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Estimating demand elasticities of mineral nitrogen fertiliser: some empirical evidence in the case of Sweden

The geopolitical developments that occurred in 2022 shook the global fertiliser market. One of the issues that the EJP SOIL 'Scenario modelling for assessing impacts of policy changes and socio-economic effects on ecosystem services of soils (SIMPLE)' project currently investigates is the potential consequences of increased fertiliser price on its demand and subsequent application. Looking at this question from an economic perspective, an answer can be found via the estimation of the relevant elasticity of demand. Therefore, we aim at providing empirical evidence on the responsiveness of demand for nitrogen (N) fertiliser to changes in its price. Having a better understanding of how farmers can react to changes in the price of this production input is key for several reasons. Firstly, lower fertiliser application can reduce soil productivity, leading to price increases of agricultural commodities due to lower production volumes. Secondly, an increase in the cost of inputs can affect negatively the financial viability of those farming activities which rely on mineral fertiliser. Thirdly, important negative environmental impacts are associated with its excessive use, creating a need to curb demand under certain circumstances. Taking Sweden as a case study, three different econometric techniques (OLS, FE and FE-IV) are applied to a panel that covers all Swedish regions over the period 1990-2022. This contribution finds a negative and inelastic relationship between urea prices and nitrogen fertiliser sales, which is in line with the existing literature providing estimates for other world regions.

Keywords: price elasticity, price responsiveness, nitrogen, fertiliser, Sweden, econometrics

JEL classifications: Q00, Q11, C01, C20, C26

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Introduction

The geopolitical developments that occurred in 2022 shook the fertiliser market globally (USDA, 2022). In the summer of 2022, fertiliser prices reached an unprecedented level, with prices almost quadrupling compared to the 2020 average level (Euronews, 2024). This sudden increase in fertiliser prices has had an important impact on the input costs that farmers have been facing worldwide. At the same time, it has made more evident the strong dependence of agriculture production on imported pesticides and fertilisers (FAO, 2022; Euronews, 2024) which are mainly produced in the United States, India, Russia and Canada.[1] Looking at the global fertiliser market, the top five countries control more than 50% of total fertiliser exports (Goretzki *et al.,* 2019). More specifically, exports from these countries represent around 53.4% (38.0 million metric tons) in the case of nitrogen, 73.4% (3.5 million metric tons) regarding phosphate and 90.8% (35.5 million metric tons) in the case of potash. In this context, characterised by high prices and market concentration, as well as the limited availability of fertiliser, farmers chose to buy and apply lower quantities (European Commission, 2022). While these choices may be based on economics, they have impacts on related factors such as food/feed production and water quality.

The use of fertilisers over the past decades has led to an increase in food/feed production worldwide (Bindraban *et al.,* 2015). However, some recent research (Penuelas *et al.,* 2023) points to the existence of inefficiencies and asymmetries between countries regarding its application (insufficient access to fertiliser *versus* overfertilisation). Overfertilisation is a problem in regions such as North America, Western Europe, China and India, whereas farmers in some parts of Latin America, Africa and Asia are facing lower crop yields due to a limited use of an important production input. In this dual context, it is crucial to improve fertiliser management (Ren *et al.,* 2022). In those areas characterised by high yields and overfertilisation, it could be possible to reduce soil imbalances and pollution without having negative impacts on yields (Ritchie, 2021). At the same time, a decline in demand for synthetic fertilisers in certain areas could improve their affordability and 'set free' production inputs for other areas in which higher use is required in order to increase production volumes.

Keeping in mind these developments, the EJP SOIL 'Scenario modelling for assessing impacts of policy changes and socio-economic effects on ecosystem services of soils (SIMPLE)' project investigates the potential consequences of increased mineral nitrogen fertiliser prices on its demand and subsequent application on EU soils.[2] Looking at this question from an economic perspective, an answer can be found via the estimation of the relevant elasticity of demand. In other words, the estimation of the own-price elasticity of demand for fertiliser can provide a response to the following query: 'If fertiliser prices increase by 1%, how would the demand for fertiliser change (in % terms)?'. Theoretically, a negative inelastic relationship between prices and nitrogen fertiliser demand can be expected (Inglesson and Drake, 1998).

The objective of this paper is to provide empirical evidence on the responsiveness of demand for nitrogen (N) fertiliser to changes in its price. Having a better understanding of how farmers can react to changes in the price of this

[1] Available at: https://worldpopulationreview.com/country-rankings/fertiliser-production-by-country.

[2] Further details on the project are available at: https://www.agroscope.admin.ch/agroscope/en/home/topics/environment-resources/soil-bodies-water-nutrients/ejp-soil/simple.html.

production input is key for several reasons. Firstly, lower fertiliser application can reduce soil productivity, leading to price increases of agricultural commodities due to lower production volumes. Secondly, an increase in the cost of inputs can affect negatively the financial viability of those farming activities which rely on mineral fertiliser. Thirdly, important negative environmental impacts are associated to its excessive use, creating a need to curb demand under certain circumstances. A key question in this regard is to which extent price changes, for example, those induced by a tax can contribute to this objective (United Nations Environment Programme, 2020).

EU Member States could benefit from quantifying the responsiveness of mineral fertiliser demand to changes in prices since there is a need to reduce dependency on nitrogen fertiliser (European Biogas Association, 2023). This becomes very relevant if one is thinking about improving circularity in agriculture and decarbonising the EU economy. From the policy-making point of view, instruments such as taxes, subsidies, import tariffs or import bans can be used to alter fertiliser demand and supply.[3] Hence, insights into how demand could react to changes in prices are very important when it comes to assessing the potential impacts of those instruments. Within the EU, an interesting case to analyse is Sweden. This is so since Swedish agriculture relies on a crop sector dominated by cereal production, as well as important livestock production.[4, 5] Secondly, as many other EU countries, Sweden is an importer of mineral nitrogen fertiliser but not a manufacturer. Thirdly, the agricultural policy framework in the country included a tax on mineral fertilisers, which was in place for 25 years. Moreover, Sweden is geographically a large country with substantial differences in the agricultural production among the regions (caused by differences in soils and climatic conditions) which enriches the analysis at regional level.[6]

The empirical evidence presented in this article is valuable information since to the best of our knowledge the vast majority of contributions looking at this issue focus on developing countries (Kopper, 2018; Nasrin *et al.,* 2022) or were published more than 30 years ago (Penm and Vincent, 1987) when the challenges faced by the agricultural sector were very different compared to what it has to deal with today. Therefore, it is important that policy-making and research can rely on updated estimates of farmers' behavioural responses.

