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Impact of Fertilizer Subsidy Program on Agricultural Productivity in Ghana

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가나 비료 보조금 제도의 농업 생산성 증대 효과에 대한 공간적 분석

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ABSTRACT : 본 연구는 가나의 비료 보조금 정책(Fertilizer subsidy program: FSP)의 농업 생산성에 대한 영향을 분석하였다. 가나의 군(district) 지역 수준의 농업 생산량 및 투입요소에 대한 자료를 사용하여, FSP 도입 이전과 FSP 도입 이후의 농업 생산성을 계측하였다. 지역적으로 상이한 수준의 농업 생산성을 반영하기 위한 지리적가중회귀(GWR)모형을 사용하여 계측의 오류를 줄이고 공간이질성을 고려하였다. 추정 결과를 바탕으로 ArcMap을 이용하여 생산성을 지도로 시각화 한 자료를 살펴보면, FSP 도입 이후 농업 생산성이 전반적으로 개선되었으며 그 중에서도 생산성이 크게 향상된 지역을 특정할 수 있다. 이러한 공간적 변화는 FSP의 지역적 할당의 효율성 증진을 위한 의사결정 자료로 이용 가능하며, 국내 ODA 추진기관에서 농업 지도 및 지원을 위해 유용한 정보로 사용할 수 있다.

Key words : Fertilizer subsidy, Ghana, Gross agricultural product (GAP), Regional variation

I. Introduction

The agricultural sector is crucial to Ghana's march toward poverty reduction through shared and equitable growth. Ghana's economy depends largely on agriculture and is predominantly practiced by smallholder family-operated farms (Ministry of Food and Agriculture, 2010). The population of agricultural households is 54.2 out of which 73.5% are from rural areas (Ghana Statistical Services, 2013). Ghana's policy setting for the agriculture sector has evolved significantly from the 1960s socialist model to the liberalized market of the 1980s and 1990s predominantly under structural adjustments. A significant effect of the different policy directions have been seen on agricultural development in Ghana (Asuming-Brempong, S., 2003).

To fast-track the transformation of agriculture and increase the productivity of Ghanaian farmers, Ghana has been implementing a fertilizer subsidy since 2008. Fertilizer use has been recognized as an important factor in achieving an African Green Revolution as populations continue to increase with declining soil fertility. The African Union Ministers of Agriculture called together a meeting for the Africa Fertilizer Summit on June 2006 in Abuja and committed to increase fertilizer use from the average 8 kg/ha to 50 kg/ha in the continent by 2015 (Africa Fertilizer Summit Report, 2006). This change has prompted most countries, including Ghana, to implement a fertilizer subsidy. Given an average fertilizer use of 7.4 kg per hectare before the subsidy, Ghana was noted as a low

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performer in terms of fertilizer use within sub-Saharan Africa as compared to Morocco (47.52 kg/ha), Cote d'Ivoire (35.16 kg/ha), and South Africa (65.42 kg/ha) (Benin et al., 2011). Realizing that most farmers in Ghana have limited access to fertilizer, the subsidy which still exist until today (2016) was introduced in July 2008 to offset the low use of fertilizer and the limited access that was primarily exacerbated by exorbitant market prices (Benin et al., 2011). The fertilizer subsidy policy was introduced to provide a sure way for farmers to increase fertilizer usage, expand the area under cultivation, and increase output. Consequently, fertilizer consumption in Ghana has increased from the 7.4 kg per hectare in 2007 —before the implementation of the fertilizer subsidy—to 34.9 kg per hectare in 2012 (World bank, 2011). Crop yields, particularly maize have increased in the different ecological zones in which the fertilizer subsidy was rolled out in the country. An average of 251 kg of fertilizer applied on a hectare triggered a yield response of 2,128 kg compared with a total yield response of 923 kg per hectare in areas without fertilizer use (Benin et al., 2011). Additionally, data from the Ministry of Food and Agriculture statistics showed that the average yields for maize, rice, cassava, and yam have increased substantially between 2007 and 2012 by 26.7%, 47%, 31.3%, and 15.6%, respectively (Ministry of Food and Agriculture, 2013). These numbers should not be viewed as outcome estimates because other factors not linked to fertilizer subsidies may have affected production.

