EUROPEAN
COMMISSION

Brussels, 15.7.2026
SWD(2026) 234 final

PART 10/11

COMMISSION STAFF WORKING DOCUMENT

EVALUATION

Evaluation of the Nitrates Directive
(Council Directive 91/676/EEC)

{SWD(2026) 235 final}

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Annex XVIII. Impact of nitrates directive on competitiveness of EU agriculture

Contents

1. Introduction

This Annex presents an econometric analysis of the impact of the Nitrates Directive (ND) on the competitiveness of farms in the European Union[1]. Competitiveness is assessed through several indicators that capture farm performance. The analysis exploits the distinction between farms located in Nitrate Vulnerable Zones (NVZs), where the ND is binding, and those outside NVZs, where it is not. This setup enables an effective comparison between farms directly affected by the ND and those unaffected.

We will assess the impact of the ND on two groups of indicators:

- Income-related indicators (costs, margins, income and subsidies) provide insight into the effect of the ND on farmers' cost structure and income.
- Activity-level indicators (crop yields, livestock numbers) capture structural changes in agriculture potentially resulting from the ND.

The effect of the ND on these indicators is estimated econometrically, using EU-wide farm-level panel data covering the period from before the first adoption of the ND in the early 1990s up to 2023. A fixed-effects regression framework is used, exploiting both the time dimension (before vs. after implementation) and the cross-sectional variation (affected vs. unaffected farms) in a single analysis. The main explanatory variable in this approach is the percentage of agricultural land that is designated as NVZ in each region, over time (Copernicus, 2018; European Environmental Agency, 2024; Eurostat, 2021). This variable serves as a proxy for the extent to which the ND has been implemented in each region. By comparing farmers in regions with varying ND adoption rates over time, one can arrive at an estimate of the effect the ND has had with regard to the above indicators.

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[1] The analysis was performed by a consultant from Ghent University as part of a service contract supporting the evaluation of the Nitrates Directive. The entire study including methodological annexes is published in ECORYS, "Complementary study to provide specific elements for the evaluation of the Nitrates Directive", 2026 (forthcoming).

2. Income-related indicators

Methodology

Table 1 provides an overview of the income-related indicators that are considered, accompanied by their respective definition from FADN[2] (Committee for the Farm Sustainability Data Network (FSDN), 2025). To test for an association between these indicators and the ND, a fixed-effect regression framework was used, with the indicator as the dependent variable and the regional share of NVZ as the main predictor. To account for the differential impact of the ND in regions with high livestock density, the interaction between NVZ coverage and livestock density was incorporated into the model. Price indices were used as controls. Year-, region-, and farm-type fixed effects were used to control for unobserved heterogeneity across years, regions, and farm classes. Regional granularity is at the NUTS2 level, or in some cases, at the NUTS1 Level or country level, depending on FADN data availability. The analysis was performed separately for livestock and arable farmers in order to account for the differential effect of the ND on both activities.

Table 1 Income-related indicators that are considered in the analysis and their definition according to FADN (Committee for the Farm Sustainability Data Network (FSDN), 2025). FADN-code is given between brackets.

Indicator	Definition (FADN)
specific costs (€/LU or €/ha)	Crops: Total specific crop costs, i.e. seeds and plants (both purchased and home-grown), fertilisers, crop protection products and other specific costs related to crop production / Total utilised agricultural area of holding (SE284). Livestock: Total livestock costs, i.e. feed, veterinary costs and other livestock-specific costs / Number animals present on holding (annual average), converted into livestock units (SE309).
specific output (€/LU or €/ha)	Crops: Total crop output (SE135)/ Total utilised agricultural area of holding (SE025). Livestock: Total livestock output (SE206) / Number animals present on holding (annual average), converted into livestock units (SE080)
specific margin (€/LU or €/ha)	specific output (€/LU or €/ha) - specific costs (€/LU or €/ha)
farm net income (€/farm)	Farm Net Income (SE420): Total output (SE131)+ – Intermediate Consumption (SE275) + Balance Subsidies/Taxes (SE600)– Depreciation (SE360) – Total External Factors (SE365) + Balance Subsidies/Taxes on Investments(SE405)
farm subsidies (€/farm)	Total subsidies excl. on investments (SE605) + Subsidies on investments

[2] The Farm Accountancy Data Network (FADN) is a stratified sample survey of commercial farms across the EU, designed to represent the economic performance of the agricultural sector. It covers roughly 1.5–2 % of all EU farms, representing about 90 % of total agricultural output value and around 40 % of agricultural area. Sampling is stratified by region, farm type, and economic size to ensure representativeness of the main production systems (EC DG AGRI, 2020).

	(SE406)

Livestock production

The effect of the NVZ designation and its interaction with country-average livestock density (LD, LU/ha) on various income-related indicators for livestock production is presented in Table 2. The net effect of the ND is always a combination of the isolated effect of the NVZ in the left column, and the change of the isolated effect with increased regional livestock density[3]. The net effect is the effect of the NVZ, compared with regions outside of the NVZ both with any level of regional livestock density[4].

Table 2 The effect of the share of NVZ and its interaction with the average livestock density (LD) at the country level (LU/ha) for various income-related indicators for livestock production, expressed in %. 95%-confidence interval between brackets. The datasets consist of all livestock-producing farms for the product-level indicators, and farms of specific farm categories for farm-level indicators[5]. Statistical significance according to legend in the last row[6].