The remainder of this article is organised as follows. Firstly, a review of the existing literature on the responsiveness of fertiliser demand to several factors is presented. This is followed by a description of the methodology. Next, the article moves onto the presentation of some stylised facts identified when looking at the evolution of nitrogen sales and related prices, as well as the relevant econometric results. Finally, it provides some discussion and conclusions.

[3] Işik and Özbuğday (2020) explore the role of tax cuts on agricultural inputs prices in the case of Turkey. Specifically, they investigate whether reductions in fertiliser prices induced by the change in the taxation system have an impact on fertiliser use, concluding that consumers benefited significantly from the tax reduction decisions.

[4] See, also: https://www.eitfood.eu/in-your-area/sweden.

[5] As indicated by Ladha *et al.* (2005), about 60% of global N fertiliser used is employed for producing rice, wheat, and maize, i.e. the most important cereals at world level.

[6] This creates room for a 'richer' analysis which pays attention to regional aspects.

Literature review

Having a good understanding of the factors driving demand for nitrogen mineral fertiliser involves the consideration of economic and non-economic elements. Firstly, as in the case of any other type of good or service, one could expect that the demanded quantity of nitrogen fertiliser is related to its price. For example, Penm and Vincent (1987) estimated phosphatic and nitrogenous fertiliser demand relationships in the case of Australia by considering fertiliser prices, the price of other farm inputs, as well as the desired level of output for given crops as the key drivers. In the case of nitrogenous fertiliser, price elasticities for sugar cane and pasture were around -0.36 and -0.32 respectively, while much larger responses were found in the case of wheat and vegetables (-3.33 and -4.05 respectively). Nevertheless, price developments are only part of the equation. Demand for fertiliser can be influenced more by non-price factors (such as acreage) than by price (Jabbar and Islam, 1981).[7]

Across the different world regions, there seems somehow to be a consensus regarding the inelastic responsiveness of fertiliser demand to changes in its price. For instance, Kopper (2018) focuses on sub-Saharan Africa and finds a price elasticity of -0.09, confirming the inelastic response of farmers in this area. In the case of China, Pang *et al.* (2021) also estimate the price elasticity of fertiliser demand, finding it to be in a low elasticity range. This inelastic behaviour has been also discussed for the United States. In particular, Chavas *et al.* (2020) highlight that the demand elasticity for nitrogen fertiliser has decreased over time. This study suggests that a more inelastic demand for fertiliser together with stronger market concentration have contributed to increases in fertiliser prices.[8]

Urea prices are considered an indicator for fertiliser prices since urea (46% N) is the most concentrated solid nitrogen fertiliser form and the most commonly used (Incitec Pivot Fertilisers, 2021). Focusing on the evolution of anhydrous ammonia and urea prices in the United States, Crespi *et al.* (2022) explore the impact of corn prices as well as domestic and international natural gas prices over the period January 1997 – February 2022. Their study concludes that international natural gas prices were more related to urea prices than domestic natural gas prices before 2000. Since then, urea prices have relied more on natural gas prices. Moreover, Crespi *et al.* (2022) identify that changes in corn prices had a positive impact on the evolution of urea prices over the period 2011-13. Beckman and Riche (2015) also investigate the relationships between changes in natural gas, corn and fertiliser prices in the United States. An interesting finding is that the relationship between fertilisers and corn prices has increased since 2008. More precisely, the correlation coefficient for ammonia and corn has increased from 0.07 (in the period 2001-07) to 0.60 (2008-onwards) (Beckman and Riche, 2015).[9]

[7] Islam and Mujeri (2021) extensively discuss the impact of fertiliser prices and the policy framework on the demand for fertilisers in Bangladesh.

[8] An overview of studies looking at fertiliser demand is provided by Bumb (1984).

[9] Huang (2007) discusses the interaction between natural gas and ammonia supply in the United States, concluding that fertiliser prices have been mainly driven by supply-side factors.

Further comments regarding other types of fertilisers and their demand can help us to complete the picture. More specifically, nitrogen (N) fertiliser and organic fertilisers may partially be substituted (Xu *et al.,* 2023; Hu *et al.,* 2023). Both types of N sources could become even more interrelated with the development of recent (and future) processing technologies for organic manure, leading to the application of new agricultural inputs such as RENURE (Recovered Nitrogen from manure) as an alternative of traditional nitrogen mineral fertiliser.[10] This potential substitution could curb demand for synthetic fertiliser and eventually affect its price. Drawing attention to phosphate, Al Rawashdeh (2023) econometrically estimates demand (short and long-run) elasticities of phosphate fertilisers, considering its price, potassium oxide (K_2O) price, income and cereal yields as the relevant driving factors.[11] Much as has been found for nitrogen fertiliser, at the global level phosphate demand is price inelastic regardless the time horizon (Al Rawashdeh, 2023). This is also the case when focusing on specific regions, for example, in Sweden Nygårds and Svenungsson (2020) estimate a long-run price elasticity of phosphorus of around -0.449 and a short-run price elasticity of around -0.192, indicating inelastic behaviour in both cases.

Methods

The responsiveness of nitrogen fertiliser demand to different factors is investigated by means of the econometric estimation of the following function (1):

$$N_d = N_d\,(\underset{-}{P_U},\ \underset{-}{O_F},\ \underset{+}{P_C},\ \underset{+}{P_O},\ \underset{+}{AL},\ \underset{+/-}{t}) \qquad (1)$$

where N_d accounts for demand for nitrogen fertiliser; P_U stands for urea prices; O_F refers to the availability of organic fertilisers; P_C is the price indicator for cereals; P_O is the price indicator for other crops; AL stands for arable land; and t represents a trend variable which captures technological change. It should be noted that demand for nitrogen fertiliser is measured in terms of 'mineral nitrogen (N) fertiliser sales', i.e. only fertiliser which is produced from natural gas is considered. The sign below a variable indicates the partial derivative of the dependent variable with respect to that variable.