Although productivity increases as a result of increased fertilizer use seem out of the question, the effect of a fertilizer subsidy program (FSP) on agricultural output has not been adequately quantified in the literature. In addition, regional variations in the effect of the fertilizer subsidy policy on Ghana's agriculture and variations in the return to input factors across the country have not been conducted. To overcome this challenge and address the issue, it was imperative to introduce approaches that account for heterogeneous relationships across geographic space. In particular, the focus of this research is to estimate the input and output elasticities of the FSP in Ghana using classic linear regression (i.e., ordinary least squares, OLS) and their regional variations mapped across districts with a Geographical Information System (GIS) using local regression (i.e., Geographically Weighted Regression (GWR)) (Chang and Chen, 2015; Fang et al., 2015; Liu et al., 2016). These estimations assist not only in exploring and investigating the spatial relationships that exist in agriculture production output and input use but also in comparing the fitness of OLS and GWR models.

Thus, the objective of this study is to evaluate the spatial variations in Ghana's gross agricultural output elasticities in relation to the fertilizer input subsidy. This objective is achieved by 1) estimating the extent to which spatial heterogeneity affect the relationship between agricultural production and input factors across Ghana and 2) evaluate the changes in the spatial structures of input use in relation with agricultural output after implementation of FSP. This study serves as an evidenced-based tool to support and inform future decision making regarding implementing fertilizer subsidies in Ghana. The results also inform targeted allocations and distributions that lead to efficient input utilization to achieve a desired output. Utilizing the recommendation provides a smart approach and a paradigm shift in the method of implementation of the subsidy program, and avoids the exorbitant expenditures of the ongoing program. This study may be also informative to Korea government in order to set the strategical and efficient support plan since the amount of ODA (Official development assistance) by the Korean government is substantial (i.e., $40 million grants since 1991 and $182 million loans since 1990).

II. Empirical Model

A Cobb-Douglas production function is applied to define the relationship between input factors, including fertilizer use and agricultural output, following the commonly used form of agricultural production specification (Debertin, 1986),

$$(1) \qquad y_i = \alpha \prod_k x_{ik}^{\beta k}$$

where each district is denoted by subscript i (i = 1, 2, ⋯, n); yi represents gross agricultural product (GAP) in district i; xik represents input factors of production (k = 1, 2, 3, and 4), including fertilizer use, tractor use, labor, and cultivated area per capita in district i; α represents total

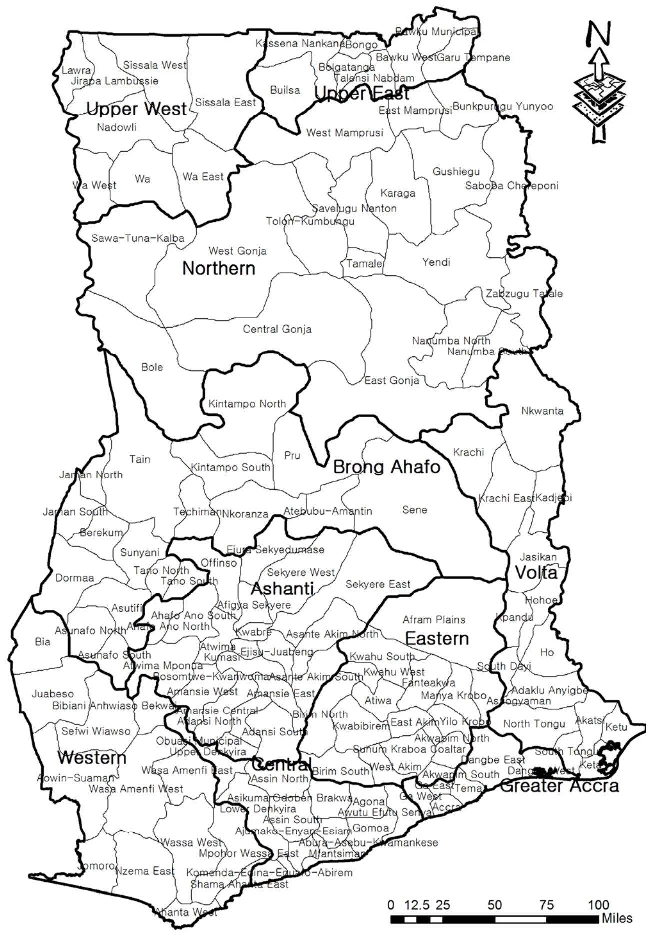

Figure 1. Administrative regions and districts in Ghana.

