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- a panel data study of price effects on phosphorus compounds in chemical fertilisers

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Abstract

Chemical fertilisers are common in the Swedish agriculture and even though there is a decreasing trend of using chemical fertilisers, they still have major negative impact on the environment (Swedish Board of Agriculture, 2019). This study focuses on the price elasticity of demand for phosphorus fertilisers in Swedish agriculture and how price changes of phosphorus fertilisers affect farmers. The aim is to contribute with estimations of the price effects on Swedish demand of phosphorus fertilisers.

A panel data set is used to estimate a log-log model through an OLS-technique. The data set is mainly aggregated on county level with data from fifteen southern counties in Sweden. Five models are produced with various number of variables. The results show that the long run price elasticity of phosphorus is approximately (-0.449) which indicates that phosphorus content in fertilisers is inelastic. The results also show that four out of five variables are significant.

The result from this study is in line with previous studies on nitrogen fertilisers. In addition, the conclusion is that farmers are affected by price changes to some extent. Yet a tax would not dramatically decrease the use of phosphorus fertilisers. However, a tax policy has several intentions and a combination of a small decrease in the use of fertilisers and a governmental tax revenue would enable investments in green technology and in the agricultural sector.

This study also discusses different policy instrument as a possible future solution. For instance, an import tariff would target unsustainable foreign phosphorus supply and simultaneously encourage innovation to enable domestic and sustainable extraction of phosphorus.

Contents

1 Introduction

Here we present the background of the study as well as the problem description and research question. Limitations are also presented in this section.

1.1 Problem description

Chemical fertilisers are heavily used in the Swedish conventional agriculture. Approximately 800 000 metric tonnes were sold in 2017/18 according to statistics from the Swedish Board of Agriculture (2019). Biochemical compounds, which are the building blocks in chemical fertilisers, cause negative environmental externalities in different ways. The most common compounds in chemical fertilisers are nitrogen, phosphorus and potassium. In addition, eutrophication of nitrogen and phosphorus from soils is one of the greatest environmental challenges, referred to as a planetary boundary in reports published by Stockholm Resilience Centre (Steffen, et al., 2015).

There is a decreasing trend in usage of chemical fertilisers in Swedish agriculture and horticulture. Meanwhile it is important to notice that there are several factors that matter when discussing sold quantity (Swedish Board of Agriculture, 2019). The arable land has increased in Sweden during the past years and simultaneously the technology for agriculture and its products has developed. An example of this is precision agriculture which can be used for more efficient agriculture, both economically and environmentally (Mallarino, 2014). Through precision farming, farmers can analyse the optimal level of fertiliser use with data brought from the soils. In most cases this result in a decreased use of fertilisers.

Phosphorus is a finite resource predominantly mined in four different countries; Morocco, USA, China and Russia, where Morocco owns approximately 75 percent of the global phosphorus reserves (Rosengren, 2019). This means that Swedish phosphorus supply is very much dependent on the world market supply. Peak phosphorus is a much-debated potential future risk, which will occur when global phosphorus mining reaches the maximum production level. Researchers have tried to estimate the time of peak phosphorus and they present different results and estimations (Cordell & White, 2011, p. 2032). However, the shared insight is that phosphorus eventually will run out, and the time of that outcome depends on the level of human extraction. The uneven distribution of phosphorus reserves raises the question of security challenges and the Swedish self-sufficiency in a world which tends to be more politically unstable (Blackwell, et al., 2019).

Sweden has had different types of taxation on chemical fertilisers since 1984, as explained by Bengtsson et al. (2014). In 1984 an environmental fee was implemented on nitrogen and phosphorus content in fertilisers. However, in 1995 the fee was changed to a tax on nitrogen and cadmium with a taxation level of approximately 1.80 SEK per kilo nitrogen and 30 SEK per gram cadmium. Cadmium is a toxic compound in phosphorus fertilisers. Previous studies have shown a correlation between the price of fertilisers and the level of the tax/fee. Söderholm and Christiernsson (2008) have presented a review of different countries' policy regulations on chemical compounds and how it has affected the price and demand. In the article, they show that the Swedish demand of chemical fertilisers during the period of 1991 to 1992 was at its lowest point and that it correlated with the highest tax rate of approximately 30 to 35 percent of the fertilisers sale price (Söderholm & Christiernsson, 2008).

In 2009 the Swedish tax on chemical fertilisers was abolished. According to Bengtsson et al. (2014), there were two main arguments: the tax was not efficient enough as a policy instrument since it did not decrease the use of fertilisers to a sufficient extent. Furthermore, the second argument for the abolishment was a willingness to strengthen the Swedish agriculture and its international competitiveness by lowering Swedish farmers' costs.

1.2 Aim and research question

The aim of this study is to contribute with estimations of the price effects on Swedish demand of phosphorus fertilisers. Researchers have this far put a lot of effort into nitrogen research and estimating models for nitrogen demand and price elasticities. However, phosphorus, which create concern among environmental researchers (Steffen, et al., 2015), has not been studied as much from an economic point of view.

