Environmental Regulation and Productivity: A Data Envelopment Analysis for Swiss Dairy Farms

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Abstract

We propose a test of the Porter hypothesis for Swiss dairy farms, using a data envelopment analysis allowing for inclusion of policy variables to account for the effects of environmental policy on farm performance. It was found that on average, the Malmquist index including environmental indicators was 0.3% greater than the Malmquist index ignoring environmental indicators. However, we find considerable heterogeneity in the relationships between farm productivity and environmental regulation. The analysis of farm level productivity for Swiss dairy farms provides results supporting the view that during the 1993-2001 period, there is no strong evidence that farm productivity increased due to environmental agreements. Our findings are mixed but do not seem to reject the Porter hypothesis.

Key words: *Porter hypothesis, environmental regulation, productivity, Data Envelopment Analysis, dairy farms*

Introduction

According to production theory and empirical evidence, the relationship between productivity and environmental regulation can be broadly classified into two groups. Firstly, the environmental economists schooled in the neoclassical tradition are tempted to assume that environmental policy has a negative impact on farm productivity. Several reasons justify this hypothesis, the most obvious being that environmental regulations almost always require farms to allocate some input (labour, capital) to pollution reduction, which is unproductive from a business perspective. In other words, environmental regulations reduce farm productivity, thereby increasing cost and cutting profit. For example, Oskam (1991) and Barnes (2002) showed that incorporating environmental impacts into a Törnqvist productivity index reduced measured productivity growth in Netherlands agriculture and the UK respectively.

A second group launched a completely opposing view in what is nowadays called the Porter hypothesis: “Strict environmental regulations do not inevitably hinder competitive advantage against foreign rivals, they often enhance it” (Porter 1991, p. 162). Porter has suggested that more severe environmental regulation may have a positive effect on farms’ productivity by stimulating innovations. He argues that the traditional view has a narrow static perspective on farms’ reactions to environmental regulations. Indeed, faced with the prospect of higher abatement costs, farms will invest in innovation activities to find new ways to meet new regulatory requirements. The resulting new production process or new product specifications would reduce pollution and at the same time lower production costs or increase product market value. These benefits will very often

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offset and even exceed the costs initially imposed by regulations. In this vein, he adds : "Reducing pollution is often coincident with improving the productivity with which resources are used" (1995, p. 98). For example, Repetto *et al.* (1997) argued that incorporating environmental impacts into a restricted Törnqvist productivity index increased measured productivity growth in US agriculture. Ball *et al.* (1999) found the difference between inclusive and conventional Malmquist productivity indexes for US agriculture to depend on the environmental impact selected for inclusion, and to vary across states. The impacts were modest in all four studies.

Given the theoretical ambiguity of the relationships, we choose to address the empirical evidence for the Porter hypothesis on the basis of a panel of Swiss dairy farms by using a Data Envelopment Analysis (DEA) as a non-parametric frontier analysis. In order to test the Porter hypothesis empirically, two Malmquist productivity indexes are calculated, with and without environmental indicators included. The paper is organised as follows. Section 2 initially discusses several possible relationships between environmental and economic performance rooted in different theoretical frameworks. Section 3 formally presents the DEA models implemented in this study. Section 4 characterises the data set and section 5 presents the main results. Finally, section 6 concludes on the major findings of this paper

Modelling technology with polluting emissions and our approach

A variety of different methods have been used in the past to study the effects of environmental regulation on productivity (Pitman, 1983, Färe *et al.*, 1989, Hetemaki, 1996, Ball *et al.*, 1994, Tyteca 1996, Färe, Grosskopf and Pasurka, 2001, Färe *et al.* 2001 and Chung *et al.*, 1997). Three sets of factors are assumed: inputs, desirable outputs and undesirable outputs2, where both desirable and undesirable outputs were combined with the inputs to yield a value for environmental efficiency. Undesirable outputs are viewed as peculiar outputs, which are minimised with respect to other production factors (inputs and desirable outputs). However, this is a sensible way because agricultural environmental pollution (for example, nitrate pollution) is a non-point source of contamination3, so that construction of data on polluting output emissions is complex (to identify bad output for individual farms) and is, at best, very much an approximation to reality. Since actual emissions are not observed directly, quantities have to be calculated through observations of use of polluting inputs, such as nitrogen fertilisers, energy, manure or pesticides. It is then usually assumed that these estimated annual quantities can be directly implicated in causing environmental damage in the same year that they are emitted – which is a pragmatic, but essentially unrealistic assumption to make, given the complexity of the environmental processes involved. In addition, environmental regulation as in Switzerland is specified in terms of polluting input rather than in terms of pol-