Three different techniques have been employed in order to test the relationships described above (1). First of all, a traditional estimation procedure relying on Ordinary Least Squares (OLS) has been applied (Wooldridge, 2019), estimating the relationships between variables without accounting for unobserved differences across entities. Secondly, the proposed model is estimated by means of the Fixed-Effect (FE) technique, which unlike OLS, incorporates entity-specific characteristics that remain constant over time. These fixed effects enable the isolation of entity-specific effects from time-invariant factors (Wooldridge, 2019). Finally, a Fixed Effects Instrumental Variables (FE-IV) specification is estimated (Murtazashvili and Wooldridge, 2008). The rationale for using FE-IV is that this technique addresses potential endogeneity concerns in the variable of interest by using an instrumental variable. The distinctive feature of the FE model is its ability to control for unobserved entity-specific characteristics, while the FE-IV model extends this control by addressing endogeneity through instrumental variables. Moreover, in the OLS, FE and FE-IV models, the standard errors are adjusted to control for heteroscedasticity, for cross-sectional and temporal dependence.

Coming back to the variables included in this analysis, there are reasons to believe that urea prices can be an endogenous variable due to omitted variable bias. A potential instrument for urea prices is the natural gas price. There are several reasons justifying this choice. Firstly, natural gas prices are strongly related to the production process of urea, and therefore, to its price. In addition, natural gas prices should not directly affect the demand of mineral nitrogen fertiliser in the agricultural setting but should instead influence it only through the urea price. Therefore, there is no direct relationship between natural gas price and nitrogen mineral sales; instead the natural gas price only influences fertiliser demand through the urea price. Moreover, the instrumental variable should be exogenous, meaning that it is not influenced by the same factors that affect the dependent variable (fertiliser sales in our case). The 'exogeneity' assumption is satisfied since natural gas prices are determined by factors such as global supply of natural gas, demand for energy from various industries and households, geopolitical events, and extraction technologies, which are typically not directly linked to agricultural practices or demand for fertilisers in Sweden.

Our sample consists of a panel including information on all Swedish regions (21 counties) over the period 1990-2022 (691 observations). The relevant descriptive statistics, together with the statistical sources that were consulted in order to compile the database are presented in the Annex.

Regarding the statistical package employed, STATA version 17 was the chosen option. All the variables have been transformed by means of natural-log transformations. Therefore, a log-log specification has been applied when estimating the model proposed in Equation (1).

Results

Stylised facts

Before moving onto the presentation of the outcomes of the econometric analysis, some descriptive information on the historical evolution of key variables such as mineral fertiliser sales, as well as natural gas and urea prices is provided.

Figure 1 shows the evolution of the average mineral nitrogen fertiliser sales in Sweden, measured in 1000 tons (left axis), since 1990. There are important disparities across counties. While on average, approximately 8.85 thousand tons were sold yearly, at regional level sales range from 0.4 (in regions Västernorrland, Jämtland, and Norrbotten) to 57.3 (Skåne region) thousand tons. Figure 1 also provides an indicator of nitrogen fertiliser sales in Kg per hectare (right

[10] See, also: https://www.europeanbiogas.eu/wp-content/uploads/2023/06/Open-Letter_RENURE-in-INMAP.pdf.

[11] Cereal yields are included as a measure of technology.

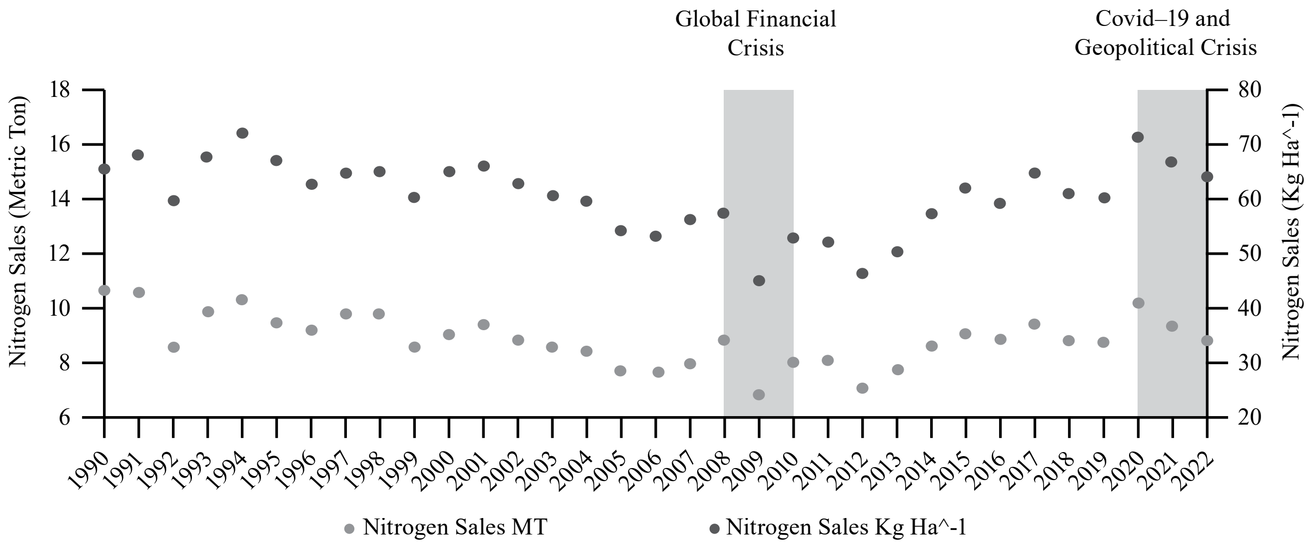

Figure 1: Nitrogen sales in Sweden from 1990 to 2022.
MT: Metric Ton, Kg: Kilogram, Ha: Hectare.
Source: own composition

