The Global Food Security–Safety Dilemma of Fertiliser Technology Use: An Analysis of Policy-Induced Mediation

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Abstract:

The world's natural population growth has generated a paradoxical challenge between food security and safety (environmental quality). In this paper, we address this question to establish the security–safety paradox by examining increased fertiliser use on decreasing land endowment, and we establish how policy inducement reflects on the food security versus safety issue. Based on the generalised method of moment estimations and panel data of 72 countries from 2002 to 2010, we for the first time answer this question and offer insightful developments in this direction. Firstly, we observe that shrinking land endowment has significant direct and indirect impacts (agricultural protection and food trade policies). Our analysis demonstrates that a decrease in the land endowment increases the fertiliser use intensity. Secondly, policy for agricultural protection induces different effects on security and safety issues in development and world economies. Developed countries have introduced policies to reduce fertiliser usage—trading food security for safety. By contrast, developing countries have introduced policies to increase food security—trading food safety for security. Thus, developed countries tend to import food from developing countries to bridge the gap, and developing countries achieve economic gains.

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ABSTRACT

The world's natural population growth has generated a paradoxical challenge between food security and safety (environmental quality). Although the increased population and shrinking agricultural land strain food security, the need for food security (productivity) strains food safety through deteriorated environmental quality. This security–safety dilemma is a conceivable concept but a rarely empirically examined phenomenon because of its feasibility and balanced solutions. In this paper, we address this question to establish the security–safety paradox by examining increased fertiliser use on decreasing land endowment, and we establish how policy inducement reflects on the food security versus safety issue. Based on the generalised method of moment estimations and panel data of 72 countries from 2002 to 2010, we for the first time answer this question and offer insightful developments in this direction. Firstly, we observe that shrinking land endowment has significant direct and indirect impacts (agricultural protection and food trade policies). Our analysis demonstrates that a decrease in the land endowment increases the fertiliser use intensity. Secondly, policy for agricultural protection induces different effects on security and safety issues in development and world economies. Developed countries have introduced policies to reduce fertiliser usage—trading food security for safety. By contrast, developing countries have introduced policies to increase food security—trading food safety for security. Thus, developed countries tend to import food from developing countries to bridge the gap, and developing countries achieve economic gains. In this trade-off between food security and safety, we infer the adverse impact of excessive fertiliser use in developing countries. Additionally, in the context of globalisation and interconnectedness, trading food security for safety can adversely influence imported food and increase environmental deterioration in the developed world.

Key Words: Food safety-security dilemma; fertiliser technology on decreasing land endowment; developed-developing world's different preferences divide; panel data analysis

1. Introduction

The world's population increased from 2.5 to 7.2 billion from1950 to 2014, and will reach approximately 9 billion by 2050 (United-Nation, 2015). Rapid population growth and economic growth-driven urbanisation have exerted considerable impact on agricultural resources and induced a worldwide food security problem (Boserup, 1976; Godfray et al., 2010; Meadows, Randers, & Meadows, 2004). The conclusion of many food supply projections has been that the additional 2.4 billion people requiring food in 35 years' time can be accommodated with the resources available (Crafton, Daugbjerg, & Qureshi, 2015). However, because the land endowment, measured by agricultural land per capita, continuously decreases, the increase in food supply to meet this gargantuan requirement leads to an intensification of industrial agriculture—producing food through industrialised technologies (WB, 2008). This industrialisation can improve productivity and enhance food security to meet the population's needs.

Food productivity to increase security induces the intensive use of industrial technologies that can significantly decrease food safety and threaten human health. For instance, fertiliser and pesticides, that is, non-point sources (NPS) of pollution, cause harmful consequences in the environment (Jorgenson & Burns, 2004; Konradsen et al., 2003; Korinek & Veit, 2015; Wang, Lyons, Kanehi, Bannerman, & Emmons, 2000). The use of industrial technologies, fertiliser, and pesticides to improve food productivity degrades food safety. At the same time, improving safety standards by reducing fertiliser decreases productivity. The resolution to this dilemma, in which food security demands the intensification of fertiliser usage and food safety demands its attenuation, is one of the world's greatest challenges (Finn & Louviere, 1992; Hertel, 2015; Millstone, 2009).

A balance between food security and safety achieved by improving productivity and environmental quality is the ideal answer to this dilemma (Chartres & Noble, 2015). The feasibility of this balance, however, is challenging (Charles & Godfray, 2015). Without fertiliser intensification, achieving the land endowment's ideal productivity is unlikely; for instance, China applied 59.12 million tonnes of fertiliser (i.e., 328.5 kg/ha) in 2013. The world's average is 120 kg/ha; thus, China's amount is approximately 2.6 and 2.5 times of that used in the United States (US) and European Union, respectively (MOA, 2015). In China, food self-sufficiency (security) is the motivation for the intensified use of fertiliser because it is striving to meet the needs of increasing population on decreasing agricultural land. Thus, the Chinese government's policies are aligned with productivity through the intensification of fertiliser use.

