Livestock regulation, land use and greenhouse gas mitigation : an analysis of second-best policies

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- Agricultural emissions : 20-25% of global anthropogenic GHG emissions (Crippa et al. 2021; FAO 2020; Hong et al. 2021)

- Emissions from livestock : 40-45 % of agricultural emissions, half of them from beef production (Herrero et al. 2016; Hong et al. 2021)

- Possible mitigation :

  - at the extensive margin, through a reduction in meat consumption[1] (Hallström et al. 2015; Hayek et al. 2021);

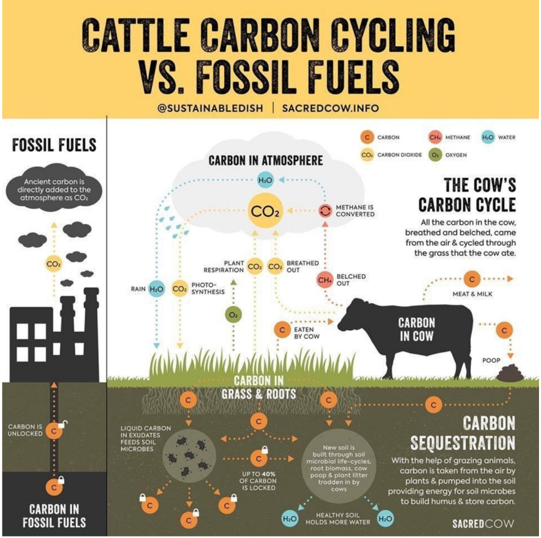
  - at the intensive margin, through a technical adjustment of production (Frank et al. 2018; Havlık et al. 2014; Herrero et al. 2016; Pellerin et al. 2017)

1. without harming human health

What policy instrument best-suited to trigger such changes?

- First-best Pigouvian tax on agricultural emissions hard to implement due to high monitoring, reporting and verification costs (Grosjean et al. 2016)
- Partial coverage of a carbon tax to overcome MRV costs (De Cara et al. 2018)
- Policies based on aggregated emission factors, targeting a specific GHG, or using input taxes (Garnache et al. 2017)
- Output-based instead of emissions based tax (Schmutzler and Goulder 1997)
  $\Rightarrow$ empirical studies on meat tax (Bonnet et al. 2018; Caillavet et al. 2016; Edjabou and Smed 2013)

To give you some intuitions about MRV costs...



Idea

- About half of agricultural emissions related to land use and land use change (LULUC) (FAO 2020; Hong et al. 2021)
- 70% of global agricultural area dedicated to grasslands / 20% of continental land (FAOSTAT)
- potential to sequester carbon in soil and above-ground biomass of spared land
- Regulating land use to reduce GHG emissions through a subsidy rewarding "natural reserves", instead of regulating directly emissions

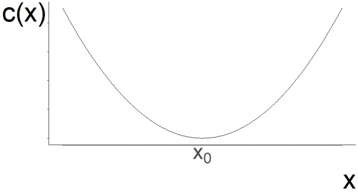
- Stylised partial equilibrium model of the beef sector (perfect competition, price takers)

Demand side :

$$\begin{cases} p \ : \text{consumer price} \\ q : \text{quantity of meat consumed} \\ S(q) \ : \text{gross consumer surplus (positive, increasing and concave)} \\ S'(q) \ : \text{inverse demand} \end{cases}$$

Supply side : cattle feeding as technological choice

$$\begin{cases} x \ : \text{quantity of grass (in kg) per kg of meat} \\ f(x) \ : \text{associated quantity of feed from crops per kg of meat} \\ c(x) \ : \text{unitary production cost} \end{cases}$$



- Minimisation of c(x) by farmers
- market clearing : $p = c(x)$
- Profit of the farming sector (BAU)

$$\Pi^0(p, x) = [p - c(x)]q \qquad (1)$$

Land use

- 3 types of land use : cropland, grasslands and natural reserves.
- Total available land $\bar{L}$ allocated between cropland L_c, grasslands L_g and natural reserves L_n
- $\bar{L} = L_g + L_c + L_n$
- Given x, land requirement per unit of meat is

$$l(x) = \alpha_g x + \alpha_c f(x)$$

  with α_g and α_c the inverse yield of grasslands and cropland
- Thus, $L_g = \alpha_g xq$, $L_c = \alpha_c f(x)q$ and $\bar{L} = L_n + l(x)q$