Focusing on the problem description above, this study intends to answer the following research question:

- *How is Swedish farmers' demand of chemical phosphorus fertilisers affected by price changes of phosphorus on the world market?*

Furthermore, we want to provide policy makers with useful insights about the efficiency of taxation on phosphorus fertilisers in today's agriculture by using well known theories and methods. In the discussion we also highlight some possible future tax policies in the context of chemical fertilisers in Swedish agriculture.

This study uses a fixed effect panel data regression model to answer the research question with data sets for the 15 southernmost counties of Sweden (to compare with the total number of 21 counties). The hypothesis in this study is that the price elasticity of chemical phosphorus fertilisers is inelastic. This is in line with previous studies on nitrogen fertilisers which we assume is comparable to this study.

1.3 Delimitations

To answer the research question this study has some limitations. The study is limited to only estimate the price elasticity of chemical phosphorus fertilisers in Swedish agriculture and no other countries' price elasticities. By focusing only on phosphorus and farmers' demand of it, the study disregards other chemical substances such as nitrogen and potassium in chemical fertilisers. However, nitrogen has been studied a lot more frequently and the results from those studies are used in this study for comparison.

1.4 Disposition

Section one presents problem description about the subject as well as aim and research question. In section two a literature review will be given while section three provides the reader with knowledge about theories and methods that are used. Section four displays the data and variables which are used in the regression analysis and in section five the results are presented. Further on, in section six a discussion and analysis about the results are conducted and in section seven we summarise the thesis and present our conclusion as well as suggestions to further research.

2 Literature Review

In this section a brief summary of earlier work and studies are presented. The purpose is to give a broader background to why this study is needed and how it will contribute to already existing literature with new facts and perspective.

Many researchers have contributed to this field of research to improve the understanding of how taxation on chemical compounds affects agriculture and the use of fertilisers. Ingelsson and Drake (1998) published a study of price elasticities on nitrogen fertilisers in Sweden. The study is interesting mainly for two reasons – the chosen independent variables and the results. It is also interesting because of its way to conduct the elasticity function through a profit function instead of a cost function, which is the normal case when calculating an elasticity function. The results show that the short run price elasticity for nitrogen in Sweden is – 0.33 if using a log-log model. By applying a charge on nitrogen, the problem with eutrophication from nitrogen leaching would be reduced but it is necessary to use other policies as well to solve the problem.

Drake (1991) presented a study where he analyses the price elasticity of nitrogen in chemical fertilisers. This study provides good information about how and why variables can be used as dummy variables in the regression analysis. The results show that the price elasticity for nitrogen in chemical fertilisers is inelastic. The results also show that the tax on nitrogen in chemical fertilisers (0.60 SEK/kilo nitrogen in chemical fertilisers), which was imposed in 1988, had an effect on the use of fertilisers. The use of chemical fertilisers decreased by 1.96 – 2.61 percent after the tax was implemented.

Denbaly and Vroomen (1993) established a study where they estimated the price elasticity for fertiliser nutrients used in corn production in the U.S. Through both a unit-root test and a cointegration test the study's results show that the short-run price elasticity for phosphorus in fertilisers is (-0.25). For the long-run price elasticity the result is (-0.37). Compared to earlier studies which had used static models, this study has used a dynamic model to conclude the results. The authors claim that their results show evidence that a tax would not have much of an effect on the use of fertilisers.

A study from Mohlin (2012) argues about the importance of fertilisers in agriculture and how their use affects the yield from crops. Simultaneously fertilisers are a major problem for the environment with their leakage of nutrients and eutrophication to land and water. Like other previous studies the article discusses potential, economic and environmental, effects of using a tax on nitrogen. The results show that an abolishment of the earlier Swedish tax on nitrogen would lead to an increase in both use of fertilisers as well as increase in nitrogen emissions. In addition, the study highlights that it is of importance that this topic, environmental effects from fertilisers, is subject for more research. It is also of importance to come up with more efficient policy instruments to better understand and solve the problem.

Söderlund and Christiernsson (2008) published their review "Policy effectiveness and acceptance in the taxation of environmentally damaging chemical compounds" where they have compared different countries taxation policies for chemical compounds and its effectiveness. They conclude that even though taxes may have an effect in reducing fertiliser use, it is important to choose the right choice of tax scheme design to best accomplish a result, both for the economy as well as the environment.

In our review of available literature, we find that the research mainly covers different aspects of nitrogen fertilisers and the related environmental pollution. Many researchers have estimated the price elasticity of nitrogen in chemical fertilisers to be able to provide policy makers with useful knowledge of effective tax policies on fertilisers. However, phosphorus and potassium together account for approximately a third of the mass of sold chemical fertilisers. We find it interesting to establish a model for phosphorus demand similar to the existing models for nitrogen demand in Sweden to be able to compare the results of the two chemical compounds. We also think it is important to study phosphorus chemical fertilisers from an economic approach. This could help policy makers understand what factors affect the demand of phosphorus fertilisers and how an implemented tax policy on fertilisers would affect the Swedish agriculture.

3 Data

The following section presents the different variables used in this study as well as some descriptive statistics of the variables.

The data set is mainly aggregated on county (län) level with data from 15 counties in Sweden, from Skåne in the south to Uppsala, Västmanland and Värmland in the north. During the time period 1997-2018 the county of Skåne has merged together with f.d. Malmöhus county and f.d. Kristianstads county while Västra Götaland county has merged with f.d. Göteborgs o Bohus county, f.d. Älvsborgs county and f.d. Skaraborgs county. Therefore, these counties are respectively compiled together.