Food security policy induces the excessive use of fertiliser on a decreasing amount of land to feed an increasing population in two ways: it provides agricultural subsidies, encouraging farmers to increase productivity at a lower cost to earn higher prices, and imposes an import quota. The policies that favour high productivity (food security) and a decreased import quota cause two consequences: these policies distort the domestic factor market and reduce the food supply from efficient and safe sources. As a result, a vicious cycle is created in which farmers are motivated to increase their use of fertiliser to expand food production, at the cost of food safety and the systematic risk of NPS pollution. Thus, the ideal balance between security and safety comes into question.

The literature has suggested that several factors lead to a systematic risk of NPS pollution. One view is that economic and demographic expansion exhibits a scale effect that accelerates agricultural intensification (fertiliser usage), which negatively influences agro–environmental resources in the early development stages of an economy in a less affluent society (Brock & Taylor, 2005; Dinda, 2004). This view is rather static and assumes that the economy is constrained to a fixed production possibility curve (Antle & Heidebrink, 1995; Carvalho, 2006; Grosman & Krueger, 1995; Schreinemachers & Tipraqsa, 2012). The alternate view is that economic and demographic expansions have either dynamic or no effects on the agricultural intensification.

To counter the economic expansion argument, Longo and York (2008) used a cross-section analysis of countries to demonstrate that fertiliser and pesticide consumption follows an inverted U relationship with per capita income. Schreinemachers and Tipraqsa (2012) analysed a cross-country dataset for the period 1990 to 2009 and observed that a 1% increase in crop output per hectare is associated with a 1.8% increase in pesticide use per hectare. However, the growth in intensity of pesticide use levels off when the using countries reach a higher level of economic development. Additionally, the growth in the intensive use of agrochemicals in developing countries is increasing rapidly because these countries prefer food security over food safety and environmental quality (Ecobichon, 2001; Schreinemachers & Tipraqsa, 2012; Wilson & Otsuki, 2004). To counter the demographic argument, Singh and Narayanan (2015) demonstrated that the impact of population on agrochemical use in India is negative. This result is counterintuitive and possibly because of public awareness regarding the harms related to the intensive use of pesticides.

A third stream of scholars has turned to the mechanisms that induce relevant policies on food security and its role in NPS pollution. Sun, Zhang, Yang, and Zhang (2012) observed that factor market distortions increase NPS pollution; therefore, relieving these distortions can reduce fertiliser use. Jorgenson and Kuykendall (2008) demonstrated that pesticide and fertiliser consumption are positively related to the level of foreign investment in agriculture. Foreign investment also encourages food security for export. For instance, Longo and York (2008) show that increasing agricultural export is positively related to fertiliser and pesticide consumption. Therefore, the economic policies for the internal factor market and external investment are responsible for the trade-off between food safety and security.

The literature provides three reasons for the food security–safety trade-off. First, the increased use of fertiliser on a shrinking amount of land increases the security but decreases safety (Schreinemachers & Tipraqsa, 2012). Second, agricultural subsidies play a role (Sun et al., 2012). Third, the food import quota influences the trade-off (Longo & York, 2008). The high-productivity and low-safety dilemmas follow these three issues. Accordingly, we pose three questions:

a. What is the relationship between the land endowment and fertiliser use intensity (does the shrinking amount of land induce increased fertiliser use)?
b. How does the land endowment's effect on fertiliser use intensity differ between developed and developing countries?
c. What are the intermediate roles played by relevant agricultural policies?

To answer these questions, this paper uses a cross-country panel dataset on land endowment and fertiliser use intensity to create dynamic models based on generalised method of moment (GMM) estimations to empirically investigate the relations of interest. Our study contributes to the literature in several aspects. Firstly, we decompose the impact of land endowment on fertiliser use intensity into direct and indirect impacts, which has not been done before. Secondly, we provide a systematic measurement for the comparison of direct and indirect impacts. The intermediate (indirect) role of agricultural policy is part of this development. Third, we establish that the developed and developing countries have differing impacts on land endowment and policies. In making this contribution, we highlight several policies for developed and developing countries.

2. Conceptual Framework

Following the research questions, we conceptualise the framework in Figure 1, which indicates a policy-induced tension between food security (productivity) and food safety (environmental quality) that differs between developed and developing countries.

Figure 1 demonstrates that the land endowment has direct and indirect impacts on the fertiliser use intensity. With a low land endowment, there is increased fertiliser use to maintain food productivity. We refer to this relationship between decreasing land (fixed resource) and increasing fertiliser use as a direct impact. Agricultural protection and food import policies reflect the two indirect paths and influence the fertiliser use intensity in agricultural activities. Figure 2 alludes to five hypotheses (one direct and four indirect), which we will discuss.

2.1. Direct impact

This inverse relationship between low land endowment and high productivity has negative implications for food safety and environmental quality. The literature has already addressed this proposition—that an increase in the land endowment should reduce the fertiliser use intensity (WB, 2008). This negative relationship between the land endowment and fertiliser use intensity has a positive implication for food safety and environmental quality. However, a decrease in the land endowment increases fertiliser use, leading to adverse effects on food safety and environmental quality. We restate the literature's perceived proposition in the first hypothesis as the direct impact of shrinking land and increasing fertiliser.