GHG emissions

- Three sources of emissions :

$$\begin{cases} \text{Direct emissions from beef production } e(x) \\ \text{Emissions from feed crops } e_c \\ \text{Emissions/sequestration from land use } \theta_i,\ i \in \{g, c, n\} \end{cases}$$

- Total emissions :

$$\begin{aligned} E(q,x) &= e(x)q + e_c f(x)q - \theta_g L_g - \theta_c L_c - \theta_n L_n \\ &= q \underbrace{\left[e(x) + e_c f(x) + (\theta_n - \theta_g)\alpha_g x + (\theta_n - \theta_c)\alpha_c f(x)\right]}_{\equiv e_1(x)} - \theta_n \bar{L} \\ &= e_1(x)q - \theta_n \bar{L} \end{aligned}$$

- *Assumption A1* $\theta_n > \theta_g > \theta_c \Rightarrow e_1(x) > 0$
- Linear damage function and marginal damage δ €.kgCO_{2eq}^{-1}
- Global welfare (objective function) :

$$W(q,x) = S(q) - c(x)q - \delta E(q,x) \quad (2)$$

Social optimum

- social optimum : couple (q^*, x^*) maximising the welfare function
- First order conditions : $\begin{cases} S'(q) = c(x) + \delta e_1(x) \\ -c'(x) = \delta e_1'(x) \end{cases}$
- An increase in the social cost of carbon induces :
  - a decrease in q^* ;
  - a decrease in x^* if $e_1'(x) > 0$
- *Assumption A2* :
  $e'(x) > -e_c f'(x)$ and $(\theta_n - \theta_g)\alpha_g > -(\theta_n - \theta_c)\alpha_c f'(x)$
  $\Rightarrow e_1'(x) > 0$

Policy instruments

- An exhaustive tax on carbon emissions τ (First-Best policy)
- A tax on meat t
- A technical standard $\bar{x}$
- A subsidy to natural reserves s

- Farmer profit with all instruments combined :

$$\Pi(x, q, \mathbf{r}) = [p - t - c(x)]q - \tau[e_1(x)q - \theta_n \bar{L}] + s[\bar{L} - (\alpha_g x + \alpha_c f(x))q]$$
$$\text{subject to } x \leq \bar{x}$$

Specifications

- Gross consumer surplus : $S(q) = (a - \frac{b}{2}q)q$
- Production cost : $c(x) = c_0 + \frac{\gamma}{2}(x - x_0)^2$
- Direct emissions: $e(x) = e_0 + \epsilon(x - x_0)$
- feed constraint: $f(x) = f_0 + \phi(x_0 - x)$

First-best and combination of instruments

- Possibility to reach the social optimum with :

  an exhaustive Pigouvian taxes $\tau = \delta$

  a technical standard $\bar{x} = x^*$ and a tax on meat $t = \delta e_1(x^*)$

  a standard $\bar{x} = x^*$ and a natural reserves subsidy s^*, with $s^* = \frac{\delta e_1(x^*)}{l(x^*)}$ [2]

2. It is also possible to set a meat quota at q^*, and to combine it with a standard x^* or a subsidy $s^* = \frac{\delta e_1'}{l'}$

Description of instruments - meat tax

- Effect limited to the extensive margin (by an increase in price)
- Optimal meat tax $t^{SB} = \delta e_1(x_0)$ with :

$$e_1(x_0) = \underbrace{e_0}_{\text{direct emissions}} + \underbrace{e_c f_0}_{\text{feed emissions}} + \underbrace{(\theta_n - \theta_g)\alpha_g x_0 + (\theta_n - \theta_c)\alpha_c f_0}_{\text{carbon opportunity cost of land use}}$$

- Meat tax $>$ optimal net pigouvian tax $\delta e_1(x^*)$
- Under *A2* : $q_t \leq q^*$ and $x_t = x_0 \geq x^*$

Description of instruments - technical standard

- Effect at both the intensive ($\bar{x}$) and extensive margins (increase in the marginal cost)
- $\bar{x}$ stricter than x^*, either $x_0 > x^* > \bar{x}^{SB}$ or $x_0 < x^* < \bar{x}^{SB}$.