Swedish agriculture differs a lot between the southern and the northern regions whereas the northern regions are more oriented towards animal production since those counties are less suitable for cultivation, facing much more difficult agricultural conditions (Asplund, et al., 2019). The counties which are excluded from the regression are Dalarna, Gästrikland, Hälsingland, Härjedalen, Medelpad, Jämtland, Ångermanland, Västerbotten, Norrbotten and Lappland. Another important reason for why the northern counties is not included is that the Swedish Board of Agriculture and Statistics Sweden are missing the majority of accurate data from these regions during the time period 1997-2018. Therefore, we do believe that the results will be biased if these counties would be included in the regression.

Data are mainly taken from the Swedish Board of Agriculture, Statistics Sweden and the World Bank. It has not been possible to find data for all years and all variables since both the Swedish Board of Agriculture and Statistics Sweden are missing data for some variables during some years. In addition, we assume both databases are trustworthy since they act on behalf of the Swedish government (Statistics Sweden, u.d.) (Swedish Board of Agriculture, 2020).

The data set we use is chosen because we think it can give an objective result which also is realistic. The used variables are also described in the literature review as important factors for those studies. Since this study partially replicate some of those studies, we think the chosen variables are correct to use in the regression model.

3.1 Variables

Here we present all variables which are included in the estimated models.

3.1.1 Total volume of sold phosphorus content in chemical fertilisers

As dependent variable we use the total volume of sold phosphorus content in chemical fertilisers aggregated on county level. By defining this variable as the dependent, the results will answer the research question. The data for the dependent variable is taken from Statistics Sweden (2020) and transformed into a logarithmic form.

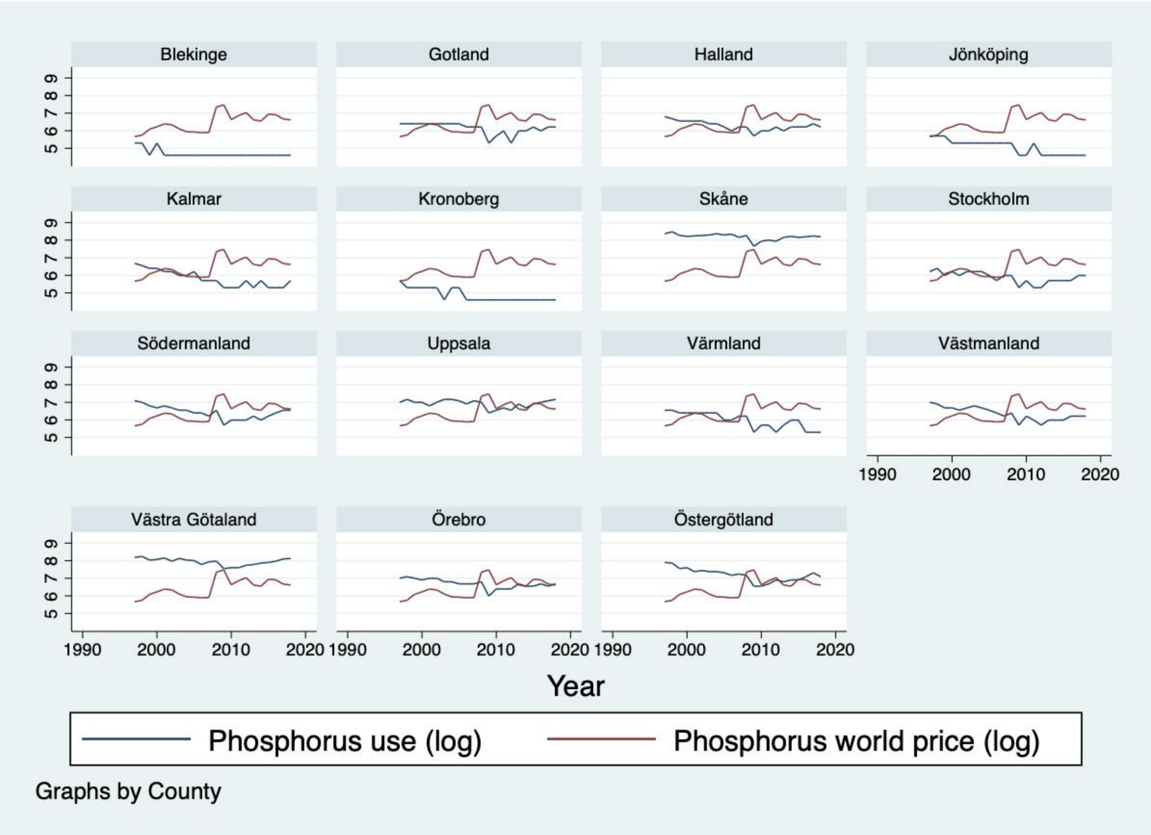
3.1.2 World price of phosphorus rock

In the best possible scenario, we would include farm gate price of phosphorus fertilisers as price variable. Since such data is not available, we use world price data of mined phosphorus. One strong assumption in this study is that Swedish supply of phosphorus compounds in fertilisers are strongly related to the world price of phosphorus. Swedish phosphorus supply is dependent on imports from foreign countries outside the European Union (Rosengren, 2019). Originally the prices are shown as dollar per million tonnes. This is converted to SEK per kilogram with exchange rates provided from the World Bank. The phosphorus rock is shipped from North Africa which is the place where most of the world's phosphorus uptake occurs (Rosengren, 2019) (The World Bank, 2020).

