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SPATIAL ANALYSIS OF DAIRY YIELDS RESPONSE TO INTENSIVE FARMING IN NEW ZEALAND

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Introduction

Following the removal of export incentive subsidies in the 1980s, New Zealand (NZ) experienced an "agricultural revolution" (Baskaran, Cullen & Colombo, 2009). Meanwhile, in recent years, international demand for dairy products has further fuelled the expansion of the NZ dairy sector (Tímár, 2011). Significantly, the dairy industry has been expanded from traditional dairy regions, such as the central North Island and the East coast of South Island, to other regions (Clark et al. 2007). These have led to more intensive dairy farming, which is represented by higher stocking densities as well as a significant increase in the use of chemical fertilisers (Evans, 2004). Thus, controlling nutrient discharge from dairy farms is now a crucial issue for the regional and central government.

In order to maintain the international competitiveness of the NZ dairy industry, it is important to understand the relationship between dairy production and intensive farming regionally and nationally, particularly if policy is to facilitate choice of intensive inputs that can help to increase dairy yields with the least damage to the environment. If sufficient nutrients are not provided then, soil fertility and production will decrease, which affects profits. Conversely, if excessive nutrients are provided, there can be negative effects on the environment and animal health. Specifically, farmers will face the challenge of whether or not high dairy yields can be sustained with high intensive inputs, particularly in respect to the choice of alternative sources of nutrients.

Policies aimed at controlling nutrient influx from intensive dairy farming are currently being developed by regional units of government in New Zealand. To better inform policy, the challenge is to take account of the complexity of regional dependence and regional diversity. On the one hand, dairy yields in one region might be influenced by its own intensive inputs and by neighbouring regions' dairy yields and intensive inputs. On the other hand, the variety of regional conditions could also influence regional dairy yields. Thus, a good means of dealing with the complexity is to recognize the effects of spatial interactions, because dairy yields and intensive inputs relationships are better understood by considering both the own region characteristics and spatial spillovers from neighbouring regions.

This paper seeks to analyse how dairy yields respond to intensive farming inputs, to establish whether unobserved spatial effects exist, and to investigate how spatial spillover effects influence the relationship between dairy yields and intensive farming across different NZ regions[1]. It contributes to the existing literature in two ways. First, this is the first empirical application of spatial econometric methods to examine the spatial relevance of dairy yields and intensive inputs in NZ. In particular, the spatial panel data model accounts for cross-

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[1] In this paper, regions refer to territorial units of government.

sectional dependence and controls for heterogeneity. Second, the paper not only takes into account traditional intensive inputs but also innovatively includes the areas of effluent sprayed over effective farm areas as one of the intensive farming indicators[2]. By including effluent and nitrogen use in the model, we can indicate whether or not there are trade-offs between these two intensive inputs and further reveal the influence of trade-offs regarding dairy yield. The results contribute to an understanding of how farmers can improve their management of intensive inputs and contribute to the formation of regional environmental policy that recognizes regional dependence and heterogeneity.

Methods

The application of spatial econometric models in policy analysis typically calls for the inclusion of more than one spatial interaction relationship. For example, a policy change by one regional unit of government may not only directly influence its own economy but indirectly influence the economy of the neighbouring regions, and vice versa. In this context, the spatial Durbin model (SDM) allows for the inclusion of both spatially lagged dependent and independent variables. This is especially applicable in policy analysis when the research interest focuses on estimating the impact of neighbouring policy in terms of two spatial interaction effects in contrast to a spatial lag model (SAR) that includes only an endogenously spatial lagged dependent variable, and the spatial error model (SEM) where the spatial autoregressive error terms may not give meaningful interpretations (Anselin, 2010). Moreover, the inclusion of the spatially lagged independent variables in the SDM could help to avoid omitted variable issues in empirical studies. Therefore, the SDM is chosen for our empirical analysis since we are concerned about not only the impact of one region’s own intensive farming practice on its dairy production but also the impacts from the neighbouring regions’ intensive farming activities. In addition, considering trade-offs between the quantity of chemical fertiliser applied and the area of irrigated effluent, we allow for interactive terms between fertiliser application and effluent use by centring these variables. In other words, the effect of chemical fertiliser application on dairy yields depends on the level of effluent sprayed over effective areas, and vice versa.

For this paper, we consider a fixed effects model, including spatial fixed effects (individual effects) and time fixed effects, to be appropriate for the following reasons[3]. Firstly, spatial fixed effects are designed to control for time-invariant variables, and time fixed effects to control for spatial-invariant variables. Thus, excluding spatial fixed effects may lead to bias in cross-sectional studies, and omitting time fixed effects may cause bias in time-series studies (Baltagi, Song & Koh, 2003). Additionally, the random effects model is particularly restrictive. One of the strictest assumptions for random effects model is zero correlation between the random effects terms and the explanatory variables. This, however, may not be satisfied in empirical studies. Furthermore, there are no time-invariant variables included in the analysis, but this is usually the main reason for most empirical studies that include random effects in order to avoid the problem of omitting time-invariant variables (Elhorst, 2014). This paper will follow the estimation method proposed by LeSage & Fischer (2008) and Elhorst (2014), and the empirical analysis will report the direct effect, the indirect effect (spatial spillover effects) and the total effect (the summation of direct effect and indirect effect) for the response of regional dairy yields to intensive inputs.