factor productivity; and βk represents the return of each input k to output. To estimate α and βk, the log-linearized Equation (1) after introducing random shock εi is defined in the following matrix form,

$$(2) \qquad Y = X\beta + \epsilon$$

where Y is a n × 1 vector of agricultural output, X represents an n × (k + 1) matrix including vectors of ones and k input factors; β is a (k + 1) × 1 vector; and ε is an n × 1 vector of error terms. The global effect of input factors can be estimated using classic linear regression techniques; however, spatial heterogeneity occurs when the same input factors provoke different responses in different aspects of the study area (Mathews and Yang, 2012). As indicated by Tobler's first law of geography (Tobler, 1970) (P. 236), spatial heterogeneity is intrinsic in all geographic data. To capture a spatially heterogeneous relationship between input factors and agricultural output, GWR techniques are applied,

$$(3) \qquad \hat{\beta}(u_i, v_i) = [(X' W(u_i, v_i) X)]^{-1} X' W(u_i, v_i) Y,$$

$$W(u_i, v_i) = \begin{bmatrix} w_{i1} & 0 & \cdots & 0 \\ 0 & w_{i2} & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & \cdots & 0 & w_{\in} \end{bmatrix},$$

$$w_{ij} = \begin{cases} [1 - (d_{ij}/d_i)^2]^2, & \text{if } b_i > d_{ij} \\ 0 & , \ otherwise \end{cases}$$

where $\hat{\beta}$ is an n × (k + 1) matrix with elements $\hat{\beta}_k(u_i, v_i)$ that capture the local relationship, and $W(u_i, v_i)$ is an n × n weight matrix in which the diagonal elements wi,j are spatial weights for each of the n observations for regression point i. The adaptive bi-square weighting function is used for wij, and dij is the Euclidean distance between observation point i and j and dij is the maximum distance between observation i and its q nearest neighbors (Fotheringham et al., 2002).

III. Study Area and Data

Ghana is comprised of 10 administrative regions. Regions are demarcated into districts on the basis of topography, climate, vegetation, and settlement patterns. These variations across regions have influenced countrywide resource distribution and utilization. The total number of districts in 2007 was 138. Additional districts were carved out of already existing districts, which brought the total number of districts to 216 in 2012 (Figure 1).

Data are collected from the Ministry of Food and Agriculture and the Ghana Statistical Service. Data on agriculture in Ghana for 2007 and 2012 are used. Data are comprised of information on agricultural production and input resources for production in Ghana. Gross Agricultural Product is the aggregated quantity in metric ton of maize, rice, cassava, and yam. GAP was used in place of Gross Value of Agricultural Output (GVAO) to avoid variations in the price of agricultural products across districts, also reflected in the variations in regional inflation values for both periods. Fertilizer distribution data for before and after implementation of the subsidy program are used to represent fertilizer use (metric ton) in Ghana. Tractor use refers to the number of tractors (i.e., the total wheel and crawler tractors for agricultural production), which represents tractors distributed in districts with an agricultural purpose. The rural population represents the people living in rural areas as defined by the offices of national statistics. The rural population is calculated as the difference between the total population and the urban population.

Table 1 provides summary statistics of the output and input variables for 2007 and 2012. In 2007, the mean GAP was 112,165 metric tons, average rural population as a proxy for agriculture labor was 84,285, average fertilizer use before the subsidy was 3,291 metric tons, average tractor use was 3.789, and average agriculture land area per capita was 0.254 ha per person. In 2012, the mean GAP was 136,333 metric tons, average rural population was 71,021 average fertilizer use after the subsidy was 18,149 metric tons, average tractor use was 7.682, and average agriculture land area per capita was 0.303 ha per person. The average GAP increased by 21%, the average rural population decreased by 15%, average fertilizer use

Table 1. Descriptive statistics of district level agriculture output and input.