Income related indicator	NVZ effect (%)	NVZ_share effect × country-average LD (%/LU/ha)	Interpretation
Product-level indicators. Based on all FADN farms with livestock production.			
Specific livestock costs (€/LU)	**21.3 (***)** **(11 ; 31)**	**10.4 (*)** **(-1; 23)**	NVZ exposure is associated with higher costs and the effect is increased at high livestock density (10.4% increase per unit increase in the country average LD (LSU/ha).
Specific livestock output (€/LU)	**13.7 (***)** **(6 ; 22)**	1.8 (ns) (-6 ; 10)	NVZ exposure is associated with higher output, with no significant effect of regional livestock density.
Specific livestock margins (€/LU)	5.6 (ns) (–16 ; 27)	**-6.3 (***)** **(–9 ; –3)**	NVZ exposure has little effect on margins in low density regions but is associated with a statistically significant decrease of margins

3 For example: for a Member State with an average livestock density of 1 LSU/ha, the combined effect of the NVZ on specific livestock costs is 21.3% (base effect NVZ) + 1*10.4% (LD effect) = 31.7%.

4 The latter is valid, as the isolated effect of the regional livestock density is not significant for any of the indicators (ECORYS, "Complementary study to provide specific elements for the evaluation of the Nitrates Directive", 2026 (forthcoming).

5 Why not taking the same subset for both analyses? Taking only the mentioned farm types for the analysis of livestock margins decreases the number of observations and makes the statistical model less powerful. Taking all farms with any livestock in the analysis of farm income, would include farms for which income from other sources than livestock is more important than livestock, obscuring the effects of the NVZ on income of livestock farmers, via its effect on livestock production.

6 As an example, the first row can be interpreted as follows: Livestock farming in a region that is 100% designated as NVZ, is associated with specific livestock production costs that are 21.3% higher than in a region that is fully outside of the NVZ (at 1% significance). This effect is increased by 10.4 percentage points for every unit increase in the average livestock density (LU/ha) where that region is located (at 10% significance). The percentages are to be interpreted as relative compared to farms outside of the NVZ at any level of regional livestock density, as the effect of regional density as such is statistically not significant.

			with increasing regional livestock density.
Farm-level indicators. Based on a subset of FADN farm categories, for which livestock contribute for an important part to farm income: "Other grazing livestock", "Granivores", "Mixed", "Milk"			
Farm Net Income (€/farm)	4.9 (ns) (–24 ; 34)	-1.2 (ns) (–28 ; 26)	NVZ exposure has no significant impact on overall farm net income; slight negative trend for high-density farms (but not significant).
Total subsidies[7] (€/farm)	19 (.) (-3.58 ;41.6)	10.2 (ns) (-7.01 ; 27.4)	No o**r very weak** evidence for a statistically significant effect of NVZ exposure on subsidies, independent of density.
(***) at 1% (**) at 5% (*) at 10% (.) at 15% (ns) not significant			

The results indicate that livestock farming in a region that is 100% designated as NVZ is associated with specific livestock production costs that are 21.3% higher than in regions fully outside the NVZ, at low levels of livestock density. At the same time, specific livestock output is 13.7% higher for this group. These effects largely offset each other, as no significant impact is observed on livestock margins. This suggests that, at low regional livestock density, the nitrate directive (ND) increases costs, but higher productivity correlated with the NVZ[8], results in no net effect on margins.

At elevated levels of livestock density, the interaction term shows that specific livestock costs associated with the ND increase by 10.4% per unit increase in livestock density at the country level (LU/ha), compared to farms in regions with any livestock density outside of the NVZ. The interaction term for the NVZ and livestock density for specific livestock output is not significant. This means productivity does not appear to rise proportionally in NVZ regions with higher livestock density, which is in contrast to the case of costs. Given that the additional cost increase is not offset by higher output in livestock-dense regions, a decreasing margin at increasing livestock density is expected. This is indeed the case, as data suggests a 6.3% decrease in livestock margin per unit increase in livestock density. This interaction term indicates that the effect of NVZ coverage on margins increases with higher livestock density. While the average NVZ

7 Subsidy coefficients should be interpreted with caution. Statistically, once year and country fixed effects are controlled for, there is very limited within-country variation left for NVZ coverage to explain. This pattern reflects the structure of agricultural subsidies, which are primarily determined by national-level CAP implementation choices (country fixed effect) and policy reform cycles (year fixed effects) rather than by regional characteristics. In contrast to the production and cost indicators, where substantial regional heterogeneity allows for a clear identification of NVZ effects, subsidies exhibit almost no spatial variation that is independent of broader policy shifts.

8 The correlation between NVZ designation and productivity increases does not imply causality. Indeed, while it might be true that NVZ exposure has lead to more efficient input use (causality), it might also be true that historically, regions with higher productivity have been more sensitive to water pollution leading it to be designated as NVZ (reverse causality). Although methodological methods have been taken to limit reverse causality, it cannot be ruled out entirely.

effect at low density levels is statistically indistinguishable from zero, the negative interaction suggests that NVZs are associated with lower margins in more intensive regions[9].