Hypothesis 1*: A decrease in the land endowment will induce an increase in fertiliser use intensity to meet the food productivity requirement.*

2.2. Indirect impact

The direct impact is conceptually clear and empirically supported. The processes other than the direct impact refer to an indirect effect through policy inducement. The induced policy, in this case, the agricultural protection policy, as the intermediary route, has land endowment as its antecedent and fertiliser use intensity as its consequence. An array of subsidies to farmers, taxation policies, and the imposition of quotas on agricultural imports are examples of agricultural protection (de Gorter & Swinnen, 2002). Regarding the antecedent to the agricultural protection policy in Figure 1, there is a negative correlation between the land endowment and agricultural protection. This negative link suggests that an increase in land reduces agricultural protection. This indirect link (H2) represents the following hypothesis.

Hypothesis 2*: An increase in the land endowment will decrease the agricultural protection policy, which will influence the fertiliser use intensity.*

The consequence of agricultural policy is an increase in fertiliser use intensity. As protection policies increase through subsidies, tax relief, and quotas on agricultural imports, there is a possible increase in fertiliser use (Longo & York, 2008; Sun et al., 2012). Keeping the land endowment fixed, we observe a positive correlation between high protection policies and an increase in fertiliser use intensity. Thus, we conceptualise this consequential link with the intensity of fertiliser use in the following hypothesis.

Hypothesis 3*: An increase in agricultural protection policies will increase fertiliser use intensity.*

The combination of the two indirect links induced through agricultural protection policies (H2 and H3) in Figure 1 implies that a land increase will reduce the hazard to food safety environment. In other words, the policy to expand the agricultural land will have positive effects on security, safety, and the environment. The policy focus on agricultural protection will have a negative influence on food safety and the environment.

The second indirect impact on the fertiliser use intensity is through food import policies. The link between the land endowment and food imports is simply negative (Fader, Gerten, Krause, Lucht, & Cramer, 2013). High land endowment means high productivity and low imports to meet the population's needs. This link (H4) reflects the land endowment as the antecedent to food imports, and the following hypothesis depicts this link.

Hypothesis 4*: An increase in the land endowment will decrease food imports.*

The consequence of the indirect impact of food imports is that the fertiliser use intensity decreases (Longo & York, 2008). The simple reason for this negative relationship (H5) in Figure 1 is that food imports will meet the population's need for food security. At the same time, food imports constrain fertiliser use. Thus, the following hypothesis captures this final link in the analytical model in Figure 1.

Hypothesis 5*: An increase in food imports will decrease fertiliser use intensity.*

Insert Figure 1 about here
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3. Methods

3.1. Sample

We intended to obtain the largest sample possible by merging various databases to form one working database. Despite the constraints on the available data, the integration helped us achieved our objective. The data panel comprises 72 countries, determined by the overlap among the databases in use. Certain countries, such as China, are unfortunately not included because of data availability. Consistent with the literature [e.g., Schreinemachers and Tipraqsa (2012)], the clear outliers are excluded. For example, Kuwait is excluded because the average fertiliser use intensity in Kuwait is greater than 1,000 kg/ha.

Because the domestic food supply variable for calculating the net food import rate only has data before 2010, and the data on fertiliser use intensity adjusted the standard in 2002 so that the data before and after 2002 are not comparable, the maximum time range that can be selected in this paper is from 2002 to 2010. Therefore, our final sample comprises observations from 72 countries from 2002 to 2010. Appendix A presents a list of these developed and developing countries. An economy with a per capita higher than US$ 15,000 is a developed country (United Nations Development Program). The method to divide these countries into two groups is given in Appendix B. The data came from the World Bank and Food and Agriculture Organization of the United Nations (FAO & FAOSTAT, 2015).

3.2. Variables

<u>Dependent variable:</u> The variables are defined in Table 1. The dependent variable is fertiliser use intensity (*fert*). Because fertiliser use is one of the main sources of NPS pollution, and fertiliser use per unit of land can better reveal a NPS pollution level resulting from fertiliser use, the index of fertiliser use intensity is widely used in the literature on NPS pollution (e.g. Singh & Narayanan, 2015). The index comes from (FAO, 1996), which divides fertiliser use by agricultural land. The

fertiliser use is the sum of the nutrients of nitrogen and phosphorus, and the agricultural land is the sum of arable land and permanent cropland (FAO, 1996).

Independent variables: The main explanatory variables are land endowment and relevant policies. The land endowment is represented by land area per capita (*land*). To maintain consistency with the fertiliser use intensity, we calculated the agricultural land used to calculate land per capita: it is the same as was used in calculating the fertiliser use intensity. The main policies resulting from land endowment are agricultural protection and food import. Agricultural protection is measured by the index of agricultural protection (*nra*), represented by the ratio of agricultural subsidies to agricultural output (Anderson & Valenzuela, 2008). Food imports are measured by the net food import rate, calculated by dividing the difference between food imports and exports by the domestic food supply.