Variables	Description	Mean	Std. Dev.	Minimum	Maximum
Year 2007					
GAP (ton)	Aggregated quantity of agriculture production	112,165	118,116	303	682,363
Fertilizer use (ton)	Amount of fertilizer distributed	3,291	2,476	600	9,000
Tractor use	Total wheel and crawler tractors for agricultural production	3.789	9.135	0	93
Labor	Number of people living in rural areas	84,285	36,653	7,090	203,926
Area per capita	Number of hectares per person	0.254	0.424	0.003	3.434
Year 2012					
GAP (ton)	Aggregated quantity of agriculture production	136,333	139,088.9	31	1,007,305
Fertilizer use (ton)	Amount of fertilizer distributed	18,149	13,466	1,741	47,815
tractor use	Total wheel and crawler tractors for agricultural production	7.682	17.117	0	152
Labor	Number of people living in rural areas	71,021	32,569	4,682	177,588
Area per capita	Number of hectares per person	0.303	0.484	0.001	3.379

Table 2. Comparison of performance between OLS and GWR.

	OLS	GWR
Year 2007		
Sample size	138	138
Bandwidth		50
Adjusted R2	0.285	0.722
Residual sum of squares	160.329	48.308
AIC	424.965	318.411
Year 2012		
Sample size	170	170
Bandwidth		54
Adjusted R2	0.397	0.728
Residual sum of squares	235.627	84.492
AIC	550.452	439.159

increased by 451% as a result of the FSP and average area per capita increased by 19%. The decrease in the rural population attests to the increase in rural-urban migration issues in Ghana.

IV. Estimation Results

A comparison of the OLS and GWR models indicates that a higher adjusted R2 associated with GWR reflects better goodness of fit of the models with correction of spatial heterogeneity (Table 2). CV scores were minimized when nearest 50 and 54 districts for 2007 and 2012 were used as adaptive bandwidth using bi-square kernel function. For both years (i.e., 2007 and 2012), the adjusted R2 increased from 0.285 to 0.722 and from 0.397 to 0.728 from OLS and GWR. The residual sum of the squared errors was significantly reduced in the GWR model. Akaike information criterion (AIC) was also reduced from the global model to the local model in 2007 and 2012, suggesting that the local model provides a better fits for the data after taking into consideration the differences in the degrees of freedom. The analysis of variance (ANOVA) between the groups indicated a reduction in the residual sum of squares, from 160.329 to 48.308 in 2007 and from 235.627 to 84.492 in 2012 for both global and local models—an improvement of 70% in 2007 and 64% in 2012. Hence, agricultural production in Ghana might be

Table 3. Parameter estimates summary of the local model of Ghanaian agricultural production.

Variables	Minimum	Lower Quartile	Medium	Upper Quartile	Maximum
Year 2007					
Intercept	−11.877	−6.219	−1.263	8.246	15.121
Ln(fertilizer use)	−1.685	−0.044	0.095	0.419	1.119
Ln(tractor use)	−0.647	−0.289	−0.037	0.055	0.267
Ln(Labor)	0.107	0.576	1.014	1.251	1.473
Area per capita	0.537	1.359	2.536	4.765	6.371
Year 2012					
Intercept	−39.698	−18.564	−5.296	0.606	8.773
Ln(fertilizer use)	−1.074	0.144	0.432	1.468	3.271
Ln(tractor use)	−0.247	0.074	0.036	0.098	0.164
Ln(Labor)	0.452	0.909	1.131	1.573	2.481
Area per capita	0.714	1.237	2.327	2.709	6.954

misrepresented as a result of the implicit assumption of no spatial variation in parameters in the OLS model. GWR has been chosen over the OLS model because of its lower AIC statistics. CV scores were minimized when nearest 50 and 54 districts for 2007 and 2012 were used as adaptive bandwidth using bi-square kernel function.