The observed increase of production costs due to the ND and the effect of regional livestock density thereon, are consistent with the estimates for implementation costs on farms set out in section 4 of the evaluation report (see also ECORYS, “Complementary study to provide specific elements for the evaluation of the Nitrates Directive”, 2026 (forthcoming)). The cost assessment also includes the breakdown of the ND adjustment costs revealing the cause of the increased production cost. This analysis revealed that costs are dominated by storage and buffer strip costs in areas with low livestock density and increase with increased regional livestock density due to the costs related to excess manure management (transport, processing and disposal) in the livestock sector. Indeed, when regional livestock density increases, the most cost-effective options for excess manure management would be exhausted first, and marginal production costs increase[10].

At the farm income level, no significant effects are observed for the ND nor for the interaction with livestock density. This suggests that NVZ exposure has had no significant impact on overall farm net income; neither at low or at elevated levels of livestock density. For lower-density regions, the lack of a net income effect is not surprising as the effect on livestock margins is not significant as well. However, the result at increasing livestock density is, as the observed effect on livestock margins is not translated into an effect on farm income.

Several factors might explain this. The first element is the fact that margins are observed at the product level and income is observed at the farm level. As a consequence, the margins in livestock products can be analysed in all farms in the FADN dataset that produce these products, while the analysis of the effect on income is only meaningful for farmers for which these products play an important role in farm income. These are the farmers classified as "Other grazing livestock", "Granivores", "Mixed" and "Milk" in FADN. So the analysis does not use identical subsets of farms. Secondly, the observed effects of livestock margin might be moderated at the level of income, as farm income is derived from more than livestock products alone. This is especially the case for '’Mixed” farming types, that have significant income from both livestock and crops. Finally, other factors such as subsidies are included in farm income, but not at the level of product margin. Although this effect might be limited, as no significant evidence of an effect of the NVZ on subsidies was observed.

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[9] To estimate the net effect of the NVZ on the livestock margin, both the NVZ coefficient as well as the level of LD and the interaction term are required. E.g., at LD = 0.5, the effect is $0.056-0.063\times0.5=0.0245$.

[10] When a farm produces more manure than can be applied at its lands during a full year (even after storage), it needs looking for alternatives to spreading on own land. This can be spreading on other farmer’s lands, but also other management options such as manure separation, (biological) treatment or long-distance transport. Costs will dictate what options are applied. The least costly one (disposal on other lands) is applied first, but is exhausted when LD is high, as disposal on surrounding lands becomes limiting as well. Then, more expensive options come into play, such as treatment options and long-distance transport.

Crop production

The effect of NVZ designation on various income-related indicators for crop farmers and its interaction with country-average livestock density (LD, LU/ha) is presented in Table 3 below.

Table 3 The effect of the share of NVZ and its interaction with the average livestock density (LD) at the country level (LU/ha) for various income-related indicators for crop production, expressed in %. 95%-confidence interval between brackets. The datasets consist of all crop-producing farms for the product-level indicators, and farms of specific farm categories for farm-level indicators[11]. Statistical significance according to legend in the last row[12].

Income related indicator	NVZ effect (%)	NVZ_share effect × country-average LD (%/LU/ha)	Interpretation
Product-level indicators. Based on all FADN farms with crop production.			
Specific crop costs (€/ha)	1.5 (ns) (−8; 11)	2.1 (ns) (−5.1; 9.4)	No evidence for a statistically significant effect of NVZ exposure on specific crop costs, independent of density.
Specific crop output (€/ha)	1.5 (ns) (−14.8; 17.8)	21.2 (ns) (−0.190; 0.615)	No evidence for a statistically significant effect of NVZ exposure on specific crop output, independent of density.
Specific crop margins (€/ha)	9.8 (ns) (−8.4; 28)	2.1 (ns) (−7.3; 11.5)	No evidence for a statistically significant effect of NVZ exposure on specific crop output, independent of density.
Farm-level indicators. Based on a subset of FADN farm categories, for which crops contribute for an important part to farm income: "Fieldcrops", "Other permanent crops", "Horticulture", "Mixed".			
Farm Net Income	−22.5 (.) (−49; 4)	+20.9 (.) (-5; 47)	NVZ exposure is associated with lower farm income, but the effect reverses with increasing livestock density. At country averages higher than 1.07 LSU/ha[13], the

[11] Why not taking the same subset for both analyses? Taking only the mentioned farm types for the analysis of arable margins decreases the number of observations and makes the statistical model less powerful. Taking all farmers with any arable income in the analysis of farm income, would include farms for which income from other sources than crops is more important than crop production, obscuring the effects of the NVZ on income of arable farmers, via its effect on crop production.

[12] As an example, the first row can be interpreted as follows: Arable farming in a region that is 100% designated as NVZ, is associated with crop production costs that are 1.5% lower than in a region that is fully outside of the NVZ. This effect increases by 10.4 percentage points for every unit increase in the average livestock density (LU/ha) where that region is located. The percentages are to be interpreted as relative compared to farms outside of the NVZ at any level of regional livestock density, as the effect of regional density as such is statistically insignificant.

[13] Since the NVZ share and the regional livestock density work in opposite direction. The point where the effect switches direction happens at an LSU level of 1.07 LU/ha since, -0.225 + 1.07*0.209=0.