The price data which are used in this study are not aggregated to county level. This implies that the study cannot show any specific price effects for each county. However, we assume that all counties are affected by the world price simultaneously.

Other available data which could be used to describe the price relation is Swedish price indices of chemical fertilisers. The reason why this data is not included is that it is weighted together with prices for nitrogen and potassium fertilisers. In addition, nitrogen fertilisers are by far the most used fertiliser compound and therefore we argue that the weighted price indices are not accurate enough.

Figure 1. Phosphorus use and world price (logged variables). Swedish counties 1997-2018
Source: Swedish Board of Agriculture, World Bank, own processing.



3.1.3 Cultivated land per county area

The ratio between cultivated land area for the five largest cereal crops and total land area in each county is used as an explanatory variable to describe Swedish farmers' demand of chemical phosphorus fertilisers. The five largest crops in Sweden are wheat (winter and spring), oat, rye, barley and triticale. The total cultivated area has been summed up and divided by the counties' total land area (Swedish Board of Agriculture, 2019). This variable is included in the model to account for land quality and the agricultural density. One assumption is that large farms in regions with a high density of agricultural businesses use more fertilisers than smaller farms in regions with less agriculture production. This assumption is based on the idea that a high density of large farms in a specific region implies that the land quality is good for agriculture.

In this regression both conventional and organic cultivated land have been included in the land variable since the Swedish Board of Agriculture does not separate conventional agriculture and organic agriculture in their data sets. In 2018 approximately 20 percent of the total arable land was classified as organic arable land. For the last fifteen years this is a value that has increased by each year (Swedish Board of Agriculture, 2019). Since organic farming by definition does not use chemical fertilisers, this create bias which we cannot control for in the model. However, we argue that it is still a variable of interest for this study.

3.1.4 Total harvest per county area

One explanatory variable used in some models is total harvest (per ton) for the five largest cereal crops; wheat (winter and spring), oat, rye, barley and triticale. For this variable some data are missing. A reason to this can be that the Swedish Board of Agriculture bases the data on a selection of agricultural firms, hence it may lead to some misleading of data. Organic harvest is also included in this data which may lead to bias (Swedish Board of Agriculture, 2019).

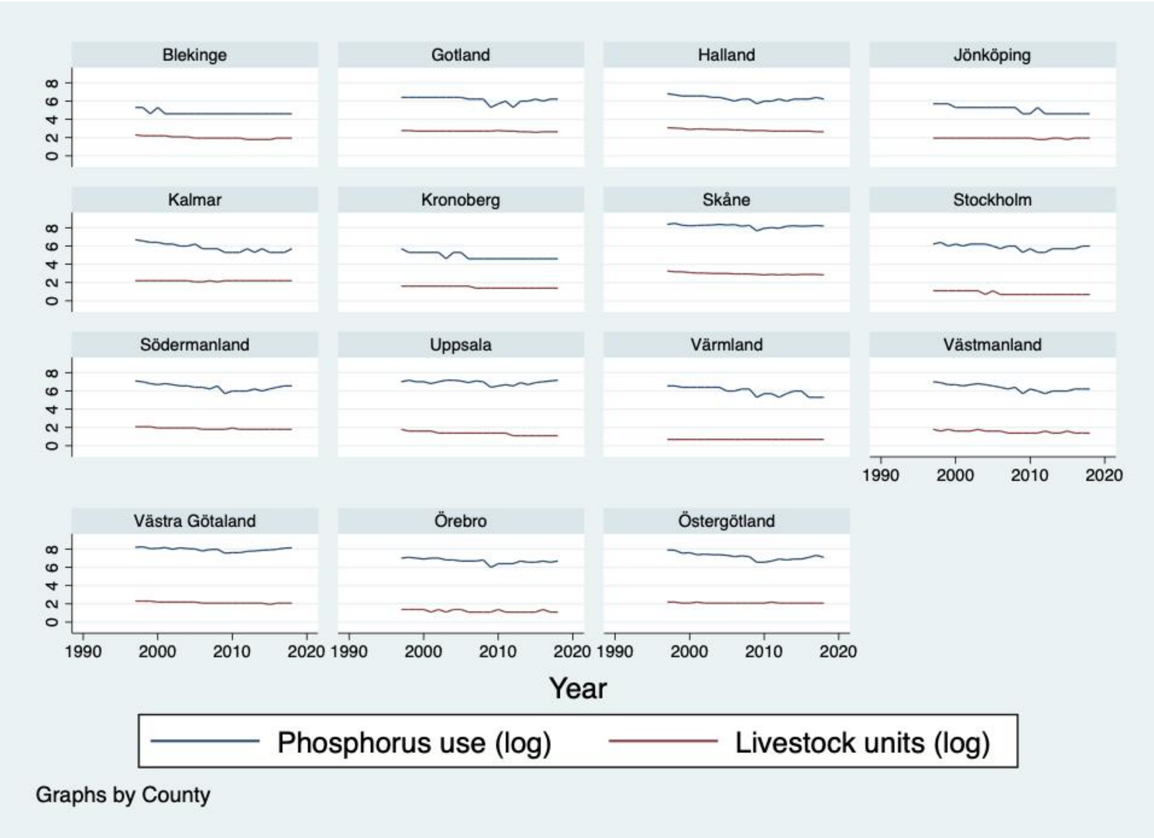
Since the counties in Sweden are of different size areas the total harvest in each county has been divided by the area of the specific county. This leads to a ratio between total harvest and total land area in each county which we think, when running the regression, leads to more realistic results. Total harvest is included in one model to account for the level of fertiliser use. There is a strong connection between fertiliser use and yield since the main purpose of fertilisers in agriculture is to increase the harvest.