[2] Generally, agricultural production analysis is concerned with describing the relationships that characterise the transformation of inputs, such as land, labour or purchased materials, into marketable outputs, such as wheat, milk or meat. Such outputs are designated desirable in the sense that they are demanded by consumers and yield utility in consumption. However, agricultural product processes also create outputs which society deems undesirable because they yield disutility in consumption. These bad outputs, such as ground and surface water contamination, runoff and leaching of nitrogenous fertilisers and pesticides or greenhouse gas emissions to the atmosphere, impose costs.

[3] For example, nitrates leached into aquifers used for drinking water may have been emitted as a result of fertiliser application or land use change several years, and possibly decades, in the past.

luting emissions of gases. Therefore, we assume that the agricultural authorities' regulatory approach is more concerned with the amount of polluting input used by individual farms than with the unobservable direct impact on the environment. Then, the economic cost to farmers of following a good agronomic practice code, expressed in terms of polluting input use (fertiliser, energy, etc.) by hectare, is evaluated. In this paper, as against previous studies (undesirable outputs) we use undesirable inputs by taking into account that agricultural production uses three sets of variables: inputs, desirable output and pollutants in the form of undesirable inputs.

Methodological issues

The DEA approach is a non-parametric mathematical programming approach. This method explicitly includes the inefficient use of resources. It allows for defining a best-practice frontier on the most efficient farms and an individual inefficiency measurement can then be defined which describes the distance of each observation in the data set from the best-practice frontier (Farrell, 1957; Charnes *et al*., 1978). In this paper, we extend previous studies by taking into account that agricultural production creates polluting impacts (Färe *et al*. 2001; Chung *et al*., 1997) and by distinguishing productivity measurements between conventional and environmental measures.

In order to give a brief insight into the methodology, let us consider a productive process that uses a vector x of N =1,…,N inputs and vector z of K=1,…K environmental input (or undesirable input) to produce a vector y of M=1,….,M outputs, through a technology and then define the production possibilities set by:

$Pt \equiv \{(xt, zt, yt): (xt, zt) \text{ can produce } yt\}$ (1)

which is the set of all feasible production vectors. We assume that Pt satisfies standard axioms, which suffice to define meaningful output distance functions (see Fuss and McFadden 1978). The distance function is defined at t as:

$d(y,x,z) = \sup\{\theta : ((x,z)/\theta, y) \in P\}$, on the output set, Pt, (2)

where $1/\theta$ is the maximal proportional amount that the input vector, xt,zt, can be reduced while remaining technologically feasible given the production set, Pt, and the output vector, yt. This input-oriented distance function is computed as the ability of a producer to contract both conventional and environmental inputs equiproportionately, conditionally on output i.e. outputs are held fixed and inputs are proportionately decreased and environmental inputs (pollution) are proportionately decreased.

The DEA involves the use of linear programming methods to construct a piecewise linear envelopment frontier over the data points such that all observed points lie on or below the frontier. In computing the distance functions, we choose the DEA methodology from competing alternatives, so as to take advantage of the fact that the distance functions are reciprocals of Farrell efficiency measures. We calculate the Malmquist productivity index by comparing distance functions in two different years (t and t+1).

Let there be I producers indexed i = 1,…,o,…,I, each observed through T time periods indexed t = 1,…,T. The within period inclusive distance function di,t(yt,xt,zt) defined on the conical benchmark technology in (2) is calculated for producer "o" as the solution to the nonlinear programming problem.

$d^{ot}(x^{ot},y^{ot},z^{ot}) = \min\theta,\lambda\ \theta$ (3)

subject to

$X^{t}\lambda \leq \theta x^{ot}$

$y^{ot} \leq Y^t\lambda$
$Z^t\lambda \leq \theta z^{0t}$
$\lambda \geq 0,$

where (x^{ot},y^{ot},z^{ot}) are the data for producer "o" in period t, Xt is an n×I matrix of all producers' purchased inputs in period t, Yt is an m×I matrix of all producers' marketed outputs in period t, Zt is a k×I matrix of all producers' environmental inputs in period t and λ is an i×1 intensity vector. Program (2) is solved I×T times, once for each producer in each period.