(€/farm)			correlation becomes positive.[14] Effects significant at 15% level.
Total subsidies (€/farm) [15]	+27.5 (.) (-2.91; 57.9)	+0.772 (ns) (-34.3 ; 35.8)	No o**r very weak** evidence for a statistically significant effect of NVZ exposure on subsidies, independent of density.
(***) at 1% (**) at 5% (*) at 10% (.) at 15% (ns) not significant			

The results indicate that there are no statistically significant effects of NVZ exposure on specific crop costs, output, or margins, independent of livestock density, at significance levels of 1%, 5% or 10%.

At 15% significance level, NVZ exposure is associated with a 22.5% decrease in farm net income at zero density levels. Interestingly, this effect reverses with increasing livestock density: the interaction term shows a positive effect of 20.9% per unit increase in LD, also significant at the 15% level. The net effect of both these effects will depend on the country-average livestock density[16]. Given that these findings are only significant at 15%, they are accompanied by large confidence intervals, suggesting substantial uncertainty in these estimates.

The counteracting effects on crop farm income suggest that in regions with high livestock density, NVZ designation may actually benefit crop farm incomes. This pattern can plausibly be explained by increased manure distribution from livestock farms to crop farms, reducing fertiliser costs for arable farmers in densely stocked regions. This observation is consistent with the estimates for implementation costs on farms set out in section 4 of the evaluation report (see also ECORYS, “Complementary study to provide specific elements for the evaluation of the Nitrates Directive”, 2026 (forthcoming)), where positive effects for crop production were found under the ND in livestock dense areas, both as a consequence of less mineral fertiliser spending, as well as the income

[14] Due to manure limits under the ND, some livestock farmers have manure surplus, which gives rise to manure transport. Arable farmers can accept manure from manure surplus farmers, resulting in a decrease in their fertilizer spending, explaining the positive effect of regional livestock density on arable farmer’s income within the NVZ.

[15] Subsidy coefficients should be interpreted with caution. Statistically, once year and country fixed effects are controlled for, there is very limited within-country variation left for NVZ coverage to explain. This pattern reflects the structure of agricultural subsidies, which are primarily determined by national-level CAP implementation choices (country fixed effect) and policy reform cycles (year fixed effects) rather than by regional characteristics. In contrast to the production and cost indicators, where substantial regional heterogeneity allows for a clear identification of NVZ effects, subsidies exhibit almost no spatial variation that is independent of broader policy shifts.

[16] For a farms in a country with a livestock density of 0.5 LU/ha, the effect would be 22.5%-0.5*20.9=12%.

from manure disposal fees[17]. For total subsidies, no significant effects of NVZ exposure were observed, and this remained the case regardless of livestock density.

In summary, unlike in the livestock sector, NVZ exposure has limited direct impact on crop costs, output, or margins. The only notable effect appears in farm income in livestock-dense regions, likely reflecting the indirect benefit of manure redistribution under the ND.

3. Activity level indicators

Animal numbers

The regional animal number is used as an indicator of competitiveness, as it reflects the level of economic activity in the livestock sector within a given region. It can be hypothesised that if the ND has created a competitive (dis-)advantage for affected farmers over the past 30 years, this would be observable in a change in livestock activity. This does not mean that the ND has targeted or limited livestock numbers directly, but rather that the set of measures implemented in the region has increased costs to livestock owners, making the activity less competitive. Therefore, one would expect to see a divergence in livestock number trends between regions located within NVZs or outside, if there have been differing trends in competitiveness.

To estimate the relationship between NVZ policy intensity and livestock density, the model adopts a panel regression framework at the NUTS-2 regional level. The dependent variable is the relative change (compared to pre-ND levels) in the logarithm of livestock density, measured as the log-difference over multi-year intervals, in order to mitigate selection bias[18]. The analysis draws on data from Eurostat (Eurostat, 2023, 2024, 2025b, 2025a). The regression results are summarised in Table 4.

Table 4 Coefficients and p-values[19] of the effects of the ND (NVZ share) on livestock density of pigs and cattle. Effects significant at 5% confidence level are indicated in bold. Short term effects are observed within 2 years of the policy adoption; long term effects are observed later.

Variable	Estimate	Std Error	p-value
Cattle sector			

[17] In livestock dense regions under the ND, land disposal of manure is limited and arable farmers having excess land for disposal receive monetary compensation from farmers with manure excess for accepting the manure on their land.

[18] Selection bias arises from the possibility that NVZ designations are not randomly assigned and might tend to be introduced in regions already characterised by intensive agricultural activity and high livestock density. That could lead the reverse causality when interpreting the results. Selection bias might be true for some member states, although some member states adopt a full country approach in which the whole territory is designated as NVZ, regardless of farming intensity. This is the case for DE, DK, AT, NL amongst others. The econometric model minimizes this bias.

[19] The p-value represents the probability of obtaining a test statistic at least as extreme as the one observed, under the assumption that the null hypothesis is true. In simpler terms, it tells us how likely it is that our results could have happened just by random chance if there were actually no real effect. When the p-value is lower than e.g. 5%, this means that the likelihood of the effect being observed by chance (instead of there being an actual effect) is lower than 5%.