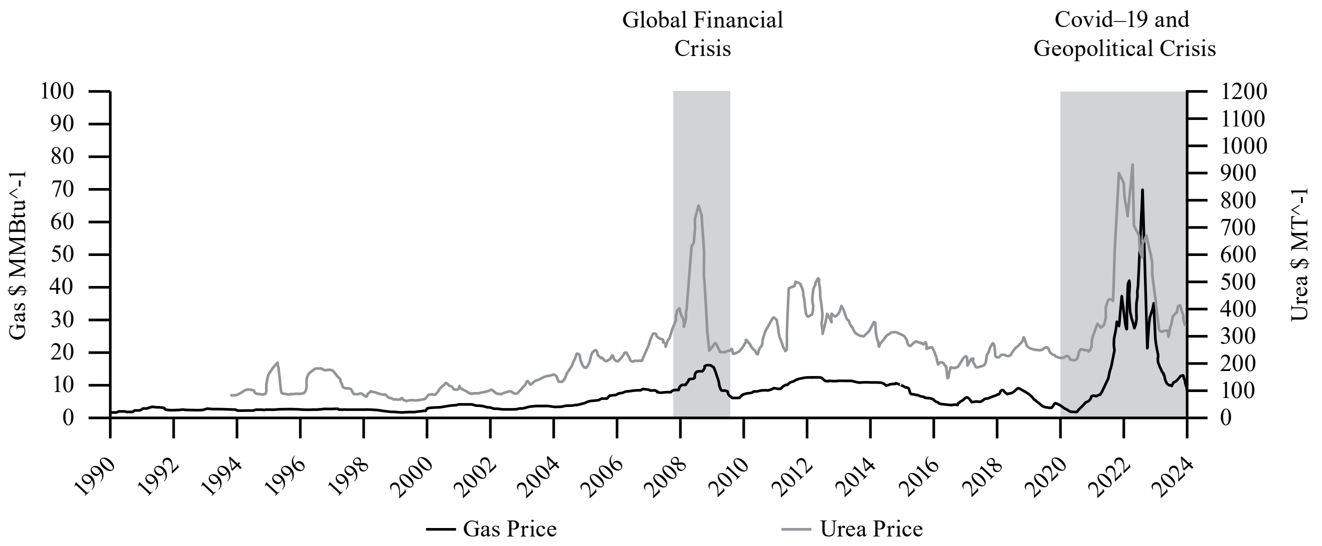

Figure 2: Natural gas and urea prices from 1990 to 2024.
MMBtu: Million Metric British Thermal Unit, MT: Metric Ton.
Source: own composition

axis), which gives some insights in terms of the intensity of fertiliser use in agriculture. The average use is around 60.61 Kg/ha annually; varying from 7 Kg/ha to 135 Kg/ha (Västernorrland region and Skåne region respectively). For a better understanding of fertiliser availability in Sweden, some figures on the use of organic fertiliser (as related to animal excretion) are also provided. On average, the annual production is nearly 4.1 thousand tons, ranging from 0.8 thousand tons in Norrbotten to 24.2 thousand tons in Skåne.

Looking at Figure 1, two periods can be distinguished in terms of the evolution of nitrogen fertiliser sales: (i) 1990-2009, in which nitrogen sales follow a negative trend and reach a value below seven thousand tons (i.e., 45 kg of N/ha of arable land); and (ii) 2010-2022, in which sales of nitrogen fertiliser were steadily increasing. The 2009 break in the time series may be related to an important development in the policy framework, i.e. the sudden abolition of the fertiliser tax in response to the financial crisis (Andersen, 2022), as well as the global financial crisis itself. [12] Nevertheless, looking at the most recent period of available data (2020-2022), it seems that nitrogen fertiliser sales curbed due to COVID-19 and the recent geopolitical developments.

Figure 2 displays the evolution of natural gas and urea prices over the period 1990-2023.[13] As shown, in the figure, prices peaked in 2009 and 2022. Overall, there is some co-movement between the two sets of prices over the mentioned period, including the occurrence of peaks around the same dates. This synchronised movement suggests a strong correlation or interdependence between natural gas and

[12] In order to check whether the abolition of the fertiliser tax in 2009 has caused an structural break in the evolution of nitrogen fertiliser sales, a dummy variable to account for this event has been included.

[13] In Figure 2, the 'urea price' variable is measured in dollars per metric ton, providing an indication of market prices of urea fertiliser. The average price was around $247.30 per metric ton, fluctuating between $62.75 and $925. The 'natural gas price' indicator reported in Figure 2 is expressed in dollars per Million Metric British Thermal Units (MMBTU), representing the cost of natural gas. The average price for the period under consideration is around $7 per MMBTU, ranging from $1.46 to $69.97.

urea prices.[14] An explanation for the synchronised movements is that urea, a nitrogen-based fertiliser, is manufactured using the Haber-Bosch process, which heavily relies on natural gas as a primary input. Therefore, fluctuations in natural gas prices directly affect the production costs of urea.

Table 1: Sales of mineral nitrogen fertiliser.

	(1)~OLS	(2)~FE	(3)~FE-IV
	Nitrogen sales	Nitrogen sales	Nitrogen sales
Urea price	-0.2334***	-0.2378***	-0.3874***
	(0.0618)	(0.0606)	(0.1052)
Trend	0.0057***	0.0049**	0.0071***
	(0.0020)	(0.0021)	(0.0025)
Organic fertilisers	0.1847***	0.0090	-0.0185
	(0.0313)	(0.0555)	(0.0516)
Cereal prices	0.3280***	0.3452***	0.4439***
	(0.0872)	(0.1008)	(0.1282)
Other crops prices	-0.1878**	-0.2018**	-0.2010**
	(0.0929)	(0.0742)	(0.0787)
Arable land	1.3527***	1.2802***	1.2750***
	(0.0410)	(0.2875)	(0.2614)
County fixed effects	No	Yes	Yes
Observations	691	691	691
F-statistic (instrument)	-	-	25.011
R-squared	0.8576	0.2395	0.2108

Note: Driscoll-Kraay robust standard errors are in parentheses, *** p<.01, ** p<.05, * p<.1. All variables are logged transformed. The estimation period is 1990-2022.
Source: own calculations