3.1.5 Livestock units per county area

Livestock units are included in the regression model as an explanatory variable to account for the possible substitution between chemical phosphorus and animal manure. We exclude broilers, horses and turkeys since the data for these animals were missing (Swedish Board of Agriculture, 2019). Livestock units is a well-established way of counting and comparing animal density based on the animal's volume (Miljöhusesyn, u.d.). This variable is also divided by each specific county area to get a ratio between livestock units and total land area in each county.

When estimating the livestock unit for each species we had to re-estimate some of the species so the data would fit better. Calves under one year is equal to calves up to six months, slaughter pig (20 kilogram and up) is equal to slaughter pig older than twelve weeks, piglets (under 20 kilogram) is equal to three sows including piglets up to twelve weeks and chickens are equal to the average value of laying hens and “young” hens.

Figure 2. Phosphorus use and total number of animals (logged variables).
Swedish counties 1997-2018. Source: SBA, own processing



3.2 Descriptive Statistics

Table 1 shows the descriptive statistics of the presented variables included in this study during the time period 1997 – 2018 for all 15 counties. The descriptive statistics show the logged values for the variables.

Table 1 Descriptive statistics. All variables are logged.

Variables	Observations	Units	Mean	Variance	Standard errors	Min	Max
Phosphorus use	326	Tonnes/year /county	6.319717	1.039508	1.019563	4.60517	.6931472
Phosphorus price	326	SEK/kg	6.4498	.2532191	.5032088	5.666427	7.477038

Cultivated area	326	Hectare	1.79409	.6771675	.8229019	0	3.044523
Harvest	326	Hectare	3.139593	1.183152	.8229019	0	6.206576
Livestock units	326	Livestock units	1.855335	.4440567	.6663758	.6931472	3.258096

4 Theory and Methodology

This section presents theories of relevance for this study. It will also present the methodology that the study is following when conducting the results.

4.1 Price Elasticity of Demand

Elasticities are derived to see a relation between two variables, shown in percentage. In this study, the function that is obtained from the panel data regression will be derived with respect to price. The general function for the Marshallian price elasticity of demand is (with respect to g):

$$e_{f,g(f)} = \frac{\Delta f/f}{\Delta g/g} = \frac{\partial f}{\partial g} * \frac{g}{f} \tag{1}$$

In this case, f equals demanded quantity and g equals price. The other variables are being hold constant since we want to see the impact of a change in only one specific variable. If $e_{f,g(f)} = -1$ then the changes in the concerned variables are the same proportionate size. If $e_{f,g(f)} < -1$ then the quantity (= f) changes more than the price (=g) changes and if $e_{f,g(f)} > -1$ then the quantity changes less compared to changes in price – inelastic good (Snyder & Nicholson, 2010). Depending on the value of the elasticity, consumers are different sensitive towards a change in price. For example, if $e_{f,g(f)} = -2$ then a 1 % increase in price leads to a 2 % decrease in the dependent variable, in this case demanded quantity (Perloff, 2014).

By assuming the equation $y = x_1^{\alpha} * x_2^{\beta} * e^{\varepsilon}$, one can calculate the elasticities of demand via logarithms instead of doing the deriving process. When the equation is logged, the α and β show the elasticity for each independent variable. Now the equation is $\log y = \alpha \log x_1 + \beta \log x_2 + \varepsilon$ where ε equals the error term in the model. Since all variables are logarithmic, a one percent change in an independent variable will show a certain percent change in the dependent variable as well (Perloff, 2014).

The long run elasticity of demand in this study is computed by adding the sum of the variables *world price phosphorus* and *world price phosphorus (lagged)* (see Table 2 in section 5).

4.2 Ordinary Least Square

Ordinary Least Square (OLS) regression is the most common regression technique used when estimating econometric models. By squaring the used coefficients in the model one gets a linear regression that is as close as possible to the real parameters. An OLS regression can be used both with one coefficient as well as with plural coefficients (Stock & Watson, 2015). In this study a multiple linear regression with OLS-technique will be used.

When estimating an OLS-model standard errors are included. They are used to illustrate how much the sample mean vary from the standard deviation of the sampling. Standard deviation measures the spread of a sample. The bigger the sample size is, the smaller the standard error becomes (Stock & Watson, 2015).