Δ NVZ share *(short-term effect)*	0.0037	0.0372	0.9218
NVZ share *(long-term effect)*	-0.0197	0.0337	0.5615
Pig sector			
Δ NVZ share *(short-term effect)*	-0.0250	0.0854	0.7745
NVZ share *(long-term effect)*	0.3199	0.2036	0.1421

For cattle, they indicate no statistically significant effect of NVZ policy on regional cattle density growth. Both the long-term share of NVZ area (NVZ_share, $\beta = -0.019$, $p = 0.56$) and its short-term change (ΔNVZ_share, $\beta = 0.003$, $p = 0.92$) are relatively small and not statistically significant. This suggests that, despite regulatory pressure in NVZs, there is no evidence that the cattle sector has responded systematically by reducing herd sizes. A similar conclusion arises for pig density: neither short- nor long-term NVZ exposure effects are statistically significant at the 5% level. Contrary to cattle, the NVZ coefficient for pigs is positive[20] and marginally significant at the 15% level (ΔNVZ_share, $\beta = 0.31$, $p = 0.14$), suggesting that pig herd sizes might have responded somewhat different to ND than cattle herd sizes, although at 15%, the evidence is very weak[21].

These results suggest that the ND has not influenced the competitiveness of the livestock sector to the extent that it has led to decreases in livestock numbers when comparing EU regions designated as NVZs with those that are not. These findings are consistent with the results observed at the level of farm income, where no evidence of a long-term effect of the ND on farm income was identified.

This does not imply that livestock numbers remained unchanged; rather, it indicates that any changes observed were not statistically different between regions within and outside of the NVZs. This pattern reflects the structure of past trends in animal numbers, which have been influenced by factors other than the ND, such as path dependency, consumer preferences, CAP support, prices, and macro drivers (EC, 2023; Neuenfeldt et al., 2019). In the statistical model, these effects are captured by year and country fixed effects. After correcting for those effects, there is very limited variation left for NVZ coverage to explain.

Crop Yield

Balanced fertilisation within the ND has decreased the amount of fertiliser farmers use. This policy might be associated with a change in crop yields. To estimate the relationship

[20] The positive correlation between NVZ and pig numbers might reflect developments in regions such as Catalonia and Aragon (Spain), where pig numbers have respectively doubled and nearly quintupled since the 1990s, despite long-standing NVZ designations (38% since 2007 in Catalonia; 15% since 2004 and 40% since 2020 in Aragon).

[21] Several factors may explain the differing responses of the cattle and pig sectors to NVZ exposure (1) Manure transport and manure treatment are generally cheaper for pigs due to higher nutrient concentration and easier collection and handling. (2) Pig farming systems, being largely indoor and intensive, can adapt more easily to environmental regulations than the land-based systems typical of cattle farming. (3) As a less land-dependent activity, pig farming is more suitable for spatial agglomeration and economies of scale, enabling continued growth even under stricter environmental constraints.

between NVZ policy intensity and crop yields, the model adopts a panel regression framework at the reference farm level.

The idea behind this statistical analysis is that if balanced fertilisation leads to suboptimal fertilisation, we would see significant differences in yield evolution between regions inside and outside the NVZ. If so, it would create a competitive disadvantage for farmers affected by the ND. The analysis was done for maize and wheat yields in the FADN data (European Commission, 2019). Table 5 shows the results of the regression analysis.

Table 5 Coefficients and P-values of the effects of the ND (NVZ share) on livestock density of pigs and cattle. Effects significant at 5% confidence level are indicated in bold. Short term effects are observed within 2 years of the policy adoption; long term effects are observed later.

Variable	Estimate	Std Error	P value
Wheat			
Δ NVZ share *(short-term effect)*	**-0.032**	0.007	0.004
NVZ share *(long-term effect)*	**0.073**	0.026	0.024
Maize			
Δ NVZ share *(short-term effect)*	-0.053	0.047	0.317
NVZ share *(long-term effect)*	**0.114**	0.029	0.011

The results indicate that in the short term, the impact of the ND is either not significant (maize) or slightly negative (-3.2%). The negative effect could be related to the short-term decrease in mineral fertiliser use, leading to decreased crop yields. However, for both maize and wheat, the long-term effects of the ND on crop yields are positive. This might indicate that farmers adapt to balanced fertilisation requirements and achieve yields that are higher than those of farmers without these requirements. A causal interpretation of this effect should be made with care, because of the risk of selection bias[22]. Additional analysis of crop yield data from Eurostat[23] confirms the absence of a long-term negative effect; however, it does not confirm a significant positive effect in the long term[24]. However, some explanations for the observed positive correlation could be

[22] The positive relationship between the ND and crop yields might also be related to selection bias in the model setup, referring to the likelihood of high intensity farms (or regions) being targeted by the ND. The model accounts for this effect in various ways, but some remaining impact of this effect should nevertheless not be ruled out.

[23] ECORYS, "Complementary study to provide specific elements for the evaluation of the Nitrates Directive", 2026 (forthcoming).