  Under *A2*, $x_0 > x^* > \bar{x}^{SB}$

Description of instruments - subsidy

- Effect at both the intensive margin (subsidy as incentive to intensify) and the extensive margin (cost of unitary land requirement)

- Reflected in the first order conditions :

$$\begin{cases} S'(q) = p = c(x) + sl(x) \\ -c'(x) = sl'(x) \end{cases}$$

- Under *A2* and $l'(x) > 0$

$$\begin{cases} \text{If } \ l'/l(x) = e_1'/e_1(x), \text{ then } \ s^{SB} = \frac{\delta e_1(x^*)}{l(x^*)}, x_s^{SB} = x^* \ \text{ and } \ q_s^{SB} = q^* \\ \text{If } \ l'/l(x) < e_1'/e_1(x), \text{ then } \ x_0 > x_s^{SB} > x^* \ \text{ and } \ q_s^{SB} < q^* \\ \text{If } \ l'/l(x) > e_1'/e_1(x), \text{ then } \ x_0 > x^* > x_s^{SB} \end{cases}$$

Equilibrium with the instruments

Instrument	Equilibrium
Pigouvian tax τ	$p = c(x^*) + \tau e_1(x^*)$
Meat tax t	$p = c(x_0) + t$
Subsidy s	$p = c(x_s) + sl(x_s)$
Technical standard $\bar{x}$	$p = c(\bar{x})$

Welfare comparison - Meat tax vs standard

- 2 main parameters at stake : technical flexibility γ and the price elasticity of beef demand [3];
- *Proposition 1. There exists* $\tilde{\gamma} \in \mathbb{R}_+^*$ *such that :*
  $WL_{\bar{x}} \leq WL_t$ *if and only if* $\gamma \leq \tilde{\gamma}$
- *Proposition 2. There exists* $\tilde{a} \in \mathbb{R}_+^*$ *such that :*
  $WL_t \leq WL_{\bar{x}}$ *if and only if* $a \leq \tilde{a}$

3. related to the mitigation cost at the intensive and the extensive margin, respectively

Welfare comparison - Subsidy vs standard

- Relative performance conditioned by the **alignment**[4] between land use and emissions
- Better performance of the subsidy when GHG emissions are relatively inelastic with respect to x
- *Proposition 3. If* $\frac{e_1'}{e_1(x)} \leq \frac{l'}{l(x)-l(0)/2}$*, then* $WL_{\bar{x}} > WL_s$
- Comparison meat tax vs subsidy not achieved

4. measured by $\frac{e_1'}{e_1(x)} - \frac{l'}{l(x)}$. In case of perfect alignment, $\frac{e_1'}{e_1(x)} = \frac{l'}{l(x)}$