A logarithmic regression model is used to directly see the percentage change in the variables. A one percentage change in any of the independent variable is connected to a percentage change in the dependent variable (Stock & Watson, 2015). Therefore, one can easily see the elasticity in the results since all is written in terms of percentages. See equation (1).

4.3 Panel Data

This study uses panel data, also known as longitudinal data, to achieve the results through a regression. Panel data consists of a various number of entities, i, collected from multiple time periods, t (Stock & Watson, 2015). In this study the time period 1997 – 2018 is observed and the entities are fifteen Swedish counties, i, where Västmanland is the northernmost county and Skåne is the southernmost county.

Stock & Watson (2015) mean that by using a fixed effect regression one can control for omitted variables without actually observing them. According to Qian (2014) panel data with fixed effects can fix the problem with endogeneity without using an instrumental variable (an exogenous variable which correlate with one or more independent variable).

By using a fixed effect regression for the panel data, the used variables might vary between counties but not over time (Stock & Watson, 2015). Mohlin (2012) uses fixed effect regression in her study and refers to that the variables might affect land allocation and nitrogen use, but still be time invariant. This is something this study replicates since we believe that the used counties in the regression have different values of the variables but are time invariant.

In an ideal panel data set, there is a balanced panel where no observations are missing. However, in this study the dataset is unbalanced meaning that for some time periods, observations are missing (Stock & Watson, 2015). According to the Swedish Board of Agriculture (2020) and Statistics Sweden (2020), the missing data has different reasons, mainly because it has not been possible to collect certain data. Nevertheless, all models used in this thesis can be used with unbalanced data because of the regression software (STATA) that is used (Torres-Reyna, 2007).

To accomplish the results in this study a fixed-effect regression is used, through an OLS-technique. The estimated regression model is shown below;

$$log\, y_{i,t} = \beta_0 + \beta_1 logP_t + \beta_2 logP_{t-1} + \beta_3 logL_{i,t} + \beta_4 logH_{i,t} + \beta_5 logA_{i,t} + Z_i + \varepsilon_{i,t} \qquad (2)$$

The dependent variable $Y_{i,t}$ is the volume of phosphorus content in sold chemical fertilisers in county i in year t. β_0 is the intercept/constant and the parameters $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ are the different regression coefficients associated with the various explanatory variables. P_t is the world price of mined phosphorus, P_{t-1} is a lagged variable of world price of mined phosphorus. $L_{i,t}$ represent the arable land in each county divided by the total area in each county. $H_{i,t}$ is the total harvest in each county, divided by the total area in each county, expressed in metric tonnes. $A_{i,t}$ is the total number of livestock units in each county divided by the total area in each county. Z_i is an unobserved variable which varies over county but not over time, it represents the county fixed effect in the model.

One assumption in this study is that farmers are affected by the world price level of phosphorus rock previous year. The supply chain of phosphorus fertilisers is complex, and it is reasonable that the farm gate price of phosphorus fertilisers will have lagged effect compared to the world price of phosphorus rock due to delivery time and farmers long-term planning. To account for that, the price variable has been lagged (t-1) in three of the models.

5 Results

In this section the findings of this study are presented. All five models are explained and in Table 2 one can see the values of the coefficients.

The focus is on the phosphorus price variable since it is of most relevance for the research question. All results are presented in tables below. All models are estimated with logged variables which mean that the regression coefficients are interpreted as elasticities. The regression models also use robust standard errors to account for heteroscedasticity.

In table 2, five different econometric models are presented. Model (1) is the most basic model which only reflects the world market price of phosphorus rock. As shown in Table 2, this regression model results in a regression coefficient of (-0.424) for the world price variable. This means that the short run price elasticity of phosphorus is (-0.424) which implies that phosphorus content in fertilisers are inelastic ($0 < | \varepsilon | < 1$). If the price increases by 1 percent the demand would decrease by 0,424 percent. The coefficients in model (1) are statistically significant at 1% level.

Model (2) also includes a lagged world price variable to control for effects from the previous year. In this model, the regression coefficient for world price of phosphorus rock is (-0.183). In addition, the coefficient for the lagged price variable is (-0.307). All coefficients are statistically significant at 1% level. The price elasticity over two years which are referred to as long run elasticity is estimated through the world price variable and the lagged world price variable. In model (2) the long run elasticity is [(-0.183) + (-0.307)] = (-0.49).

In model (3) we add a variable for cultivated arable land. In this model, the results imply that the variable *cultivated area* has greatest effect on the dependent variable. In model (4) the variable for harvest is also included. The results from model (4) show that all coefficients included are statistically significant at 1% level.

In model (5) we combine all significant variables except the variable for harvest which is excluded. We also add a variable which describes the number of livestock units per county. In this model all variables are significant except livestock units. By analysing Figure (2) showing the number of animals it is clearly shown that the total number of animals in respectively county has been relatively stable during the period 1997-2018. The data set does not show a significant trend over the studied time period (see figure 2).

In models 2 – 5 the regression coefficient for the logged variable of world price of phosphorus rock varies between –0.183 (model 4) and –0.201 (model 5). This is a small variation which does not create any significant difference for the analysis of these results. In these models the observations are respectively 311 while in model (1) there are 326 observations. This is explained by the variable world price phosphorus (lagged), which is included in models 2 – 5.