Econometric analysis

Table 1 provides the results of the estimated models by OLS in (Column 1), FE (Column 2) and FE-IV in (Column 3). All the estimated models indicate that nitrogen fertiliser sales respond negatively to urea price increases. This negative sign is consistent with general economic theory, i.e., the law of demand, which suggests that the quantity demanded of a good tend to be negatively related to its price. Focusing on the size of the coefficients and their statistical significance, the three models indicate an inelastic relationship between the two variables significant at the 1% level.[15] However, the OLS and FE models show smaller coefficients than the FE-IV. In the case of the FE-IV model, which eliminates potential endogeneity issues, the parameter indicates that 1% increase in urea prices leads approximately to a 0.3874% decrease in nitrogen fertiliser sales. [16]

For a better understanding of the responsiveness of nitrogen sales to changes in prices, an additional set of models is estimated. Firstly, we proceed to include step-wise the explanatory variables in the FE-IV model in order to examine whether the results are robust in controlling for different factors (Table 2). Although the size of the estimated parameters for urea prices varies across the models, the relationship between sales of nitrogen fertiliser and urea prices seems to be consistently negative and significant at 1%, indicating the robustness of the results.

Table 3 focuses on the relationship between urea price and nitrogen fertiliser sales (measured in Kg per hectare of arable land) by means of different econometric techniques (OLS, FE, FE-IV). Regardless of the econometric technique used, urea prices have a negative and statistically significant

Table 2: Step-wise inclusion of explanatory variables in the FE-IV model.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Nitrogen sales	Nitrogen sales	Nitrogen sales	Nitrogen sales	Nitrogen sales	Nitrogen sales	Nitrogen sales
Urea price	-0.1986***	-0.3226***	-0.1983***	-0.3318***	-0.2799***	-0.1678***	-0.3874***
	(0.0199)	(0.0455)	(0.0255)	(0.0229)	(0.0365)	(0.0250)	(0.0409)
Trend		0.0035***					0.0071***
		(0.0009)					(0.0012)
Organic fertilisers			0.0020				-0.0185
			(0.0799)				(0.0772)
Cereal prices				0.4103***			0.4439***
				(0.0430)			(0.0457)
Other crops prices					0.1297***		-0.2010***
					(0.0470)		(0.0484)
Arable land						0.4475**	1.2750***
						(0.2175)	(0.1982)
County fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	691	691	691	691	691	691	691
F-statistic (instrument)	164.721	38.830	103.271	79.842	33.886	113.206	25.011
R-squared	0.1148	0.0726	0.1150	0.1710	0.0824	0.1363	0.2108

Note: Driscoll-Kraay robust standard errors are in parentheses, *** p<.01, ** p<.05, * p<.1. All variables are logged transformed. The estimation period is 1990-2022.
Source: own calculations

[14] The estimated correlation coefficient is 0.8 and significant at 1% level. A strong and positive correlation (0.9) has been also reported by IEA (2022) looking at the period 2016-2022.

[15] A value below 1 suggests that quantities (demand) will respond less than proportionally to a change in price, i.e. demand is inelastic.

[16] As already explained, the abolition of the fertiliser tax in 2009 implied a change in the policy framework. Therefore, additional regressions including a dummy variable accounting for this event have been run. The variable is not included in models presented in this article since it is not significant.

relationship with nitrogen fertiliser sales measured in Kg per hectare of arable land, with the parameters in the range of -0.2569 (OLS) to -0.3793 (FE-IV). Once again, a negative response of nitrogen fertiliser sales to changes in urea prices is found regardless the definition used for nitrogen fertiliser sales.

Table 4 presents the responsiveness of nitrogen supply of different types of crop by using a fixed effects model. In this case, FE is used instead of FE-IV since no suitable instrument has been identified. This could be partly explained by the smaller size of the sample used in this case. Focusing on the results, the relationship between urea price and nitrogen supply for cereals is negative and statistically significant at 5% level (Column 1). A similar type of negative and significant response is also identified in the case of other crop types (Column 3).

For a better understanding of the price responsiveness at regional level, Tables 5 and 6 present two additional sets of estimates. In Table 5, the first model (Column 1) is estimated by using a sample that only includes data for Skåne, Östergötland, Halland and Uppland, which are the Swedish counties with the highest average fertiliser consumption over 1990-2022. The second regression (Column 2) presents the results of estimating a similar model using a sample that excludes the four counties mentioned above. Overall, the results indicate that regions with a higher consumption of mineral nitrogen

Table 3: Sales of mineral nitrogen fertiliser measured in Kg ha^-1.

	(1)~OLS	(2)~FE	(3)~FE-IV
	Nitrogen sales	**Nitrogen sales**	**Nitrogen sales**
Urea price	-0.2569***	-0.2602***	-0.3793***
	(0.0618)	(0.0595)	(0.0991)
Trend	0.0047**	0.0041*	0.0059**
	(0.0020)	(0.0021)	(0.0026)
Organic fertilisers	0.1114***	-0.0130	-0.0349
	(0.0315)	(0.0585)	(0.0560)
Cereal prices	0.2790***	0.2909***	0.3696***
	(0.0880)	(0.1039)	(0.1162)
Other crops prices	-0.1296	-0.1395*	-0.1388*
	(0.0925)	(0.0739)	(0.0836)
Arable land	0.4181***	0.3590	0.3548
	(0.0411)	(0.2881)	(0.2661)
County fixed effects	No	Yes	Yes
Observations	691	691	691
F-statistic (instrument)	-	-	25.011
R-squared	0.4243	0.4093	0.1395

Note: Driscoll-Kraay robust standard errors are in parentheses, *** p<.01, ** p<.05, * p<.1. All variables are logged transformed. The estimation period is 1990-2022.
Source: own calculations.

Table 4: Nitrogen supply in Sweden per type using fixed effects model.