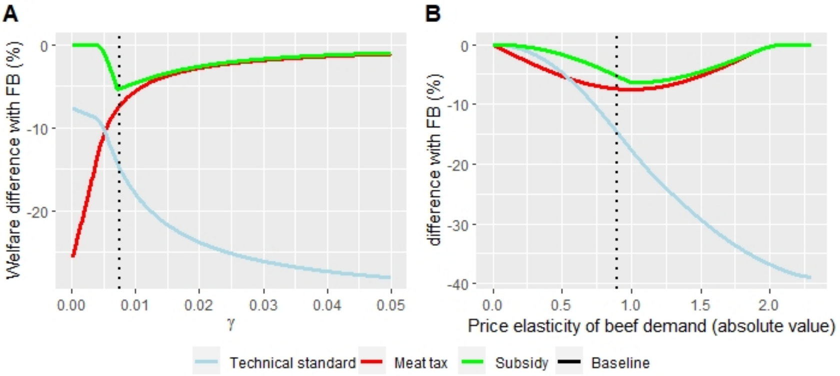
The data

Parameter name	Description (unit)	Value	Source
a	intercept the inverse demand function	8.23	Authors' calculations
b	slope of the inverse demand function	$4.51.10^{-9}$	Authors' calculations
-	own price elasticity of beef demand	-0.90	Gallet (2010)
x_0	initial amount of grass to produce beef (kg DM.kg carcass weight^{-1})	15.00	hypothesis based on data from representative farms provided by the French livestock Institute
f_0	initial amount of feed from crops to produce beef (kg DM.kg carcass weight^{-1})	4.10	Authors' calculations from the value taken by x_0 and f function
γ	technical flexibility of beef production	0.0075	Hypothesis
ϕ	substitution rate between feed from crops and grass	0.08	Author's calculations from the meta-analysis
c_0	initial production cost of beef (€.kg carcass weight^{-1})	3.	hypothesis relying on data from Idele and CNE (2021)
p_0	initial equilibrium price of beef (€.kg carcass weight^{-1})	3.9	hypothesis relying on data from Idele and CNE (2021)
q_0	initial equilibrium quantity of beef (tonnes of carcass weight)	$9.60.10^5$	authors' calculations with data from Idele and CNE (2021) and Agreste (2021)
α_g	reverse grassland yield (ha.tDM^{-1})	0.22	hypothesis relying on data from Agreste (2021)
α_c	reverse crop yield (ha.t DM^{-1})	0.14	hypothesis relying on data from Agreste (2021)
$\overline{L}$	total available land (ha)	$3.76.10^6$	hypothesis relying on data from Agreste (2021), assuming a stocking rate of 1 suckler cow per hectare
ϵ	emission growth rate associated to the amount of grass (kgCO2eq.kg DM^{-1})	0.36	Author's calculations from the meta-analysis
e_0	emission factor of initial beef production, excluding emissions of feed from crops (kgCO2eq.kg carcass weight^{-1})	21.9	Author's calculations from the meta-analysis
e_c	emission factor of feed from crops (kgCO2eq. kgDM $^{-1}$)	0.6	hypothesis based on ECOALIM, database of the Agribalyse program
θ_g	annual carbon storage by grasslands (tCO2eq.ha^{-1})	0.85	Efese (2019) and Pellerin et al. (2020)
θ_c	annual carbon storage by crops (tCO2eq.ha-1)	-0.3	Efese (2019) and Pellerin et al. (2020)
θ_n	annual carbon storage by natural reserves (tCO2eq.ha^{-1})	5	Efese (2019) and Pellerin et al. (2020)
δ	social cost of ghg emissions (€.tCO2eq^{-1})	50	Level of the French carbon tax

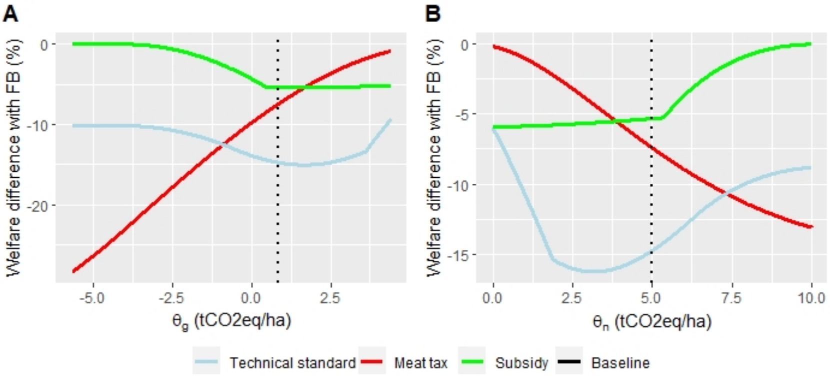
Results of the baseline scenario

	Laissez-faire	First-best	Meat tax	Technical standard	Subsidy
q (kt of carcass)	960.0 (+73.6%)	553.1	502.5 (−9.1%)	837.0 (+51.3%)	734.1 (+32.7%)
x (kg DM grass/ kg carcass)	15.0 (+108.3%)	7.2	15.0 (+108.3%)	2.8(−61.1%)	5.0 (−30.5%)
Price (€.kg^{-1})	3.9 (−32.0%)	5.7	6.0 (+4.0%)	4.5 (−22.3%)	4.9 (−14.2%)
Emissions ($MtCO_{2eq}$)	20.8	-1.0	1.9	3.8	2.9
Welfare (M €)	1038.0 (−36.4%)	1631.3	1510.3 (−7.4%)	1390.4 (−14.8%)	1544.6 (−5.3%)
L_n (thousand ha)	0.4 (−100.0%)	2502.4	1792.0 (−28.4%)	2626.9 (+5.0%)	2429.9 (−2.9%)
L_g (thousand ha)	3196.8 (+261.6%)	884.0	1673.4 (+89.3%)	525.8 (−40.5%)	815.7 (−7.7%)
L_c (thousand ha)	562.8 (50.6%)	373.6	294.6 (−21.1%)	607.2 (+62.5%)	514.4 (+37.7%)