The short run elasticity is shown through the world price variable and thus varies between

(-0.183) and (-0.201). In addition, the estimated long run elasticity is approximately (-0.449), in model (5).

Table 2 Regression results
Price and demand of phosphorus fertilisers. Swedish counties 1997-2018

Table 1	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Variables	Sold phosphorus	Sold phosphorus	Sold phosphorus	Sold phosphorus	Sold phosphorus
World price phosphorus	-0.424***	-0.183***	-0.184***	-0.201***	-0.192***
	(0.037)	(0.021)	(0.020)	(0.023)	(0.023)
World price phosphorus (lagged)		-0.307***	-0.254***	-0.282***	-0.257***
		(0.037)	(0.042)	(0.037)	(0.043)
Cultivated area			0.485***		0.505***
			(0.149)		(0.162)
Harvest				0.266***	
				(0.045)	
Livestock units					-0.109
					(0.172)
Constant	9.053***	9.457***	8.285***	8.573***	8.523***
	(0.239)	(0.283)	(0.489)	(0.286)	(0.637)
Observations	326	311	311	311	311
R-squared (adjusted)	0.417	0.512	0.558	0.546	0.559
Number of counties	15	15	15	15	15

All columns represent separate regressions. Robust standard errors in parentheses.
The dependent variable in each regression is the volume of sold phosphorus fertilisers (metric tonnes, log transformed), observed by county. All explanatory variables are logged. All regressions include county fixed effects.

6 Analysis and Discussion

In this section the authors discuss the results which are given in section 5. A discussion around policy instruments is also presented, as well as suggestions for further research.

6.1 Discussion of results

The purpose of this study was to estimate the price effects on Swedish demand of phosphorus fertilisers in relation to the world price of phosphorus rock. Our results support the hypothesis that fertilisers are inelastic commodities which is shown through the estimated short run price elasticity –0.192 (model 5) and long run price elasticity -0.449 (model 5). If the price of mined phosphorus increases by 1 percent the use of phosphorus fertilisers in Sweden would decrease by 0.192 percent in the short run and in a time period of two years by 0.449 percent.

However, it is important to interpret these results with caution since the use of fertilisers are strongly related to technological improvement. Precision farming has developed fast during the last decades which, among other things, has resulted in a decreased need of fertilisers in Swedish agriculture (Mallarino, 2014). The technological improvement has also led to better agricultural machines and knowledge about how to best cultivate and farm the arable land. Therefore, it is difficult to control for such effects with the methods used in this study.

If we compare the results from this study with the results from the report published by the National Institute of Economic Research, (Konjunkturinstitutet), (Bengtsson, et al., 2014) we find that the short run price elasticity of our model (-0.192) is slightly lower compared to their model 3 (-0.441). When comparing the results with the study from Mohlin (2012) we find that the difference of the short run price elasticities is even smaller compared to her model (-0.257). The price elasticities in those studies are short-run price elasticities. The results are in line with what we would expect and the difference in price effects between nitrogen and phosphorus is marginally small. It is reasonable that the price elasticity is similar for the two chemical compounds since both are essential for agriculture and one could assume that farmers make decisions for their fertiliser use simultaneously for both nitrogen and phosphorus.

The most interesting result in this study is the long run elasticity of (-0.449) which is shown in model (5). This result indicates that the demand of phosphorus in a two-year time period would decrease sufficiently more than for one year. Based on common economic theory this result is expected since price elasticities tend to increase in the long run. This result is in line with the study from Denbaly and Vroomen (1993) which showed that a long run price elasticity of phosphorus is equal to (-0.37).

The results from this study indicate that phosphorus fertilisers are inelastic goods and that the demand of phosphorus will decrease less relative to a hypothetical price increase. Furthermore, this implies that a tax on phosphorus will have relatively small effect on the demand and use of phosphorus fertilisers. Yet a tax is not totally ineffective according to our results and a tax would decrease the use of phosphorus to some extent which is in line with previous studies on nitrogen taxation (Söderholm & Christiernsson, 2008), (Mohlin, 2012), (Denbaly & Vroomen, 1993).

Taxation allows policy makers to hold on to the polluter pay principle and hence force farmers to pay for negative external effects related to agriculture. In addition, taxes have several intentions where one is to control consumers' behaviour, in this case decrease the use of chemical phosphorus. However, another intention could be to increase the governmental income to enable investments in green technology and substitutes to chemical mined phosphorus.

Throughout this study we had an intention to extend the analysis with a difference-in-difference model (DID-model) to compare the results with a control group, in this case Denmark. By doing so it would be possible to show the price effects by a potential tax policy when comparing data from Sweden and Denmark during the time period when Sweden abolished previous tax policy in 2009. Due to limitations in time and resources we had to focus this study to estimating the demand of phosphorus fertilisers. However, a DID-study is an interesting new approach which would be relevant for further studies, both on phosphorus and nitrogen fertilisers as dependent variables. By establishing a DID-model the study would account for the technological improvements during the studied time period since we can assume that Swedish and Danish agriculture has had a similar technological development.