The constraints in equation (3) construct the reference (or frontier) technology from the data for year t. Every point in this technology set is a linear combination of observed output/environmental input/input vectors or a point dominated by a linear combination of observed points. The Total Factor Productivity (TFP) can be decomposed into measures associated with Technological Change (TCH), i.e. the shifts in the production frontier, and Efficiency Change (ECH), i.e. the changes in the position of a production unit relative to the frontier – so-called "catching up", following Färe *et al*. (1994): The following equation implies the multiplicative formation of two components to explain TFP.

$$TFP = TCH \times ECH \quad (4)$$

In order to test the Porter hypothesis empirically, two Malmquist productivity indexes are calculated with and without environmental indicators included. The inclusive index provides an environmentally sensitive measure of productivity change. A comparison of the inclusive index with the conventional index generates an environmental productivity index. The conventional TFP index is calculated exactly as in (3), with (xot,yot) replacing (xot,yot,zot) and retaining (Xt,Yt).

Application to Swiss dairy farming

The main environmental issues associated with milk production concern water and air pollution and biodiversity. Water pollution arises from the inappropriate disposal of manure and the application of fertilisers for forage production. Nutrients, principally nitrogen and phosphorous, are a significant component of pollution from agriculture of surface water, groundwater and marine waters, damaging ecosystems through eutrophication and degrading their recreational use. Water bodies can also be affected by organic effluents and pathogens contained in manure. Water pollution is mainly a local or regional concern, although cross-border pollution can occur. Dairy farms are also a source of greenhouse gas (GHG) emissions, mainly from enteric fermentation (methane) and manure management (methane and nitrous oxide).

Agri-environmental indicators and input/output data

Linking agri-environmental indicators to statistical sources on agriculture, in this case the Farm Accountancy Data Network (FADN), provides a good basis for monitoring since the data are collected on a yearly basis according to uniform standards across Switzerland. On the other hand, it also implies that the information is limited in scope because the data are not, at present, collected for agri-environmental purposes. Initially, these limitations need to be acknowledged. Firstly, many of the indicators derived from the Swiss FADN database can only be expressed in monetary terms and not as quantities. However, we believe that the set of farm management indicators we have chosen (see below) provides a farm management profile of the different dairy farming systems that gives sufficient detail for assessment of a wide range of agri-environmental issues. This, combined with good possibilities for monitoring over time at farm level and the option of linking to economic indicators, makes the suggested set of indicators very suitable for environmental assessments of agricultural policies.

In this study we utilise data describing the production activities of 152 specialised dairy farms that were in the Swiss Farm Accountancy Data Network for the whole of the 1993-2001 period. We have a total of 1,368 observations in this balanced panel and so each farm appears during the 1993-2001 period. We employed an input-oriented multi-output multi-input model, which was applied at farm level. The output variables used were returns from crop production (CHF[4]), returns from livestock production (CHF) and miscellaneous production (CHF). Miscellaneous returns are returns from trade, services and plant, including in particular wages and rent for machines. Government direct payments output (ecological deliverance, hectare-bound and animal-bound payments and so forth) is defined as the fourth variable.

Four conventional inputs were included: agricultural area utilised in hectares as a land factor, annual work units (days) as a labour factor, depreciation plus interest as a capital factor, livestock and intermediate consumption as a variable input factor. In our experience, quantification of the input factor "capital" is especially problematic in efficiency analysis, as it should include all durable means of production with the exception of work and land. The input factor capital is approximated in this investigation as depreciation plus interest in own capital and credit. The fourth final input variable (intermediate consumption) summarises material expenditures and other farm-internal expenditures. All monetary variables are normalized by the base year price indices (1990).

The agri-environmental indicators evaluated in this study are grouped into a set of four indicators measuring the adoption of practices aimed at reducing the environmental intensity related to greenhouse gas (GHG) emissions.