Sensitivity analysis to supply and demand parameters



Sensitivity analysis to land-use emissions parameters



Conclusion

- An analytical and numerical comparison of second best policies to reduce GHG from the livestock sector
- Optimal meat tax should integrate the carbon opportunity cost of land use
- Strong performance of natural reserves, even under imperfect alignment of emissions and land use
- Mitigation at both the intensive and extensive margins with a natural reserves policy

Perspectives

- Effect of altruist behaviour of consumers valuing animal welfare ($p(x)$ increasing in x)
- Policy consequences of imperfect alignment of biodiversity and climate objectives

Thank you!



Références

Agreste. 2021. **Statistique agricole annuelle 2020, chiffres définitifs.** Technical report. Ministère de l'agriculture et de l'alimentation. Accessed January 27, 2022. https://agreste.agriculture.gouv.fr/agreste-web/disaron/Chd2114/detail/.

Bonnet, C., Z. Bouamra-Mechemache, and T. Corre. 2018. An Environmental Tax Towards More Sustainable Food: Empirical Evidence of the Consumption of Animal Products in France. **Ecological Economics** 147:48–61. https://doi.org/10.1016/j.ecolecon.2017.12.032.

Caillavet, F., A. Fadhuile, and V. Nichèle. 2016. Taxing animal-based foods for sustainability: environmental, nutritional and social perspectives in France. **European Review of Agricultural Economics** 43 (4): 537–560. https://doi.org/10.1093/erae/jbv041.

Crippa, M., E. Solazzo, D. Guizzardi, F. Monforti-Ferrario, F. N. Tubiello, and A. Leip. 2021. Food systems are responsible for a third of global anthropogenic GHG emissions. **Nature Food** 2 (3): 198–209. https://doi.org/10.1038/s43016-021-00225-9.

De Cara, S., L. Henry, and P.-A. Jayet. 2018. Optimal coverage of an emission tax in the presence of monitoring, reporting, and verification costs. **Journal of Environmental Economics and Management** 89:71–93. https://doi.org/10.1016/j.jeem.2018.03.001.

Edjabou, L. D., and S. Smed. 2013. The effect of using consumption taxes on foods to promote climate friendly diets – The case of Denmark. **Food Policy** 39:84–96. https://doi.org/10.1016/j.foodpol.2012.12.004.

Efese. 2019. **La séquestration de carbone par les écosystèmes en France.** Technical report. Commissariat général au développement durable. Accessed January 27, 2022. https://ree.developpement-durable.gouv.fr/donnees-et-ressources/ressources/publications/article/efese-la-sequestration-de-carbone-par-les-ecosystemes-en-france.

FAO. 2020. The share of agriculture in total GHG emissions. Global, regional and country trends 1990-2017. **FAOSTAT Analytical Brief Series No 1.**

Frank, S., R. Beach, P. Havlík, H. Valin, M. Herrero, A. Mosnier, T. Hasegawa, J. Creason, S. Ragnauth, and M. Obersteiner. 2018. Structural change as a key component for agricultural non-CO2 mitigation efforts. **Nature Communications** 9 (1): 1060. https://doi.org/10.1038/s41467-018-03489-1.

Gallet, C. A. 2010. Meat Meets Meta: A Quantitative Review of the Price Elasticity of Meat. **American Journal of Agricultural Economics** 92 (1): 258–272. https://doi.org/10.1093/ajae/aap008.

Garnache, C., P. R. Mérel, J. Lee, and J. Six. 2017. The social costs of second-best policies: Evidence from agricultural GHG mitigation. **Journal of Environmental Economics and Management** 82:39–73. https://doi.org/10.1016/j.jeem.2016.10.004.