6.2 Discussion of policy instruments

The efficiency of taxation on fertilisers is a thoroughly discussed topic among researchers and decision makers. The main argument for abolishing the fertiliser tax in 2009 was the inefficiency of taxes as a policy instrument (Bengtsson, et al., 2014). Yet, this study together with a range of other studies, for instance Mohlin (2012) and Söderholm & Christiernsson (2008) indicate that a tax policy would decrease the use of both phosphorus- and nitrogen fertilisers.

According to Brady (2002) emissions from biochemical compounds are difficult to control through standard environmental policy solutions, such as Pigouvian tax or pollution tax. Policies with purpose to control for nonpoint source pollution, for instance eutrophication from biochemical compounds, need to be targeting variables which are observable at reasonable cost. In case of eutrophication, observable variables could be commercial inputs or crop management practices (Brady, 2002). This support the idea of a tax targeting biochemical compounds in fertilisers. However, there is a contradiction of imposing a new tax for farmers and at the same time argue that Swedish agriculture needs to be strengthened to secure Swedish self-sufficiency.

An alternative policy would be to impose import tariffs in imported phosphorus fertilisers. Import tariffs are similar to normal taxes with the distinction that tariffs apply to imported goods and thus do not affect domestic production (Perloff, 2014). Further on import tariffs are common in trade with agricultural commodities and is manly used to protect domestic production and reduce dependence on foreign countries. Yet import tariffs counteract the benefits from free trade. According to common economic trade theory, free trade between two countries increases the total welfare for both countries. Import tariffs would decrease the total welfare.

7 Conclusion

In this section the conclusions of the study are presented as well as some suggestions for further research.

This study aims to contribute with estimations of the price effects on Swedish demand of phosphorus fertilisers. Furthermore, it answers the research question *“How is Swedish farmers’ demand of chemical phosphorus fertilisers affected by price changes of phosphorus on the world market?”.* We also want to provide policy makers with insights about taxation on phosphorus fertilisers and how it would affect today’s Swedish agriculture. A regression analysis with a panel data set has been used whereas the data are taken from Statistics Sweden, the Swedish Board of Agriculture and the World Bank. The analysed time period is 1997 – 2018 and data from 15 southern counties in in Sweden has been used. Five models have been developed with different number of variables and the results show that the short run price elasticity of phosphorus fertilisers is approximately (-0.192). The short run results are in line with previous studies which has focused on similar questions and hypothesises, on nitrogen fertilisers. The results support the hypothesis of this study, that the price elasticity of chemical phosphorus fertilisers is inelastic.

In addition, the estimated long run price elasticity is approximately (-0.449) which is encouraging from an environmental point of view. This implies that the use of phosphorus fertilisers can be efficiently controlled through economic policies and which also would have a substantial effect on the demand. However, our ‘long run’ is only two years. The price elasticity over a longer time period might indicate a different result. Phosphorus fertilisers have a long-term effect in the soil which could change the long run demand of phosphorus fertilisers. Farmers will eventually need to fertilise to maintain the level of harvest which will make them less price sensitive. This will most likely result in a lower price elasticity in a longer time period. Therefore, the long run price elasticity of phosphorus content in fertilisers in this study might be overestimated.

This is problematic from an environmental point of view since the eutrophication and pollution from phosphorus fertilisers would rise again in the future if the assumption holds. If this reasoning is confirmed through a new estimation of the long run price elasticity (approximately $t \geq 10$), it implies that it would be necessary to discuss other possibilities to ensure a sustainable future phosphorus supply.

Sweden is a net importer of phosphorus and highly dependent on the four largest phosphorus exporting countries. Therefore, by implementing an import tariff on phosphorus compounds it would be possible to internalize the negative external costs of fertiliser use in Swedish agriculture in a similar way as through domestic taxation. In addition, it would increase the incentives of investing in domestic alternatives for phosphorus extraction, since those would not be targeted by the tax. This is not only interesting from an environmental point of view but also a question concerning Swedish self-sufficiency in case of, for example, a global crisis where the international supply chain cannot satisfy the domestic needs. An import tariff on phosphorus compounds is also supported by the idea of how to control nonpoint source pollution, as described by Brady (2002). However, the ideal policy from an environmental perspective would probably be a combination of a domestic fertiliser tax and an import tariff on phosphorus. This would allow policy makers to decrease fertiliser use efficiently and at the same time encourage domestic circular phosphorus extraction. The Swedish government has already initiated a public inquiry to provide options to ensure a circulated sustainable phosphorus extraction (Swedish Department of Environment, 2018). It is a clear signal of the political ambitions which make this idea even more credible. Even though import tariffs would decrease the total economic welfare in the short run, it could be the only possible solution in the long run when accounting for the environmental damage related to phosphorus imports.

For further research it would be interesting to do an optimization of phosphorus use in chemical fertilisers. Obviously, this is something that differs between counties depending on soil and other environmental factors, but it could lead to a greater understanding of how much farmers should fertilise their arable lands. This would be a contribution to the development of precision farming technology. It would also be interesting to establish a difference-in-difference model for the use of phosphorus fertilisers. By doing so, it would be possible to be more precise when discussing the price effects on chemical fertilisers since it allows us to adjust for technological development. We would also like to encourage a developed study of the long run price elasticity of demand on phosphorus fertilisers to be able to confirm the assumptions presented in this conclusion.

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