Fertiliser use (Real CHF per ha) indicates the intensity in farmland using the cost of fertilisers and soil improvers per ha. It is an important indicator of the pressure on the environment from a nutrient management perspective. High values indicate a high risk of eutrophication of habitats and recipients. The indicator is based on the cost of fertilisers, not on the actual amount of fertilisers used.

Stocking density (Livestock units of all livestock per ha). The stocking density gives an indication of the organic component of the nutrient pressure on the environment. The indicator does not take into account potential sales of manure to or agreements with other farms, which potentially lessens the pressure on the environment. The indicator, together with the fertiliser indicator, gives a general indication of the pressure on the environment from nutrients.

Energy use (Real CHF spent on direct use of energy par ha). Energy use is a rough indicator of the use of non-renewable resources. It is of interest since this use contributes to greenhouse gas emissions, which may lead to global warming. Note that only the energy used directly for machinery, heating and electricity is included.

Use of purchased concentrate feedstuff (Real CHF spent on concentrate feedstuff

[4] 1CHF = 0.77 $

per ha). The use of concentrates can be seen as a general indicator for the intensity of production.

Main results

Two models of the Malmquist index were calculated following the methodology discussed above. Model 1 ignored environmental indicators, while the second incorporates environmental indicators into the model, imposing a positive direction on good outputs and a negative direction on bad inputs, i.e. more good outputs, fewer bad inputs. The two models were then decomposed into the technical change and efficiency change components as an average of the 1993-2001 time period for each farm. When environmental indicators are included in the model the geometric mean growth rate is 2.1% productivity growth per year for dairy farming, as opposed to 1.8% when environmental indicators are ignored. The results of the two models are shown in Table 1. On average, technical change for the 1993-2001 period is calculated to be the same in model 1 and model 2, at 2.4%. However, when a comparison is made between the two models on estimation of efficiency change, the change is greater when environmental indicators are included in the model. A basic t test was run to test the null hypothesis that over the 1993-2001 period the two productivity measures were the same. This null hypothesis could be rejected at the 0.01 confidence level (see Table 2, Hypothesis a). In fact it was found that the Malmquist index including environmental indicators was 0.3% greater than the Malmquist index ignoring environmental indicators.

Table 1 - Productivity index (average annual) with and without environmental indicators.

	Measures without environmental indicators			Measures with environmental indicators		
Year	Efficiency [5]change	Technical change	Productivity index	Efficiency change	Technical change	Productivity index
1994	0.984	0.971	0.955	0.976	0.971	0.948
1995	0.993	0.959	0.952	0.987	0.96	0.948
1996	0.939	1.237	1.148	0.967	1.179	1.133
1997	0.986	0.778	0.967	1.017	0.800	1.014
1998	1.042	1.031	1.075	0.993	1.077	1.07
1999	1.026	1.117	1.146	1.015	1.122	1.139
2000	1.004	1.092	1.096	0.984	1.129	1.111
2001	0.987	0.923	0.911	1.04	0.861	0.895
Geo. mean	0.995	1.024	1.018	0.997	1.024	1.021
St.dev	0.039	0.014	0.042	0.039	0.017	0.043
Max	1.090	1.069	1.115	1.084	1.076	1.135
Min	0.910	0.994	0.920	0.896	0.985	0.898

[5] The value greater than, equal to or less than one means improvement, unchanging or decrease of the index. For example, 0.984 means a decrease of efficiency change by 1.6%.

Table 2 - Hypothesis testing using basic t test (paired t test on averages)

Null Hypothesis	P value	Condition
H1: Malmquist productivity index with environmental indicators 93-2001= Conventional Malmquist productivity index 93-2001	0.01	**Reject**: Malmquist productivity index with environmental indicators # Conventional Malmquist productivity index 93-2001
H3: Conventional technical change, 93-2001 = Technical change with environmental indicators, 93-2001	0.01	**Reject:** Technical change with environmental indicators, 93-2001 # Conventional technical change, 93-2001
H3: Conventional efficiency change, 93-2001 = Efficiency change with environmental indicators, 93-2001	0.05	**Reject:** Efficiency change with environmental indicators, 93-2001 # Conventional efficiency change, 93-2001