[24] The fact that significant effects are not confirmed in both analyses originates from the use of different source data. Eurostat data provides more crop specific information, but it has less observations and

that: (1) NVZs have larger, more commercial farms, possible having stronger capacity to adopt high-efficiency machinery and optimise operations and benefiting from scale economies (Bokusheva R & Kimura S, 2016; OECD, 2023) and (2) NVZs often come with stricter nutrient management rules and monitoring. Farms operating under such regimes may adopt precision agriculture technologies (e.g., variable-rate fertilisation, yield mapping, NDVI monitoring) to comply and optimise productivity. Empirical studies find that such technologies improve yield and nutrient use efficiency (Basso et al., 2016; Silvestri et al., 2024; Videgain et al., 2024).

Given these findings, the general impact of balanced fertilisation on crop productivity appears to be limited, and even slightly positive. As a result, we find no evidence that the ND has had a significant impact on crop productivity. This finding aligns with the results at the level of farm income, where evidence of a long-term effect of the ND on farm income was not observed. Additionally, this result aligns with the technical literature on field trials, suggesting that fertilisation under balanced fertilisation standards tends to be at the agronomic optimum (Hofman et al., 2014).

4. Discussion of the results according to scientific literature

The previous sections have analysed the impact of the ND on livestock and crop production farmers, using statistical analysis based on FADN data. Income-related and activity-related indicators were analysed to account for both financial and structural impacts. The analysis compares farms within and outside the NVZ before and after implementation of the ND[25]. This way, farms impacted by the policy are statistically compared to their situation before implementation and the situation of comparable farms not impacted by the policy.

This analysis reveals that livestock production systems have been more significantly impacted by the ND than crop production systems.

For livestock farms, exposure to NVZ measures is associated with higher specific production costs (+21%) and higher specific outputs (+14%), both of which are significant at the 5% level. These effects offset each other at low livestock density levels, resulting in no significant change in livestock margins. However, at higher country-average livestock density, costs increase further—by about +10% per additional livestock unit per hectare (LU/ha)—while output does not increase proportionally. As a result, livestock margins decrease by approximately −6% per LU/ha, consistent with the notion that higher-density regions incur greater costs from ND compliance (e.g., manure management, storage, or transport). At the level of farm net income, no significant ND effect is observed.

By contrast, for crop farms, no statistically significant effects are found for the farmer in NVZ or its interaction with livestock density. Only a weak negative association

therefore less statistical power. On the other hand, FADN data contains more observations, but only reports on the yields of wheat and maize.

[25] Data ranged from early 90's to 2022, the starting point being dependent on data availability in country level.

(significant at the 15% level) is observed for farm net income (−22%), which becomes positive in regions with higher livestock density. This is consistent with a situation where, in areas where arable and livestock activities coexist in conditions of high livestock density, the ND has fostered manure redistribution from livestock to crop farms, thereby reducing fertiliser costs and improving crop farmers' net positions.

Overall, the results indicate that the ND has imposed higher compliance costs on livestock systems, especially in high-density regions. Conversely, crop systems have been mitigated through nutrient recycling and cross-sectoral adaptations.

The effects found at the farm income level are consistent with those identified at the activity level. Since income from livestock production has not exhibited a significant change, a corresponding effect on the number of animals is not expected. Indeed, the statistical analysis provides no evidence of significant changes in animal numbers in regions impacted by the ND, compared with others. This holds true for both cattle and pig production. However, this does not imply that animal numbers have remained stable over the past 30 years; rather, it indicates that historical trends in animal numbers have not differed significantly between regions within or outside the NVZ.

One of those trends has been a decrease in livestock density in the EU. This is shown in Figure 1 on Cattle and pig density in heads/ha per member state between early 90's and 2023 (Eurostat, 2025a). Most member states have seen stagnating or decreasing trends for both cattle and pig numbers over the last decades[26]. The total number of LU for EU-27 member states taken together fell from 121 million LSU in 2007 to 113 million in 2020. This trend has been observed in countries with varying degrees of exposure to the ND, and in some instances, started well before the inception of the ND[27]. Moreover, some regions have seen a notable increase in animal numbers (for instance, pigs in Catalonia and Aragon, Spain), despite being at least partially designated as NVZ. This suggests that other factors may play a more significant role in animal population trends than the ND (CAP, prices, macro drivers etc.). In the livestock sectors, Neuenfeldt et al. (2019)[28] shows that farm structural change is mostly determined by path dependency followed by – especially for livestock - natural conditions such as land type and topography and input and output prices (Neuenfeldt et al., 2019). Other sources cite prime drivers for shifts in animal numbers to be consumer demand (population and dietary preferences), commodity and meat prices and CAP support (EC, 2023).

Measures in the ND are typically more costly for farmers in livestock-dense regions[29]. As a result, it would be expected that the concentration of livestock production would decrease and become more evenly distributed across regions. However, Figure 1 shows

[26] With Spain (pigs) and Cyprus (cattle) as notable exceptions to this trend.