As developed and developing countries have systematic differences in their policies on food security, agricultural protection, and food trade, the impact mechanism of the aforementioned variables may be different. Therefore, we conduct regressions not only for the whole sample but also for developed and developing countries, respectively, to test the robustness of the results and observe the differences between the two types of countries. The two types of countries are divided based on gross national income per capita, that is, the countries with an average income per capita higher than US$ 15,000 are defined as developed countries. This definition is consistent with the standard set by the United Nations Development Programme.

Control variables: Angrist and Pischke (2008) suggested three types of control variables in regressions. The first type is variables affected by variables of interest (here is land endowment). Because this type represents mediators between variables of interest and dependent variables, controlling for this type will lead to biased results because of over-controlling. The second type is variables irrelevant to variables of interest. For example, income per capita has no clear relation with land endowment here. Controlling for this type has no impact on the consistency and unbiasedness of the results. The third type is variables having a simultaneous impact on the dependent and independent variables. If this type is not controlled for, the estimation of variables will be biased. Agricultural protection and food imports belong to the first type of variables. When these two variables are not included as explanatory variables, the coefficient displays the combined effect of the variable of interest. After including these two variables, the coefficient displays the net direct effect, excluding the impact of mediators. To differentiate the combined effect from the net effect, we conducted two sets of regressions, specified in equation (1) and (2), respectively. Table 1 provides the definitions and descriptions of the main variables.

Insert Table 1 about here

3.3. Analysis (GMM model)

We use the GMM model in the analysis. This model has several advantages. First, it models the dynamic behaviours of actors (individuals or organisations). Past behaviours influence the actor's current behaviour. For instance, the past behaviour in the use of fertiliser by the agent can influence the current behaviour of the agent in fertiliser use intensity. Because of inertia or partial adjustment, individuals' current behaviours are often affected by ante behaviours. Accounting for the past behaviour in a test of the policy variables is possible through lagged dependent variables in the analysis of the panel data.

Second, a possible correlation exists either between the explanatory variables and individual characteristics in the error terms or between lagged dependent variables and the error terms. Either of the two can ensure the problem of endogeneity. A simple panel data cannot manage the endogeneity problem in the cross-country panel datasets. The GMM method takes the explanatory variables as instruments to solve the problem of endogeneity. Furthermore, the system GMM estimation is superior to the GMM model because it derives unbiased results (Blundell & Bond, 1998). The following mathematical models present the analysis.

(E1)

$$\ln(fert)_{it} = \beta_1 \ln(fert)_{i,t-1} + \beta_2 \ln(land_{it}) + \beta_3 \ln(gni_{it}) + \beta_4 (\ln(gni_{it}))^2 + \beta_5 \ln(pop_{it}) + c_i + y_t + u_{it}$$

(E2)

$$\ln(fert)_{it} = \beta_1 ' \ln(fert)_{i,t-1} + \beta_2 ' \ln(land_{it}) + \beta_3 ' \ln(gni_{it}) + \beta_4 ' (\ln(gni_{it}))^2 + \beta_5 ' \ln(pop_{it}) + \beta_6 ' X_{it} + c_i + y_t + u_{it}$$

i = countries;

t = years;

c_i = dummies countries;

y_t = year dummies, through which global economic shocks can be controlled;

u_{it} = error term;

X_{it} = mediators: agricultural protection (nra_{it}) and food imports (fir_{it})

β_2 and $\beta_2 '$ = combined and the net effect of land endowment respectively.

Whether the mediation mechanism exists remains unknown. The test of the validity depends on the two mediators:

(E3)

$$X_{it} = \beta_1'' X_{i,t-1} + \beta_2'' \ln(land_{it}) + \beta_3'' \ln(gni_{it}) + \beta_4'' (\ln(gni_{it}))^2 + \beta_5'' \ln(pop_{it}) + c_i + y_t + u_{it}$$

4. Results

We present the results in chronological order. The average fertiliser use intensity is 93.369 kg/ha (Table 1), with certain countries higher or lower than the average. Table 2 demonstrates that the top-10 fertiliser-using countries include developed and middle-income (i.e., Egypt and Chile) economies. The literature on pesticide use draws similar inferences: that developed and middle-income countries lead in pesticides use intensity (Schreinemachers & Tipraqsa, 2012). By contrast, the countries that use least fertiliser (the bottom- 10) are the least developed economies in Africa (i.e., except Kazakhstan).

Insert Table 2 about here

Figure 2 presents the plots containing the per capita income and fertiliser use in the 72 countries. The X-axis demonstrates per capita income; the Y-axis shows kg/ha fertiliser use. The plot indicates that low- and high-income countries use less fertiliser kg/pa than middle-income countries. Dividing this trend into two groups (i.e., developed and developing countries) reveals specific differences concerning protection policies.