In order to explore the source of the divergence between conventional productivity measures and productivity measures with environmental indicators, cluster analysis is used. The study utilized k-means non-hierarchical cluster analysis on all farms. The factors examined included difference between Malmquist and its two components index that accounts for environmental indicators (model 2) and measures that does not account for environmental indicators (model 1). If difference is positive, then there has been productivity, efficiency or Technological improvement. Six different types of farms were identified (see Table 3). This shows that farms in the first, third and fifth clusters have a higher productivity with environmental indicators than the conventional productivity growth during the period covered. However, the farms in these three clusters differed in the source of the divergence between the two measures of productivity growth (efficiency, technology or both). In contrast, productivity growth with environmental indicators for the farms in the second, fourth and sixth clusters was lower than conventional productivity measures; they may be working to maintain a high level of efficiency, or they may be undermining their efforts in this area by being too attentive to market signals and changing their farm plans too frequently and too substantially.

Table 3 - Main characteristics of the clusters

	Efficiency change Model(2)-model(1)	Technical change Model(2)-model(1)	Productivity index Model(2)-model(1)
Medium benefit [6](Cluster 1)	+	-	+
High loss (Cluster 2)	-	-	-
High benefit (Cluster 3)	+	+	+
Medium loss (Cluster 4)	-	+	-
Low benefit (Cluster 5)	-	+	+
Low loss (Cluster 6)	+	-	-

Results in Figure 1 show that if environmental indicators are included, approximately 57.2% of the farms increased at a much faster rate of productivity index than the conventional productivity measure. In fact, it was found that this increase in total factor productivity can be attributed to efficiency growth for 17.1% of farms (cluster 1), tech-

[6] High, medium and low are defined see to the impact of environmental regulation on Malmquist index growth (see the last row in table 4).

nical change for 15.8% (cluster 5) and both components simultaneously for 24.3% (see equation 4 for breakdown of efficiency change, technical change and Malmquist productivity change). Table 4 shows selected farm characteristics by cluster or group. On average, cluster 3 has attained (3.2% productivity growth per year) more productivity growth when environmental indicators are included than the conventional productivity measures (0.7%). In contrast, cluster 2 is the least productive producer with environmental regulations (0.4%). This result can partly be explained by the use of polluting inputs. Table 5 shows that on average, cluster 3 decreased the use of all the environmental factors during the 1993-2001 period, while cluster 2 increased the use of all environmental inputs (concentrate feedstuff, energy and stocking density for livestock). As a result, the decline in polluting inputs from farms over the period translates into a productivity growth that increases at a much faster rate than does the conventional TFP index.

Table 4 - Average productivity index with and without environmental indicators by cluster, 1993-2001.

	Index	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Mean
With environmental indicators	Efficiency change	1.003	0.992	1.003	0.995	0.996	0.995	0.998
	Technical change	1.019	1.012	1.029	1.028	1.042	1.012	1.024
	Productivity index	1.022	1.004	1.032	1.023	1.038	1.007	1.022
Without environmental indicators	Efficiency change	0.991	1.007	0.988	1.017	1.001	0.987	0.995
	Technical change	1.028	1.027	1.02	1.022	1.02	1.026	1.024
	Productivity index	1.019	1.034	1.007	1.039	1.021	1.013	1.019
Impact of[7] environmental regulation	Efficiency change	1.19%	-1.49%	1.52%	-2.16%	-0.50%	0.81%	0.30%
	Technical change	-0.88%	-1.46%	0.88%	0.59%	2.16%	-1.36%	0.00%
	Productivity change	0.29%	-2.90%	2.48%	-1.54%	1.67%	-0.59%	0.29%

Table 5 - Main characteristics of the groups of farms obtained from the Cluster Analysis, 1993-2001

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
Number of farms	26	29	37	16	24	20
Total production	7.3%	-2.1%	7.2%	-6.9%	-9.3%	9.1%
Intermediate consumption	26.0%	3.1%	17.1%	-5.9%	2.0%	16.9%
Capital	-28.3%	-21.2%	-17.4%	-30.9%	-33.8%	-14.1%
Labour	4.4%	-12.7%	1.7%	-17.0%	-4.4%	-1.8%
Land	12.5%	-15.2%	29.9%	-6.4%	2.1%	4.2%
Fertiliser use/ha	12.9%	23.7%	-38.4%	-0.4%	-2.8%	-9.7%
Concentrate feedstuff/ha	-33.0%	51.7%	-30.1%	2.1%	25.9%	-22.9%
Energy use/ha	-2.0%	54.9%	-11.2%	35.6%	14.9%	25.7%
Stocking density	-7.4%	3.3%	-1.8%	10.3%	-7.9%	-3.4%

[7] To calculate the environmental regulation impact, we divide the Malmquist and its two components index that accounts for environmental indicators by the Malmquist and its two components index that does not account for environmental index. If ratio is positive, then there has been improvement.