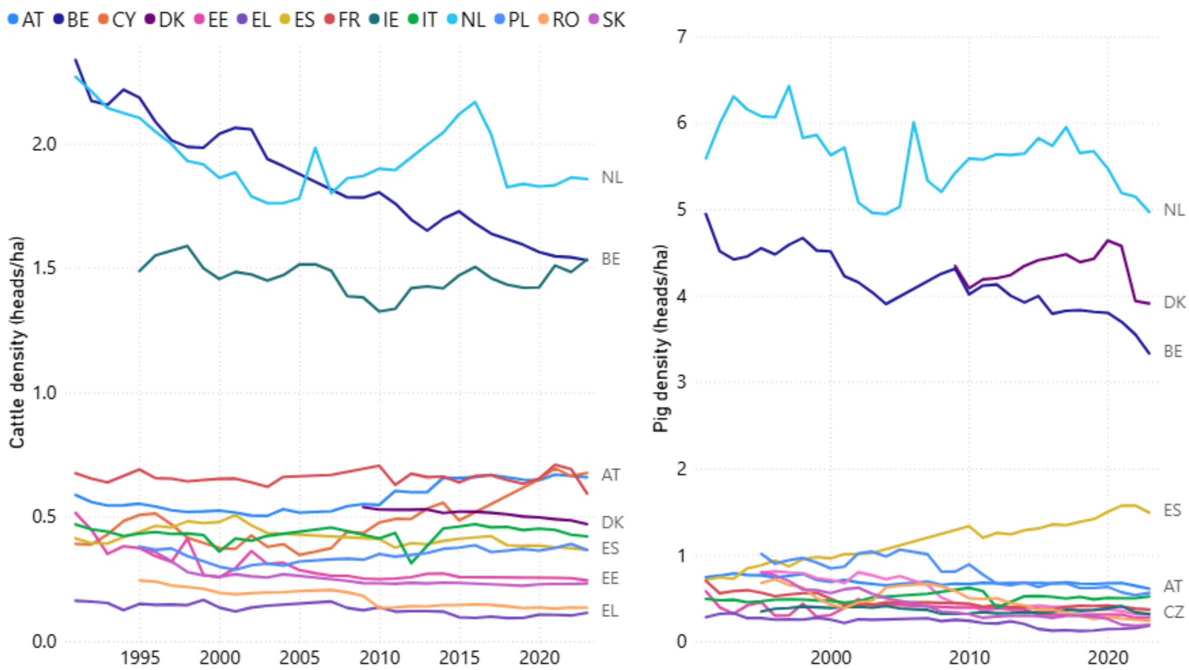
[27] For example, in Belgium, cattle number decrease ever since the late early 90's, while the ND livestock limit became binding around 2002.

[28] Sebastian Neuenfeldt, Alexander Gocht, Thomas Heckelei, Pavel Ciaian, Explaining farm structural change in the European agriculture: a novel analytical framework, *European Review of Agricultural Economics*, Volume 46, Issue 5, December 2019, Pages 713–768, https://doi.org/10.1093/erae/jby037

[29] For example: the manure application limit induces costs for farmers producing more manure than they can dispose. The higher the livestock density of the region where the farmer is located, the more costly will be the management of the excess manure, as disposal options become more scarce.

that there has been a concentration of livestock production in the most competitive areas and on increasingly larger farms, and that this concentration has persisted over the last 35 years. Production is indeed unevenly distributed across the European territory with areas characterised by a high livestock density stretching from northern Denmark to Belgian Flanders, through north-west Germany and the Netherlands, western France, northern Italy (Po Valley), north-eastern Spain (Catalonia) and, to a lesser extent, in Ireland, western Great Britain, southern Germany, central-eastern Poland, and along the northern, western and south-western edges of the Massif Central. High livestock density often results from the simultaneous presence of several animal species in the same area (as is the case, for example, in Brittany, the Netherlands, or Belgium), or from a significant concentration of grain-fed animals (e.g., Spain, Denmark). By relying on feed purchased from other regions or countries and being less directly dependent on land, these productions allow for higher levels of intensification than those of herbivore-based systems (European Commission, 2023).

Figure 1 Cattle and pig density in heads/ha per member state between early 90's and 2023 (European Commission, 2019).



Note that a decline in cattle and pig density (heads/ha) does not necessarily result in a decline in production. In general, productivity per head has increased, resulting in higher livestock production (mostly dairy) than in the 1990s. Moreover, our results show that livestock productivity (reflected by specific livestock output) has increased more in the NVZ than outside of the NVZ. This does not signify a causal relationship per se, but in an attempt to understand these effects, one could argue that the ND was an incentive to increase productivity per animal because this contributes to higher nitrogen use efficiency. Thus, even though the ND leads to measurable implementation costs, it could also have contributed to the long-run efficiency gains that increase (international) competitiveness. These dynamics can help understand the results that we observe, namely (1) the attributable direct costs of the Nitrates Directive), (2) seeing these costs increase being confirmed statistically while (3) at the same time observing significantly higher productivity to (4) arrive at no significant long term impacts on income, gross margins or animal numbers. These results suggest that the ND has not influenced the competitiveness of the livestock sector to the extent that it has led to decreases in livestock numbers when comparing EU regions designated as NVZs with those that are not.

Regional trends confirm this finding. One such example is dairy production in Belgium. The cost of compliance with the Nitrates Directive is the highest in Flanders and much higher than in the Walloon region. Yet, 71% of the milk production of 2024 was delivered by Flemish farms, while in 2005 the Flemish production accounted for only 60% of the total Belgian production (Belgische Confederatie van de Zuivelindustrie, 2025; Van Der Straeten et al., 2012). The dairy production in Flanders increased by 71% for the period 2005 – 2024[30]. Only Ireland and Cyprus have achieved similar or higher dairy production increases during the same period, and both of these member states fall under the Nitrates Directive.