Grosjean, G., S. Fuss, N. Koch, B. L. Bodirsky, S. De Cara, and W. Acworth. 2016. Options to overcome the barriers to pricing European agricultural emissions. **Climate Policy** 18 (2): 151–169. https://doi.org/10.1080/14693062.2016.1258630.

Hallström, E., A. Carlsson-Kanyama, and P. Börjesson. 2015. Environmental impact of dietary change: a systematic review. **Journal of Cleaner Production** 91:1–11. https://doi.org/10.1016/j.jclepro.2014.12.008.

Havlık, P., H. Valin, M. Herrero, M. Obersteiner, E. Schmid, M. C. Rufino, A. Mosnier, et al. 2014. Climate change mitigation through livestock system transitions. **Proceedings of the National Academy of Sciences** 111 (10): 3709–3714. https://doi.org/10.1073/pnas.1308044111.

Hayek, M. N., H. Harwatt, W. J. Ripple, and N. D. Mueller. 2021. The carbon opportunity cost of animal-sourced food production on land. **Nature Sustainability** 4 (1): 21–24. https://doi.org/10.1038/s41893-020-00603-4.

Herrero, M., B. Henderson, P. Havlík, P. K. Thornton, R. T. Conant, P. Smith, S. Wirsenius, et al. 2016. Greenhouse gas mitigation potentials in the livestock sector [in en]. **Nature Climate Change** 6 (5): 452–461. https://doi.org/10.1038/nclimate2925.

Hong, C., J. A. Burney, J. Pongratz, J. E. M. S. Nabel, N. D. Mueller, R. B. Jackson, and S. J. Davis. 2021. Global and regional drivers of land-use emissions in 1961–2017. **Nature** 589 (7843): 554–561. https://doi.org/10.1038/s41586-020-03138-y.

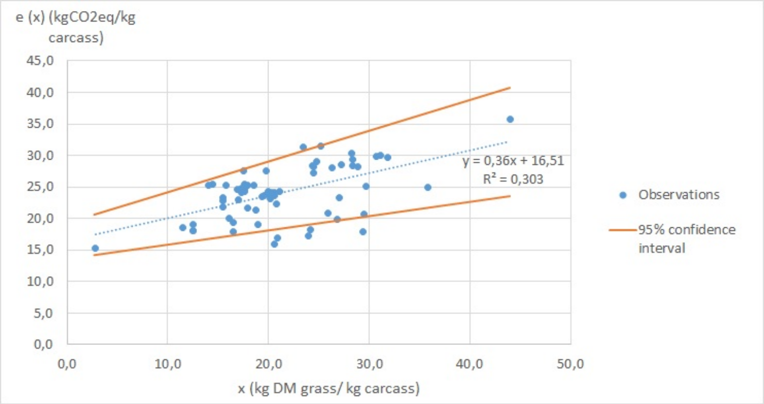
Idele and CNE. 2021. **Les chiffres clés du GEB - Bovins 2021 : Production lait et viande.** Technical report. Institut de l'Elevage, Confédération Nationale de l'Elevage. Accessed December 15, 2021. https://idele.fr/detail-article/les-chiffres-cles-du-geb-bovins-2021.

Pellerin, S., L. Bamière, and al. 2020. **Stocker du carbone dans les sols français, quel potentiel au regard de l'objectif 4 pour 1000 et à quel coût ? Synthèse du rapport d'étude.** Technical report. INRA. Accessed January 27, 2022. https://www.inrae.fr/actualites/stocker-4-1000-carbone-sols-potentiel-france.

Pellerin, S., L. Bamière, D. Angers, F. Béline, M. Benoit, J.-P. Butault, C. Chenu, et al. 2017. Identifying cost-competitive greenhouse gas mitigation potential of French agriculture. **Environmental Science & Policy** 77:130–139. https://doi.org/10.1016/j.envsci.2017.08.003.

Schmutzler, A., and L. H. Goulder. 1997. The Choice between Emission Taxes and Output Taxes under Imperfect Monitoring [in en]. **Journal of Environmental Economics and Management** 32 (1): 51–64. https://doi.org/10.1006/jeem.1996.0953.

Meta-analysis of LCA of meat from suckler beef systems



Comparison of instruments under different carbon prices