Insert Figure 2 about here

Figures 3a and b show trends of fertiliser use intensity, land endowment, and agricultural protection in the developed and developing countries, respectively. The comparison of these two figures reveals the fundamental differences between the two groups. First, the developed and developing countries have average fertiliser intensities of approximately 130 and 50 kg/ha, respectively. The developed countries use fertilisers two times more than the developing countries. Second, the fertiliser intensity in developed countries decreases gradually, from 136.767 kg/ha to 123.061 kg/ha. By contrast, the fertiliser intensity in the developing countries increases from 46.348 to 54.984 kg/ha in the same period. Third, land endowment is stable in the developed countries and decreasingly significantly in developing countries. Fourth, the agricultural protection in developed countries is much greater than that in developing countries. However, it is decreasing rapidly from nearly 0.600 to less than 0.200.

These trends (Figures 3a and 3b) reveal the possible policy mechanisms in the two groups to link theory with the evidence. Theoretically, a low land endowment should increase the fertiliser use intensity; therefore, a stable land endowment should attract a similar level of fertiliser use intensity. However, the evidence counters this assumption by showing decreased fertiliser use on a stable land endowment in developed countries. This evidence (Figure 3a) rebuts the perceived theory that land endowment determines fertiliser usage. The plausible explanation for this counterintuitive evidence is the decrease in developed countries' agricultural protection policies.

Insert Figure 3a about here

In the developing countries, the explanation of policy protection does not hold. The trend in Figure 3b indicates that since 2008, the land endowment has been steadily decreasing while fertilisier use and agricultural protection policies are increasing. Because agricultural protection policy appears to be a recent upwards trend, compared with the steady trends of decreasing lands, the land endowment is a possible reason for this difference in the developing countries. To confirm these differences in the developed (protection policies) and developing countries (land endowment) as the impetus of fertiliser usage, we rely on the statistical analysis in Figure 3b.

Insert Figure 3b about here

Table 3 displays the differences among sample means of fertiliser usage, agricultural protection policy, and food imports between the two groups (rich land endowment and poor land endowment). The groups are divided by using the median value of the whole sample as the cutoff. The difference between rich and poor land endowment groups shows two statistically significant differences. First, the poor land endowment has a significantly high level of fertiliser use. Second, poor land endowment tends to induce agricultural protection policies. These results suggest that poor land endowment and protection policies are responsible for the increase in fertiliser use. Moreover, the rich and poor land endowment groups differ on the effects of food imports. However, even though net food imports may decrease fertiliser use, the descriptive statistics reveal that this effect is not sufficient to countervail the effect of land scarcity on agricultural protection.

Insert Table 3 about here

Table 4 presents several models, with and without the entries of mediating variables (agricultural protection and food import) and provides the results to confirm hypotheses H1, H3, and H5. According to H1, land endowment negatively affects fertiliser use. Model 1 demonstrates that rich land endowment can decrease fertiliser use. On average, the fertiliser use intensity decreases by 0.076% if land endowment increases by 1%. This impact is significant ($p < .01$). These results mean that rich land endowment represents better production conditions, mitigating food security concerns and thereby decreasing the fertiliser usage. The relationship between land endowment and fertiliser use has not been affected by sample selection. The results in Models 2 and 3 are consistent with Model 1. Thus, H1 has support.

Notably, the results show a statistical difference between the developed and developing countries. In developed countries, the impact of the land endowment on fertiliser use is marginally significant (10%). In developing countries, the impact of the land endowment is highly significant. These results imply that the land endowment strongly influences the fertiliser usage. This effect stands for the whole sample and the subsample of developing countries. After confirming this difference, we now consider the differentiated effects of the land endowment on fertiliser use intensity in Models 4 to 6 to confirm our hypotheses through Table 4.

Insert Table 4 about here

Model 4 demonstrates that when agricultural protection and food imports are controlled, the negative impact of the land endowment on fertiliser use remains, providing evidence of the direct impact of land endowment. The direct impact means that fertiliser use intensity will increase by 0.193% when land endowment per capita decreases by 1%. This effect is significant at 1% and much greater than the results where agricultural protection and food import are not controlled.

H3 predicted that protection policies induce fertiliser use. The coefficients in protection (row 3, H3) demonstrate an increase in fertiliser use. Agricultural protection often benefits food production and factor markets; hence, it enhances fertiliser use. The coefficients of net food imports (row 4, H5) show a significant decrease in fertiliser use. These results show that food imports supplement the deficiency of a domestic food supply, decrease dependence on domestic food production, and decrease fertiliser use, accordingly. If agricultural policies are constrained by food security condition, as demonstrated by the descriptive statistics, the indirect impacts of food security condition via agricultural protection and food trade exist. However, whether food security significantly affects agricultural protection and food import requires further explication.

Models 5 and 6 in Table 4 reveal the differences of the impact of food security in developed and developing countries. For the developed countries, the coefficient of agricultural protection is greater than those countries in the sample and the subsample of developing countries. This difference demonstrates that agricultural protection affects fertiliser use more significantly in developed countries. The direct impact of the land endowment is not significant when agricultural protection and food import are controlled. The relatively small impact of the land endowment in developed countries results from other strong agricultural policies. Developed countries either pay more attention to environmental quality, decreasing agricultural protection, or increase food imports to guarantee food security. The ultimate result is decreased fertiliser use intensity.