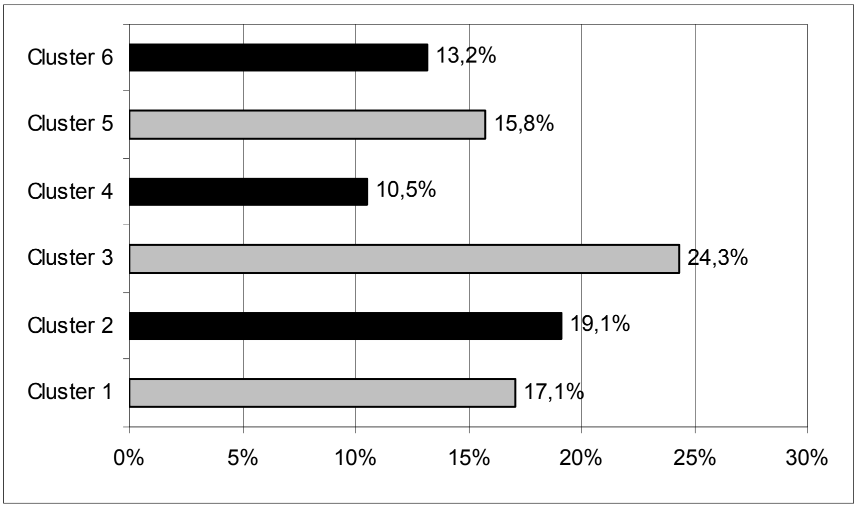

Figure 1 - Distribution of farms by cluster (in %)

Summarising, our findings are mixed but do not reject the hypothesis that farm productivity increased due to environmental agreements. Furthermore, the estimates indicate farm-specific heterogeneity in the productivity index. The fact that dairy farms for example achieve more productivity growth when environmental indicators are included could be explained by the relative growth rates in the traditional output and the relative decrease rates of the desirable and undesirable inputs. If the percentage decrease in desirable inputs exceeds the absolute value decrease in the undesirable input, then the growth rate of traditional productivity exceeds the growth rate of environmental productivity8. In Table 5, we report average growth in environmental indicators and desirable inputs for the 1993-2001 period.

Conclusions

Environmental policy regulations have many effects. Mostly, they are designed to benefit society by reducing pollution. However, costs are also associated with these regulations. How these environmental laws and abatement costs affect productivity is still under debate. Some believe that if resources are used for abatement then those inputs are an extra cost and must decrease productivity. Others find that environmental laws promote the creation of technologies that allow farms to be more competitive and efficient (Porter hypothesis).

This paper proposed a test of the Porter hypothesis for Swiss dairy farms, using a Data Envelopment Analysis (DEA). We have constructed two Malmquist productivity indexes. The first conventional index incorporates just the conventional input-output

[8] Over the 1993-97 period, Bedfordshire, Buckinghamshire, East Sussex, Hampshire, Hertfordshire, Lancashire, Somerset, Greater Manchester and South Yorkshire have a lower productivity growth when bads are included. According to Färe, Grosskopf and Pasurka this could be because of the relative growth rates in the traditional output and the adjusted output measures depend on the relative growth rates of the desirable and undesirable outputs. If the percentage increase in desirable outputs exceeds the absolute value decrease in the undesirable output, then the growth rate of traditional productivity exceeds the growth rate of adjusted productivity.

variables whereas in the second, four environmental indicators are added. Our main conclusion is that there is considerable heterogeneity in the relationships between farm productivity and environmental regulation. The analysis of farm level productivity for Swiss dairy farms provides results supporting the view that during the 1993-2001 period, there is no strong evidence of farm productivity increasing due to environmental agreements. Our findings are mixed but do not seem to reject the hypothesis that farm performance increased due to environmental agreements.

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