	(1)	(2)	(3)
	Nitrogen supply for cereals	**Nitrogen supply for slåttervall**	**Nitrogen supply for other crops**
Urea price	-0.0342**	-0.0306	-0.0766**
	(0.0157)	(0.0594)	(0.0315)
Organic fertilisers	-0.0004	0.2785***	-0.0428
	(0.0413)	(0.0910)	(0.0270)
Cereal price	0.0287*		
	(0.0150)		
Area for cereals	0.1615***		
	(0.0441)		
Trend	0.0118***	0.0138*	0.0165***
	(0.0014)	(0.0074)	(0.0033)
Area for slåtervall		-0.2182	
		(0.1553)	
Other crops price			0.0316
			(0.0362)
Area for other crops			0.1282***
			(0.0155)
County fixed effects	Yes	Yes	Yes
Observations	175	106	117
Pseudo R^2	0.5368	0.2416	0.7355

Note: Driscoll-Kraay robust standard errors are in parentheses, *** p<.01, ** p<.05, * p<.1. All variables are logged transformed. The estimation period is 1999-2022.
Source: own calculations

fertiliser have a lower price responsiveness.[17] In other words, those counties, which have higher fertiliser mineral nitrogen requirements, present a lower elasticity than those counties in which fertiliser needs are not as strong. Therefore, our results confirm the inelastic behaviour of fertiliser demand.

Finally, the Swedish counties are ranked (in quintiles) according to level of nitrogen fertiliser sales per year. More specifically, the first quintile includes the counties with the lowest mineral nitrogen fertiliser sales, while the fifth quintile gathers the counties with the highest nitrogen mineral fertiliser sales. The results presented in Table 6 are statistically significant at 1% in the case of each quintile. Moreover, the results suggest that at the lower quintiles the relationship between urea price and mineral nitrogen fertiliser sales is relatively more elastic than in those counties included in higher quintiles, i.e. counties in which fertiliser sales are higher.

These findings are similar to those reported by previous studies focusing on Sweden. In particular, Inglesson and Drake (1998) suggest that the elasticity of demand for nitrogen fertiliser is around -0.33. Mohlin (2013) provides estimates for the elasticity of demand for nitrogen fertiliser being around -0.27, while Konjunkturinstitutet (2014) indicates an elasticity of around -0.39. From a broader perspective, the negative and inelastic response of fertilisers to its own price has also been identified in other countries such as Bangladesh (Nasrin *et al.,* 2022), China (Pang *et al.,* 2021) or the United States (Chavas *et al.,* 2020).

Table 5: Nitrogen sales for counties with high usage of mineral fertiliser.

	(1)~FE-IV	(2)~FE-IV
	Nitrogen sales	**Nitrogen sales**
Urea price	-0.3171***	-0.4041***
	(0.0681)	(0.1181)
Trend	0.0053***	0.0071**
	(0.0016)	(0.0029)
Organic fertilisers	-0.2293***	0.1506
	(0.0550)	(0.1142)
Cereal prices	0.3303***	0.4643***
	(0.0929)	(0.1472)
Other crops prices	-0.1090	-0.2079**
	(0.0663)	(0.0874)
Arable land	0.8371**	0.9169***
	(0.3315)	(0.2885)
County fixed effects	Yes	Yes
Observations	132	559
F-statistic (instrument)	24.128	25.076
R-squared	0.1648	0.2304

Note: Driscoll-Kraay robust standard errors are in parentheses, *** p<.01, ** p<.05, * p<.1. All variables are logged transformed. Column 1 includes counties with high use of nitrogen, which are Skåne, Östergötland, Halland, Uppland. Column 2 includes the rest counties. The estimation period is 1990-2022.
Source: own calculations

Table 6: Sales of mineral nitrogen fertiliser measured in 1000 tons for different quintiles of mineral nitrogen sales.

	Quintile	Urea price coefficients	Mean value of nitrogen sales in 1000 tons
Lowest	1	- .5395***	1.03
	2	- .3774***	2.51
	3	- .3477***	4.57
	4	- .3508***	8.17
Highest	5	- .3075***	28.48

Note: Driscoll-Kraay robust standard errors are in parentheses, *** p<.01, ** p<.05, * p<.1. All variables are logged transformed. Control variables are Trend, Organic fertilisers, Cereal prices. Other crops prices. Arable land. County fixed effects included. FE-IV regression. The estimation period is 1990-2022.
Source: own calculations

Discussion and conclusions

This article has examined the demand nitrogen fertiliser price responsiveness in the case of Sweden. The econometric results confirm an inelastic and negative relationship between the demand for nitrogen fertiliser and its price. These results are in line with the existing literature and also provide further insights at the regional level. The outcomes of this piece of research have set the basis for further work that will be extended in the context of the SIMPLE project, which aims at delivering insights at the EU level.

From an economic point of view, it is important to quantify this type of responses (and make them available for the broader research community) since often agricultural economists rely on elasticities as the basis for their analysis, or they are used as input to calibrate models of a larger size. Outside the agricultural field, researchers from other disciplines can also benefit from this type of research. For instance, it is often the case that environmental models have a strong focus on representing technical aspects of agricultural activities without taking into account farmer behaviour.

Policy makers should be aware that in the short run the implementation of a tax on fertilisers (and the related price) will have a limited impact on its application. This can be expected in view of the inelastic behaviour that have been observed). Nevertheless, in the long run, higher fertiliser prices will ‘squeeze’ the profit margin for agricultural activities. Therefore, a reduction in mineral fertiliser affordability will create incentives to increase efficiency in its use, look for alternatives such as RENURE and reduce overfertilisation. Along the same lines, a reduction in subsidies to fertiliser purchases could trigger similar effects in the long run.

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[17] See, Matthews and Grové (2023) for further discusssion on the impact of increased fertiliser prices and its application.

References

Andersen, M.S. (2022): Fertiliser tax in Sweden. Available at: https://ieep.eu/wp-content/uploads/2022/12/SE-Fertiliser-tax-final_REV.pdf (Accessed on 5 June 2024).

