_{k,it}^y)^2 + \sum_t \sum_i \sum_{k \in K_{it}} \sum_j (\epsilon_{jk,it}^x)^2 \right. \\
 & \quad \text{s.t.} \\
 & \quad y_{k,it} = \alpha_{k,i}^y + \beta_{k,t}^y + \sum_{m \in K_{i,t-1}} z_{mk,it}^* \delta_{mk}^y + \epsilon_{k,it}^y \\
 & \quad x_{j,k,it} = \alpha_{j,k,i}^x + \beta_{j,k,t}^x + \sum_{m \in K_{i,t-1}} z_{mk,it}^* \delta_{j,mk}^x + \epsilon_{j,k,it}^x \\
 & \quad z_{mk,it}^* (\delta; \mu_{it}) = \frac{\exp(\pi_{mk,it}(\delta) - \mu_{m,it})^\rho}{\sum_{n \in K_{i,t-1}} \exp(\pi_{nk,it}(\delta) - \mu_{n,it})^\rho} \\
 & \quad \left. \sum_{k \in K_{i,t}} z_{mk,it}^* a_{k,it} = a_{m,it-1}, \forall m \in K_{i,t-1}^{-r}; \mu_{r,i,t} = 0 \right\}
 \end{aligned}$$

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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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)
- 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	1	1	1	1	1	1	1	3
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	1	1	1	2	1	2	1	3
wheat	1	1	2	2	1	2	1	3
barley	2	2	2	2	1	2	1	3
rapeseed	2	1	1	1	1	1	1	1
corn	2	1	1	1	1	1	1	1
peas	2	2	2	2	2	1	1	1
alfalfa	2	2	2	2	1	1	1	1
sugarbeet	2	2	2	2	1	1	1	1
potato	2	2	2	2	1	1	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	0.23	0.59	0.52	0.49	0.64	0.18	0.61	0.24
wheat	0.02	0.09	0.45	0.06	0.35	0.23	0.24	0.50
barley	0.35	0.05		0.02	0.00		0.02	0.00
rapeseed	0.05	0.05		0.41	0.00		0.01	0.01
corn	0.04	0.00	0.04	0.01				0.00
peas	0.08	0.01		0.01		0.60	0.00	0.00
alfalfa	0.18	0.18		0.01	0.01		0.12	0.07
sugarbeet	0.04	0.04					0.00	0.18
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barley	0.35	0.05		0.02	0.00		0.02	0.00
rapeseed	0.05	0.05		0.41	0.00		0.01	0.01
corn	0.04	0.00	0.04	0.01				0.00
peas	0.08	0.01		0.01		0.60	0.00	0.00
alfalfa	0.18	0.18		0.01	0.01		0.12	0.07
sugarbeet	0.04	0.04					0.00	0.18
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- Close to what can be observed at the plot level

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Estimated crop rotation effects

- Percentage change in yields compared to 'reference' preceding crops (δ_{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
	potato	-0.08	-0.07				-		0.02

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	peas	-0.08	-	-0.10	-0.10			-	-
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- Legumes : Increase nitrogen content in soils

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	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	-	-
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- Legumes : Increase nitrogen content in soils
- Root crops : positive impact on soil structure

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	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
	potato	-0.08	-0.07				-		0.02

- 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	

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 - Compare results obtained with and without observed crop sequence acreages
 - Use of better crop sequences references

Thank you