Table 3 presents the summary of the parameter estimates of the GWR model. This summary table suggests that labor and area per capita had the most consistent influence on GAP in 2007 as they showed the highest minimum values of 0.107 and 0.537 and maximum values of 1.473 and 6.371 respectively in the local model and also comparing with the other variables which showed negative minimum values of -1.685 for fertilizer and -0.647 for tractor use and low maximum values of 1.119 and 0.267 for fertilizer and tractor respectively. This scenario changed in 2012, with fertilizer being the second largest contributor to agricultural production after area per capita as they showed maximum values of 3.271 and 6.954 for fertilizer and area per capita respectively.

To illustrate the spatial heterogeneity of the parameters for fertilizer use across the country, the GWR estimates for fertilizer are mapped for 2007 and 2012 in Figure 2, respectively. Figure 2 indicates that spatial heterogeneity exists in the parameter estimates of fertilizer input use across the regions in Ghana. Before the implementation of the FSP, output elasticity for fertilizer was negative (−1.684 to −1.058) for most districts in the Upper West, Upper East, and Northern regions. Fertilizer use in the three northern regions was inelastic and negative, with elasticity values ranging from −1.6 to 1.5. Fertilizer use for most districts in the Ashanti, Brong-Ahafo, Greater Accra, and

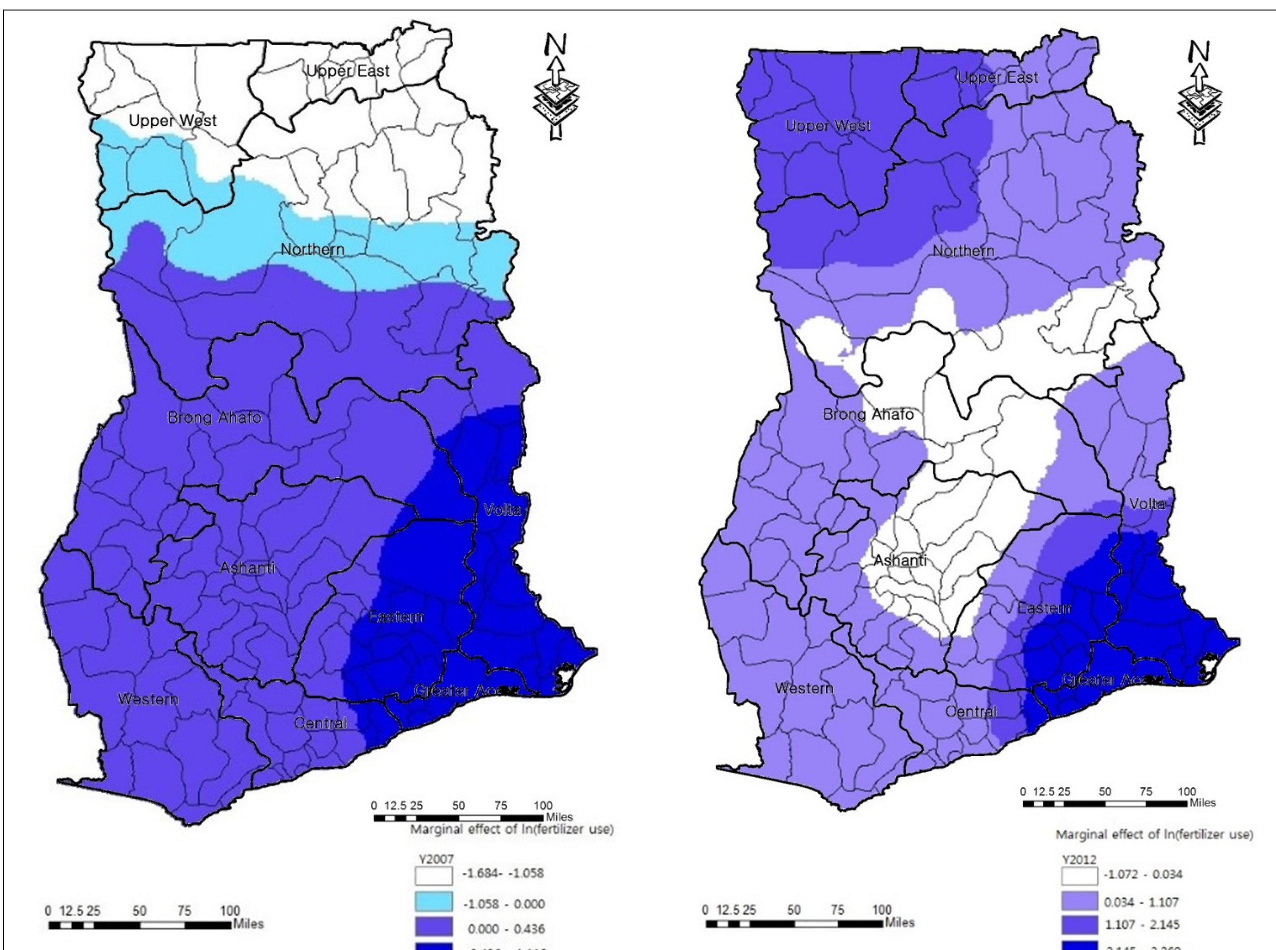

Figure 2. Output elasticities with respect to fertilizer for 2007 (Left) and 2012 (Right) district level agricultural production in Ghana.

Western regions was inelastic and positive, with values ranging from 0 to 0.437. Interestingly, fertilizer use in Volta and in most districts in the Central, Eastern, and Greater Accra regions ranged from inelastic to elastic, with elasticity values of 0.437 to 1.118.

In 2012, after the introduction of the fertilizer subsidy policy, the output elasticity of fertilizer input was positive in all districts in the Volta region and in major districts of the Eastern, Central and Greater Accra regions, with elasticity of 1.107 to 3.269. The output elasticity of fertilizer input for all districts in the Upper West region was high, with positive elasticity values of 1.107 to 2.146. Agriculture output to fertilizer input was inelastic but positive in all districts in the Upper East and Northern regions, with values ranging from 0.030 to 1.107. Additionally, all districts in the Western region and major parts of the Brong-Ahafo region were inelastic but recorded positive elasticity of fertilizer input to agricultural output.