Beckman, J. and Riche, S. (2015): Changes to the natural gas, corn, and fertiliser price relationships from the biofuels era. Journal of Agricultural and Applied Economics, **47** (4), 494–509. https://doi.org/10.1017/aae.2015.22

Bindraban, P.S., Dimkpa, C., Nagarajan, L., Roy, A. and Rabbinge, R. (2015): Revisiting fertilisers and fertilisation strategies for improved nutrient uptake by plants. Biology and Fertility of Soils, 51, 897–911. https://doi.org/10.1007/s00374-015-1039-7

Bumb, B. (1984): Studies on fertiliser demand a selected annotated bibliography. AGREP Division Working Paper No. 105. Available at: https://documents1.worldbank.org/curated/en/285181468914714875/pdf/Studies-on-fertiliser-demand-a-selected-annotated-bibliography.pdf (Accessed on 12 May 2024).

Chavas, J.P., Shi, G. and Stiegert, K. (2020): Pricing and Industry Structure when Demand Elasticity Changes. Review of Industrial Organization, **57** (4), 891–907. https://doi.org/10.1007/s11151-019-09745-y

Crespi, J.M., Hart, C., Pudenz, C.C., Schulz, L.L., Wongpiyabovorn, O. and Zhang, W. (2022): An Examination of Recent Fertiliser Price Changes. Staff Report 22-SR 117, June, Iowa State University. Available at: https://www.card.iastate.edu/products/publications/pdf/22sr117.pdf (Accessed on 22 March 2024).

Euronews (2024): Farmers hit by record high fertiliser costs since Ukraine war: Can nature-based solutions help? Available at: https://www.euronews.com/green/2024/02/19/farmers-hit-by-record-high-fertiliser-costs-since-ukraine-war-can-nature-based-solutions-h#:~:text=The%20price%20of%20fertiliser%20spiralled,to%20the%20average%20in%202020 (Accessed on 18 April 2024).

European Biogas Association (2023: Unlocking the safe use of RENURE products in the INMAP: an opportunity for nutrients recycling and on-farm circularity. Available at: https://www.europeanbiogas.eu/wp-content/uploads/2023/06/Open-Letter_RENURE-in-INMAP.pdf (Accessed on 5 March 2024).

European Commission (2022): Ensuring availability and affordability of fertilisers. Available at: https://agriculture.ec.europa.eu/common-agricultural-policy/agri-food-supply-chain/ensuring-availability-and-affordability-fertilisers_en#:~:text=The%20increase%20in%20prices%20has,agricultural%20yields%20mean%20less%20food (Accessed on 19 May 2024).

FAO (2022): The importance of Ukraine and the Russian Federation for global agricultural markets and the risks associated with the current conflict, 25 March 2022 Update. Available at: https://www.fao.org/3/cb9236en/cb9236en.pdf (Accessed on 12 March 2024).

Goretzki, P., Perekhozhuk, O., Glauben, T. and Loy, J.P. (2019): Price discrimination and market power in the international fertiliser market: Empirical evidence for exports from Russia. Agricultural and Resource Economics, **5** (2), 5–24. https://doi.org/10.51599/are.2019.05.02.01

Hu, N., Liu, C., Chen, Q., Fan, J., Wang, Y. and Sun, H. (2023): Substitution of Chemical Fertiliser with Organic Fertiliser Can Affect Soil Labile Organic Carbon Fractions and Garlic Yield by Mediating Soil Aggregate-Associated Organic Carbon. Agronomy, **13**, 3062. https://doi.org/10.3390/agronomy13123062

Huang, W.-Y. (2007): Impact of Rising Natural Gas Prices on U.S. Ammonia Supply. Washington DC, U.S. Department of Agriculture, Economic Research Service.

IEA (2022): Correlation between gas and urea fertiliser price indices, 2016-2022, June 14. Available at: https://www.iea.org/data-and-statistics/charts/correlation-between-gas-and-urea-fertiliser-price-indices-2016-2022 (Accessed on 8 May 2024).

Incitec Pivot Fertilisers (2021): Urea, Factsheet, November. Available at: https://www.incitecpivotfertilisers.com.au/~/media/Files/IPF/Documents/Fact%20Sheets/32%20Urea%20Fact%20Sheet.pdf (Accessed on 12 March 2024).

Inglesson, M. and Drake, L. (1998): Price Elasticity of Nitrogen in Sweden. Swedish Journal of Agricultural Resources, **28**, 157–165.

Işik, S. and Özbuğday, F.C. (2020): The role of tax cuts on agricultural input prices in Turkey Studies in Agricultural Economics, **122** (3), 167–171. https://doi.org/10.7896/j.2070

Islam, N. and Mujeri, M.K. (2021): Fertiliser policy in Bangladesh: State intervention in markets and prices, Chapter 5. Available at: https://www.ifpri.org/publication/fertiliser-policy-bangladesh-state-intervention-markets-and-prices (Accessed on 5 February 2024).

Jabbar, M.A. and Islam, M.S. (1981): Elasticity of demand for fertiliser and its implication for subsidy. Bangladesh Journal of Agricultural Economics, **4** (1), 47–57.

Konjunkturinstitutet (2014): Miljö, ekonomi och politik 2014. Available at: www.konj.se (Accessed on 13 March 2024).

Kopper, S.A. (2018): Agricultural labor markets and fertiliser demand: Intensication is not a single factor problem for non-separable households. Available at: http://barrett.dyson.cornell.edu/NEUDC/paper_540.pdf (Accessed on 28 March 2024).

Ladha, J.K., Pathak, H., Krupnik, T.J., Six, J. and van Kessel, C. (2005): Efficiency of Fertiliser Nitrogen in Cereal Production: Retrospects and Prospects. Advances in Agronomy, **87**, 85–156. https://doi.org/10.1016/S0065-2113(05)87003-8

Matthews, N. and Grové, B. (2023): Economic evaluation of increased nitrogen fertiliser prices on risk-efficient fertiliser applications. Outlook on Agriculture, **52** (4), 434–445. https://doi.org/10.1177/00307270231194080

Mohlin, K. (2013): Essays on environmental taxation and climate policy. Available at: https://gupea.ub.gu.se/handle/2077/33425 (Accessed on 12 May 2024).