For developing countries, the impact of agricultural protection is smaller than that in the samples of all the countries and the developed countries. These results demonstrate that the agricultural protection in developing countries is minimal and has a weak impact on fertiliser use. Therefore, the land endowment has a higher significant direct impact in developing countries.

We now focus on the main point in the paper to assess the role of mediation mechanisms in agricultural policies. The existence of indirect impacts of the land endowment on fertiliser use requires that the impacts of the land endowment on mediators, including agricultural protection and food trade, are significant. Although Table 3 demonstrates that land endowment, agricultural protection, and food imports are correlated, to determine if causal relations exist requires empirical tests.

Table 5 demonstrates that land endowment decreases agricultural protection and food import significantly. However, the impact of the land endowment on agricultural protection is positive in developing countries. One possible explanation for this phenomenon is that although developing countries with poor land endowment are willing to protect agriculture, they have limited resources to do so. They even rely on the agriculture sector to provide financial revenue. The previous sub-section explained that mediators can affect fertiliser use. By contrast, this sub-section presents evidence that land endowment affects mediators and alludes to the mechanism that the land endowment affects fertiliser use via the agricultural protection and food imports predicted in H2 and H4.

Insert Table 5 about here

Combining the results in Tables 4 and 5, we calculated the relative impacts by using the two mediators and compared them with each other. The column of β' in Table 6 represents the relevant coefficients of the three pathways in Model 4 of Table 4. β'' represents the impact coefficients of the land endowment on the mediators, among which the coefficient of the land endowment is equal to 1, and the other coefficients are the corresponding coefficients in Table 5. The interaction of these two coefficients ($\beta' \times \beta''$) represents the absolute impacts of land endowment via the respective pathways[①]. The last column demonstrates the relative impacts. For the whole sample, the direct impact is dominant, and the relative impact of food imports is larger among the two indirect impacts. In the results of sub-samples, the absolute value of the

[①] Although the units of the mediators are different, the effect of the different units is cancelled out by interaction because the ultimate impact is of land endowment on fertiliser use, that is, $\frac{\partial(\ln(fert))}{\partial X} \times \frac{\partial X}{\partial(\ln(land))} = \frac{\partial(\ln(fert))}{\partial(\ln(land))}$. Therefore, indirect impacts from different mediators, or direct and indirect impacts, are comparable.

combined impact in the developing countries (-0.349) is larger than that in the developed countries (-0.009). The direct impact is dominant in developing countries, whereas the indirect impact via agricultural protection is dominant in the developed countries.

Insert Table 6 about here
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6. Discussion and Conclusions

This study examined whether protection and import policies differently mediate the influence of land endowment on fertiliser use in developed versus developing countries. Based on the data from 72 countries, grouped into developed and developing economies, the panel data analysis reveals insights regarding the differential effects of policy effects on fertiliser use in developed versus developing countries. As displayed in Figure 1, developed countries take the path of -H2 and +H3, suggesting that land endowment decreases protection policies (H2), which themselves increase fertiliser use (H3). In other words, although land endowment should decrease the fertiliser use in theory (H1), the protection policy mediates these effects in the developed world compared with the developing countries.

The developing countries must manage a different policy path. The increase in land endowment decreases imports (-H4), which decrease fertiliser use (-H5). The path that the developing economies take in the context of Figure 1 offers a different explanation from that of the developed countries on agricultural protection policy. Firstly, the developing countries increase imports through fewer import restrictions when the land endowment is low, that is, the decrease in the land endowment leads to the increase in imports provided the import restrictions are weak. In this sense, a high land endowment should reduce imports through policy mechanisms in the developing world. Secondly, the increase in imports through lenient import policies can lead to a decrease in fertiliser use. These results mean that when the import barriers are low, the imported food can mitigate the food security concerns, leading to a decrease in the fertiliser use (in favour of food safety concerns).

Two groups of countries and their policies demonstrate that the developed countries favour agricultural protection policy mechanisms and developing countries favour food import policies—the former group uses protection policies and the latter favours trade policies. In the context of the security–safety dilemma, developed and developing countries focus on food safety and food security (productivity), respectively. In this divide, the developed countries import food from developing countries to meet their food security needs in favour of environmental protection, which appears to be a rational solution. However, the concern remains as to whether the productivity through excessive fertiliser technology in the developing countries may bring their safety issues to the developed countries through imports (Knight, Holdsworth, & Mather, 2007).

Our study contributes to the literature in several aspects. Firstly, we decompose the impact of the land endowment on fertiliser use intensity into direct and indirect impacts, which has not been accomplished before. Secondly, we provide a systematic measurement for the comparison of direct and indirect impacts. The intermediate (indirect) role of the agricultural policy is part of this development. Thirdly, by closely following Schreinemachers and Tipraqsa (2012), we observe that the developed and developing countries have different impacts on land endowment and policies. In making this contribution, this study advocates for variegated policies for developed and developing countries.