Figure 2 provides a comparison of 2007 and 2012, and indicate that agriculture output elasticity to fertilizer use improved during the period. Notable changes observed include the disappearance of the negative elasticity for all districts in the Upper East and Upper West regions and major districts in the Northern region. Fertilizer input for all districts in the Volta region now has positive elasticity ranging from 0.437–1.118 to 2.14–3.269 during the period. A few districts in the Ashanti region had negative elasticities in 2012 compared with in 2007, when they did not record negative elasticity. Although negative elasticities occurred in 2012, they were limited to a few districts, thus indicating a reduction in their magnitude. Elasticities changed from −1.685–1.058 to 2.146–3.269 from 2007 to 2012, respectively, for the Upper West region, an improvement attributable to the introduction of the FSP throughout the country.

V. Conclusion

The agriculture sector in Ghana experienced significant changes since the introduction of the FSP in 2008. After recognizing fertilizer use as a major factor in achieving a green revolution in Africa (Avea, 2016), the subsidy was introduced in Ghana to facilitate a transformation in agriculture and to increase the productivity of Ghanaian farmers. The estimation of production function using GWR model performed better in terms of the overall goodness of fit. The GWR estimates suggest that area per capita, fertilizer, and labor are inputs with the most consistent influence on GAP across the districts in Ghana, whereas fertilizer use is second in terms of the highest contribution to overall agricultural production. Spatial heterogeneity exists for the parameters for fertilizer use to agricultural output across the districts. Agricultural output elasticity to fertilizer use improved during the period. Negative elasticity disappeared for all districts in the Upper East and Upper West regions and major districts in the Northern region. The output elasticities with respect to inputs generally improved in the country after implementation of the fertilizer subsidy. Regional variations of the impact of the fertilizer subsidy throughout the country — as this study made evident — indicated that the efficient design and utilization of a subsidy policy has an important influence on regional economic inequalities in Ghana.

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