Murtazashvili, I. and Wooldridge, J.M. (2008): Fixed effects instrumental variables estimation in correlated random coefficient panel data models. Journal of Econometrics, **142** (1), 539–552. https://doi.org/10.1016/j.jeconom.2007.09.001

Nasrin, M., Vortia, P., Salam, S. and Palash, M.S. (2022): Is fertiliser demand elastic to its own price? Assessing the consequences of fertiliser subsidy policy in Bangladesh. SN Business and Economics, **2**, 110. https://doi.org/10.1007/s43546-022-00289-0

Nygårds, J. and Svenungsson, E.S. (2020): The elasticity of demand for phosphorus fertilisers in Swedish agriculture - a panel data study of price effects on phosphorus compounds in chemical fertilisers. Available at: https://stud.epsilon.slu.se/15990/7/nygards_j_svenungsson_e_200914.pdf (Accessed on 14 March 2024).

Pang, Y., Dang, J. and Xu, W. (2021): Elasticity of substitution, price effect and sustainable fertiliser use: A TRANSLOG and SUR analysis in china. Prague Economic Papers, **30** (2), 189–215. https://doi.org/10.18267/j.pep.764

Penm, J.H. and Vincent, D.P. (1987): Some estimates of the price elasticity of demand for phosphatic and nitrogenous fertilisers. Australian Journal of Agricultural Economics, **31** (1), 65–73.

Penuelas, J., Coello, F. and Sardans, J. (2023): A better use of fertilisers is needed for global food security and environmental sustainability. Agriculture and Food Security, **12,** 5. https://doi.org/10.1186/s40066-023-00409-5.

Rawashdeh, R.A. (2023): Estimating short-run (SR) and long-run (LR) demand elasticities of phosphate. Mineral Economics, **36**, 239–253. https://doi.org/10.1007/s13563-021-00294-z

Ren, K., Xu, M., Li, R., Zheng, L., Liu, S., Reis, S., Wang, H., Lu, C., Zhang, W., Gao, H., Duan, Y. and Gu, B. (2022): Optimizing nitrogen fertiliser use for more grain and less pollution. Journal of Cleaner Production, **360**, 132180. https://doi.org/10.1016/j.jclepro.2022.132180.

Ritchie, H. (2021): Can we reduce fertiliser use without sacrificing food production? Published online at OurWorldInData.org. Available at: https://ourworldindata.org/reducing-fertiliser-use (Accessed on 10 April 2024).

United Nations Environment Programme (2020): Study on the effects of taxes and subsidies on pesticides and fertilisers. Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/33582/STSPF.pdf?sequence=1
(Accessed on 10 March 2024).

USDA (2022): Impacts and Repercussions of Price Increases on the Global Fertiliser Market. International Agricultural Trade Report. Available at: https://fas.usda.gov/data/impacts-and-repercussions-price-increases-global-fertiliser-market (Accessed on 22 March 2024).

Xu, W., Liu, W., Tang, S., Yang, Q., Meng, L., Wu, Y., Wang, J., Wu, L., Wu, M., Xue, X., Wang, W., Luo, W. (2023): Long-term partial substitution of chemical nitrogen fertiliser with organic fertilisers increased SOC stability by mediating soil C mineralization and enzyme activities in a rubber plantation of Hainan Island, China. Applied Soil Ecology, **182**, 104691. https://doi.org/10.1016/j.apsoil.2022.104691

Wooldridge, J.M. (2019): Introductory Econometrics: A Modern Approach, 7th Edition. South-Western College Publishing.

Annex

Table A.1: Overview of variables/sources.

Variable	Source	Comments
Mineral nitrogen fertiliser sales	Statistics Sweden	Data for 21 counties in Sweden covering sales period from 1/7/1989 -30/6/1990 to 1/7/2021 - 30/6/2022 (annual data)
Organic fertiliser	Derived. Own compilation.	Calculated as livestock units * excretion coefficients.
Livestock units (animal heads)	Jordbruksverket	Including milk cows, other cow types, sheep, pigs, piglets, geese, layers, and broilers across the 21 Swedish regions. Annual data over the period 1990-2022
Nitrogen excretion coefficients	European Commission	Only available for 2009. Kept constant for the whole period
Arable land	Jordbruksverket	Total arable land across each Swedish region – including land dedicated to cultivating crops like mixed grain, potatoes, oats, barley, grain, rye, rapeseed, sugar beet, and triticale. Annual data over the period 1990-2022
Cereals prices	Statistics Sweden, Jordbruksverket	Annual data over the period 1990-2022 (unweighted average of wheat, rye, barley and oats prices)
Other crops prices	Statistics Sweden, Jordbruksverket	Annual data over the period 1990-2022 (unweighted average of sugar beet, potatoes and rapeseed prices)
Urea prices	IndexMundi/World Bank	Since October 1993 monthly data is published by IndexMundi. World Bank data for urea prices is used for the period 1990-1993
Natural gas price	Federal Reserve Bank of St. Louis	Monthly data from January 1990 to December 2022
Exchange rate (USD/ Swedish krona)	Swedish Central Bank	Monthly data covering the period 1990-2022

Source: own composition

Table A.2: Descriptive statistics for the variables used in the analysis.

Variable	Metric	Mean	Std. Dev.	Min	Max	Obs.
Sales of Nitrogen	1000 tons	8.85	11.85	0.4	57.3	691
Sales of Nitrogen	Kg ha^{-1} of arable land	60.61	27.79	7	135	691
Organic fertiliser	Kg	4,070,265	4,008,625	886,785.7	24,200,000	693
Arable land	ha	127,135.5	117,591.1	30,083	506,742	963
Urea price	SEK t^{-1}	1,702.89	1,079.12	595.61	6,291.52	963
Natural gas price	SEK $MMBTU^{-1}$	47.07	40.58	11.52	236.79	963
Cereal price	Kr 100 kg^{-1}	125.29	40.33	86.25	292.38	963
Other crops price	Kr 100 kg^{-1}	142.46	52.78	47.87	311.56	963

Note: Kg: Kilograms; ha: Hectares, SEK t^{-1}: Swedish Krona per metric ton; SEK MMBTU-1: Swedish Krona per Million Metric British Thermal Units; Kr 100 kg^{-1}: Swedish Krona per 100 kilograms. Sales of Nitrogen contain 691 obs (two obs less than the rest variables) because the regions Jönkoping and Kronobergs have missing values for the year 1991.
Source: own composition