There are several policy options. Firstly, the focus of the policy should shift to the expansion of agricultural land. Cleaning the polluted land is one example; optimisation of the land planning for industrial and residential use is another possible option. Developing smart houses and industrial complexes can be an approach to serving this purpose. Secondly, because the land endowment is a less flexible (fixed) resource in developing and developed countries, there are two policy options (agricultural protection and imports). In the first case, the agricultural protection policy option has a negative outcome for the environment and food safety. High protection leads to a high use of fertiliser. In the second case, the relaxed food import policy has a positive influence on the environment and food safety by reducing fertiliser use. Protection is bad; openness is good. Developed countries apply the former policy (agricultural protection), and the pathway via agricultural protection can decrease fertiliser use intensity. The developing countries invoke the later type of policy (openness for food import), and the pathway via food imports (barrier) increases the fertiliser use intensity. The developed countries demonstrate a preference for agricultural protection; the developing countries show the land endowment and fertiliser are significant.

The policy-making agencies should pay close attention to the trade-off between food security and safety. The tendency towards the emphasis on food production (food security) will lead to a highly polluted environment as an unavoidable by-product. The food security focus via fertilisation causes NPS pollution, which is a high environmental cost that cannot be ignored. Moreover, the rich land endowment is helpful to mitigate reliance on fertiliser use. Protecting agricultural land against invasion by other users guarantees food security and decreases fertiliser use. By contrast, the modification of agricultural protection is a powerful mechanism to reduce fertiliser use in developed countries, whereas protection of land endowment can reduce fertiliser use in developing countries.

We also suggest a third alternative: developed and developing countries should take on the responsibility of inventing a productive and safe technological solution. Joint research and development activities towards the safe production of food represent the principal and most sustainable answers to the dilemma in the long term. Reducing pollution with technological innovation in the existing resources, such as rivers and canals, and directing the water resources from surplus areas to less deficient lands are joint solutions in the world of sustainability.

This study has some limitations. Firstly, future research could complement GMM with an analysis with instrumental variables. Of course, as we have interest in several variables simultaneously, choosing suitable instrumental variables may be challenging. Secondly, the robustness of the main results may be checked by using other variables that indicate the impact on food safety. For example, the data on pesticides is very promising. Thirdly, there may be other mechanisms behind these variables that could be explored by using moderation models.

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Table 1: Definition and Descriptive Statistics of the Variables

Variables	Abb.	Definition	Unit	Means	S.D	Min	Max
Fertiliser use intensity	*fert*	Fertiliser use / Land area	kg/ha	93.369	90.478	0.010	521.200
Land per capita	*land*	Agricultural land area / Population	ha per capita	0.340	0.345	0.035	2.449
Agricultural protection	*nra*	Agricultural redistribution / Agricultural output×100	%	0.161	0.363	-0.604	2.369
Rate of net food import	*fir*	(Food import - Food export) / Domestic food supply×100	%	9.734	46.652	-200.905	148.233
Income per capita	*gni*	GNI / Population, based on PPP。	10^3 $ per capita	15.804	14.067	0.480	61.060
Population	*pop*	Count of national of the country	million	60.118	138.175	1.033	1190.138

Notes: The number of countries and observations are 72 and 593, respectively.

Source: World Bank (http://data.worldbank.org/indicator), FAO (http://faostat3.fao.org/).

Table 2: Top and Bottom 10 Countries According to Fertiliser Use Intensity

Top 10 highest users			Rank	Bottom 10 least users	
Rank	Country	Intensity (kg/ha)	Rank	Country	Intensity (kg/ha)
1	Egypt	427.246	63	Nigeria	4.514
2	Ireland	375.636	64	Tanzania	4.169
3	Korea	296.994	65	Sudan	3.920
4	Netherland	283.158	66	Ghana	3.920
5	Chile	245.922	67	Mozambican	3.534
6	Japan	230.916	68	Togo	3.149
7	U.K.	211.827	69	Benin	2.164
8	Slovenia	207.153	70	Madagascar	1.870
9	Viet Nam	199.690	71	Kazakhstan	1.407
10	Colombia	185.748	72	Uganda	0.971

Notes: The estimates of fertiliser use are based on statistics for the period 2002–2010 (FAO, 1996; FAO & FAOSTAT, 2015).

Table 3: Differences between Countries with Rich and Poor Land Endowment

Variables	Poor land endowment (1)	Rich land endowment (2)	Difference (1) - (2)
Fertiliser	135.196	53.065	82.130***
	(107.743)	(39.937)	(0.000)
Agri-protection	0.238	0.085	0.153***
	(0.463)	(0.201)	(0.000)
Food imports	31.670	-11.402	43.073***
	(33.649)	(47.709)	(0.000)
Observations	291	302	-

Notes: The standard error is in parentheses, less than the sample means. *** represents a significance of 1%.