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[2] For simplicity, effluent application and effluent use are also used in this paper, which represent “areas of effluent sprayed over effective farm areas”.

[3] I will also use hypothesis tests to support the choice in the following section.

Data

Data used for this study come from three main sources, the agricultural production census (Statistics NZ), dairy statistics (DairyNZ), and the national climate database (the National Institute of Water and Atmospheric Research (NIWA)). We utilize 2002, 2007 and 2012 data from fifty-five NZ regional authorities. Statistics NZ ran a full agricultural production census in 2002, 2007 and 2012, which is especially consistent with the data obtained from DairyNZ. The annual climate data of the year 2002, 2007 and 2012 is from the combined statistics calculated from regional observation stations by NIWA.

Fifty-five out of sixty-seven regions are included in the analysis due to information being incomplete for the other eleven territories. In this paper, we use kilogram milk solids per hectare (kg MS/ ha) to measure dairy yields, i.e. the dependent variable. Variables representing regional intensive farming inputs are average stocking rate, fertiliser use (including nitrogen, phosphorus, lime, and potassium) and effluent use[4]. Theses independent variables are also measured by per hectare corresponding to the dependent variable. In addition, except for regional intensive input variables, we also include two commonly used climate variables, which are annual (total) rainfall and average soil moisture (December to February). To some extent, these two variables may control for regional climate variation, and particularly the average soil moisture in summer season may capture the impact of summer drought on dairy yields[5]. Descriptions the variables are shown in Table 1.

Table 1 Descriptions of Variables

Variable name	Descriptions	Data Source
Dairy yields (Y)	kilogram milksolids per hectare (kg MS/ ha)	DairyNZ
Nitrogen fertiliser (N)	Total urea use and all other nitrogen containing fertilisers (tonnes/ ha).	Statistics NZ
Phosphorus fertiliser (P)	Total phosphatic fertiliser, diammonium phosphate and ammonium sulphate (tonnes/ ha).	Statistics NZ
Lime (L)	Total lime use (tonnes/ ha).	Statistics NZ
Potassic fertiliser (K)	Total potassic fertiliser (tonnes/ ha).	Statistics NZ
Effluent use (E)	Areas sprayed by effluent over total effective farm areas (percentage).	Statistics NZ
Average stocking rate (SR)	Regional average number of peak cows milked divided by effective areas.	DairyNZ
Annual rainfall (RF)	Annual (total) rainfall (millimetres).	NIWA
Average soil moisture (SM)	Average soil moisture in summer season (%).	NIWA

Results and Discussions

We regress four empirical models, the non-spatial model, the one-way SDM (with time-fixed effects), the one-way SDM (with individual-fixed effects), and two-way SDM (with both time-fixed and individual-fixed effects) for comparison purposes. The results of pooled model (non-spatial model) are estimated by using OLS and the other three spatial models are all regressed by using maximum likelihood estimation. Results show that the two-way SDM outperforms the other models in terms of R^2 (0.96), adjusted R^2 (0.89), and log-likelihood value (425.24). The results also indicate that ignoring spatial interaction effects can result in

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[4] Although labour and machine are important inputs to dairy yields, there are no territorial level data on those indicators. Thus, this study does not include those as explanatory variables.

[5] Note that we intend to use climate variables to control for regional climate variance, but do not declare that the results reflect the effects of climate change on NZ dairy yields.

biased estimates and lead to inaccurate interpretations of the relationship between dairy yields and intensive inputs.

The direct and indirect effects, shown in Table 2, are derived using the methods of LeSage and Pace (2009). Here, direct effects measure the own impact of intensive inputs and own regional characteristics on one region's dairy yield, and the indirect effects measure the neighbouring impact on the dairy yield of this region.

Table 2 Direct, Indirect and Total Effects Estimates

Explanatory variables	Direct effects	Indirect effects	Total effects
N	3.10e-01*	2.89e-01*	5.99e-01**
	(2.11)	(1.89)	(2.74)
P	8.63e-02***	2.93e-02**	1.16e-01***
	(3.96)	(1.99)	(3.83)
L	3.89e-02	1.32e-02	5.21e-02
	(1.27)	(6.72e-01)	(5.70e-01)
K	2.61e-02**	2.32e-02	4.93e-02
	(2.51)	(1.13)	(1.39)
E	6.34e-01***	3.49e-01*	9.83e-01**
	(3.58)	(2.81)	(2.90)
SR	9.96e-01***	1.92e-01**	1.19**
	(5.03)	(2.89)	(4.14)
N*E	-1.35e-01***	-4.42e-02	-1.97e-01**
	(-5.90)	(-8.68e-01)	(-3.19)
P*E	-5.52e-02***	-4.94e-02**	-1.05e-01*
	(-3.58)	(-3.23)	(-2.35)
L*E	-1.21e-02*	-4.81e-02	-6.02e-02*
	(-2.68)	(6.16e-01)	(-2.06)
K*E	-1.40e-02	-4.09e-02*	-5.49e-02*
	(-2.87e-01)	(-1.12)	(2.61)
RF	1.42e-02	2.09e-02	3.51e-02
	(1.02)	(2.43e-01)	(5.13e-01)
SoM	-3.53e-02***	-2.11e-02**	-5.64e-02**
	(2.62)	(-2.31)	(-2.38)