These results show that the ND has not had the effect of significantly curbing the phenomenon of territorial concentration of livestock activities, and that other factors have had more significant effects. In particular, improvements in animal performance, technological progress, the consolidation of strategies between upstream and downstream sectors, and the pursuit of economies of scale and agglomeration have been the main factors influencing developments in animal numbers. Also, the rationalisation of livestock management practice, such as the batch management of sows, together with the reorganisation of housing structures and the advancement of technologies (including the automation of tasks, milking robots, and automatic feeders), has led to significant gains in labour productivity. These gains are further amplified by farm consolidation, which facilitates economies of scale in the execution of specific operations (feeding, cleaning, milking, etc.). The expansion of livestock units is also driven by the increasing specialisation of farms, a trend attributable to the limited potential for economies of scope arising from the integration of diverse production activities within a single holding. Moreover, this process is reinforced by the development of corporate farming structures and the growing reliance on hired labour in the EU (Bokusheva R & Kimura S, 2016; OECD, 2023).

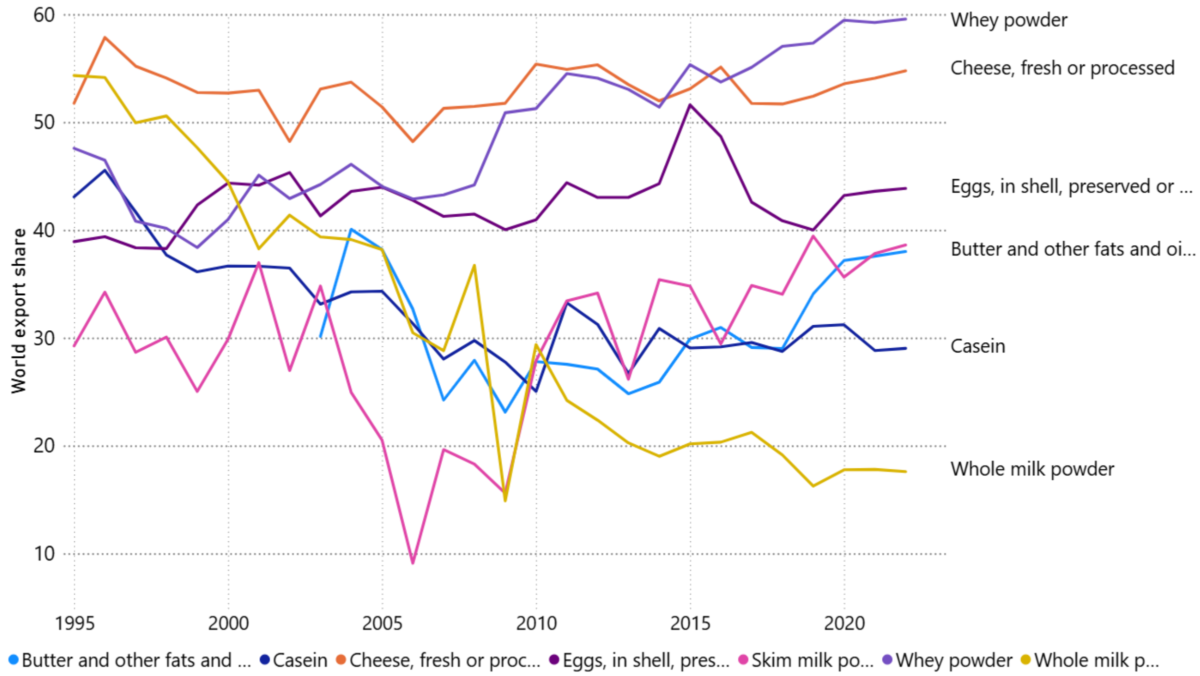
Finally, our results are also reflected in international competitiveness indicators. Taking dairy again as an example[31], Figure 2 shows the relative share of the EU-28 in the total global dairy product exports (OECD/FAO, 2021). It shows that the share in 2025 is comparable to the share in the 1990s for most of the products, with the exception of whole milk powder (decline) and whey powder (increase). Furthermore, it shows a clear dip in the mid-2000s for butter and skimmed milk powder. This dip can be explained by the fact that the dairy quota from the CAP kept the dairy industry from growing, and this

[30] Despite of the fact that the number of cows have actually decreased (as shown in Figure 1). This is because of productivity gains in milk production such as feed optimisation, milking robots, automatic feeding, etc.

[31] The dairy sector being an agricultural sector where international trade is relatively more important (OECD/FAO, 2021)

resulted in a loss of market share (Tacken et al., 2009). Additionally, this may have also slowed the pace of structural change, which could have reduced the speed of cost reductions. After the abolition of the dairy quota, the EU share for butter and skim milk powder returned to levels comparable to those of the 1990s. Overall, these statistics suggest that other forces are significantly more influential in shaping the industry's development than EU environmental legislation. Furthermore, the relative long-term stability of the export share of the EU livestock sector suggests that the impact of the Nitrates Directive on competitiveness has been limited.

Figure 2 Share of the EU-28 in the world market export of dairy products (OECD/FAO, 2021).



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