Source: authors' elaboration based on Matlab software; '***', '**', '*' indicate coefficients that are significant at 0%, 1% and 5%, respectively; figures in parentheses represent t-values.

From the estimated effects in Table 2, we firstly look at the impact of intensive inputs on dairy yields. The total effects of most of the intensive input variables are positive and statistically significant. Furthermore, there are also significantly positive spillover effects of the intensive input variables, except for lime and potassic fertiliser. These imply that regional dairy yields highly depend on intensive inputs, and spatial dependence exists in regional intensive dairy farming. Specifically, among all the intensive input variables, stocking rate has the greatest influence on regional dairy production, with regional dairy yields increase 1.2 percent in response to 1 percent increase in stocking rate.

The interpretation of the magnitude of chemical fertiliser use should be considered together with the interactive terms between fertiliser and effluent use. For nitrogen and phosphorus use, the direct, indirect and total effects of the two are all positive and statistically significant given an average level of effluent use (*E* equals to 0). In particular, the total effect of nitrogen on dairy yields increases by 0.6 percent for a 1 percentage increase in nitrogen use, where the total effect can be decomposed to 0.3 percent direct effect and 0.3 percent indirect effect. And associated with a 1 percentage increase in the use of phosphorus fertilizer, there is a 0.11 percent total effect on dairy yields, coming from a positive direct effect (0.8 percent) and a positive indirect effect (0.3 percent). However, when the proportion of effluent irrigation areas increase, I find that the positive response of yields to either nitrogen or phosphorus turns to be negative when I consider the negative interactive term of *NE* and *PE*. Meanwhile, regional dairy yields increase by about 1 percent for an 1 percent increase in effluent irrigation area, given the average level of nitrogen and phosphorus use. Similarly, when either nitrogen or phosphorus use is increased, the results show that dairy yields response to effluent use are negative due to the negative interactive term of *NE* and *PE*. These can be interpreted as trade-offs between nitrogen and effluent use and trade-offs between phosphorus and effluent use, indicating that there is no need to apply as much as nitrogen and phosphorus because effluent use can achieve the expected level of dairy yields.

There is no spillover effect associated with potassic fertiliser use on dairy yields; regional dairy yields increase by 0.3 percent only due to a 1 percent increase in own region use. None of the three effects (direct, indirect and total effect) are statistically significant for lime use. There is no influence of regional rainfall on dairy yields, indicating that total annual rainfall may not explain the variance of regional dairy yields. This is because dairy yields vary with changes in seasonal rainfall patterns, to a large extent. Both the direct and indirect impacts of soil moisture on dairy yields are statistically significant. Specifically, with 1 percent rise in the average soil moisture in summer, regional dairy yields are expected to decrease by 0.06 percent, with 0.04 percent direct effect and 0.02 percent spillover effect.

Conclusions

In this paper, we analysed the response of regional dairy yields to intensive farming inputs spatially in New Zealand. Regional dairy yields are characterized by substantial differences in regard to intensive inputs including chemical fertiliser use, stocking rates, effluent application and regional characteristics. To avoid biased estimates, we applied spatial panel data models to the data and compared the results to those obtained from the non-spatial model. The results clearly show that ignoring spatial interaction effects among regions can provide misleading estimates of the impacts of intensive inputs on regional dairy yields. The results also show that there are significant spatial spillover effects associated with nitrogen use, effluent use and stocking rate.

This paper leads to several conclusions for policy. To begin with, we find significant spatial spillover effects on regional dairy yields regarding some intensive inputs. This indicates that although the regional governments have different policies and regulations, spatial dependence exists between neighbouring regions. From a national perspective, to reduce nutrient pollution, results of this paper indicate that policy makers should take into account the neighbouring impact between regions. Consequently, political decisions may not only affect the region to which they are targeted but also the neighbouring regions. This calls for political cooperation between different regional authorities. In addition, the significant and positive impact of intensive inputs, especially stocking rate, indicate a close relationship between dairy yields and intensification of dairy farming. This reminds policy makers to consider the balance between the pursuit of dairy output and pollution regulations, as intensive inputs are still significant factors for achieving higher dairy yields. Fortunately, results of the paper indicate trade-offs between the use of chemical fertilisers and effluent use. Thus, it is wise for regional governments to highlight the trade-off in the policy making process, as rational utilization of effluent may help dairy farmers to save money on chemical fertilisers and help the dairy industry to better maintain its international competitive advantage.

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