Table 4: Impacts of Land Endowment on Fertiliser Use Intensity

Model	1	2	3	4	5	6
Sample	All	Developed	Developing	All	Developed	Developing
L.ln(fertiliser)	0.713***	0.635***	0.742***	0.747***	0.804***	0.730***
	(184.901)	(4.561)	(53.444)	(83.207)	(10.234)	(28.773)
ln(land) ***(H1)***	-0.076***	-0.391*	-0.254***	-0.193***	-0.058	-0.370***
	(-4.515)	(-1.694)	(-3.361)	(-11.490)	(-0.929)	(-6.494)
Protection ***(H3)***				0.092**	0.158*	-0.185
				(2.192)	(1.668)	(-1.358)
Net imports ***(H5)***				-0.001***	-0.000	-0.003***
				(-3.436)	(-0.219)	(-3.649)
ln(GNI)	0.466***	-0.712	0.408***	0.438***	-1.842	0.415***
	(27.988)	(-1.081)	(6.193)	(9.496)	(-0.947)	(4.917)
(ln(GNI))^2	-0.067***	0.154	-0.062***	-0.071***	0.281	-0.057
	(-15.914)	(0.954)	(-3.252)	(-7.311)	(0.953)	(-1.634)
ln(population)	0.051***	-0.017	0.038	0.027***	0.007	0.038**
	(6.254)	(-0.671)	(1.219)	(4.321)	(0.708)	(2.030)
Constant	0.351***	1.834***	0.013	0.216***	3.832	-0.084
	(12.466)	(3.054)	(0.211)	(4.744)	(1.265)	(-1.021)
Year dummies	controlled	controlled	controlled	controlled	controlled	controlled
AR(1) P value	0.081	0.004	0.089	0.076	0.000	0.087
AR(2) P value	0.180	0.314	0.178	0.175	0.247	0.173
Hansen test P value	0.971	1.000	1.000	1.000	1.000	1.000
Observations	522	230	292	522	230	292

Notes: Numbers in parentheses are t values. ***, **, and * represent significances of 1%, 5%, and 10%, respectively.

Table 4a: Impacts of Land Endowment on Fertiliser Use Intensity in Developing Countries

Model	1	2	3	4
Sample	Poorest	Poor	Poorest	Poor
L.ln(fertiliser)	0.673***	-0.012	0.437***	0.504*
	(7.154)	(-0.031)	(2.981)	(1.701)
ln(land) ***(H1)***	-2.177*	-1.905*	-1.465*	0.143
	(-1.742)	(-1.954)	(-1.875)	(0.346)
Protection ***(H3)***			-0.043***	0.001
			(-2.670)	(0.608)
Net imports ***(H5)***			0.713	-0.013
			(1.223)	(-0.025)
ln(GNI)	0.768	0.174	1.881*	-2.611
	(0.543)	(0.134)	(1.729)	(-1.262)
$(ln(GNI))^2$	-1.187	0.141	-0.351	0.394
	(-1.491)	(0.999)	(-0.393)	(1.224)
ln(population)	-0.304	0.025	-0.424*	-0.014
	(-1.137)	(0.357)	(-1.713)	(-0.050)
Constant	-0.946*	0.441	0.812	6.192
	(-1.800)	(0.188)	(1.397)	(1.385)
Year dummies	controlled	controlled	controlled	controlled
AR(1) P value	0.122	0.088	0.118	0.594
AR(2) P value	0.197	0.798	0.187	0.736
Hansen test P value	1.000	1.000	1.000	1.000
Observations	144	148	144	148

Notes: Numbers in parentheses are the t values.

***p < .01

**p < .05

*p < .1

Table 5: Mediation of Policies

Model	1	2	3	4	5	6
Sample	All	Developed	Developing	All	Developed	Developing
Dependent	*Protection **(H2)***			*Imports **(H4)***		
L.Protection	0.786***	0.726***	0.616***			
	(242.103)	(39.618)	(11.013)			
L.Imports				0.688***	0.825***	0.859***
				(95.818)	(29.994)	(88.419)
ln(land)	-0.045***	-0.059*	0.069*	-18.516***	-9.482***	-6.914***
	(-10.665)	(-1.745)	(1.736)	(-39.255)	(-4.501)	(-6.744)
ln(GNI)	0.002	-2.081***	-0.000	0.557	-15.588	4.801***
	(0.233)	(-3.768)	(-0.017)	(0.599)	(-0.117)	(4.286)
$(ln(GNI))^2$	0.000	0.283***	-0.006	-0.791***	4.066	-2.906***
	(0.246)	(3.893)	(-0.553)	(-3.412)	(0.205)	(-6.774)
ln(pop)	0.003***	0.023***	0.020**	-2.935***	-2.309**	-1.698***
	(3.234)	(3.641)	(2.335)	(-8.818)	(-2.207)	(-5.347)
Constant	-0.083***	3.647***	0.053	-11.006***	-1.142	6.082**
	(-12.649)	(3.632)	(1.179)	(-6.620)	(-0.005)	(2.369)
Year dummies	controlled	controlled	controlled	controlled	controlled	controlled
AR(1) P value	0.000	0.039	0.001	0.072	0.182	0.003
AR(2) P value	0.457	0.343	0.285	0.871	0.439	0.172
Hansen test P value	0.896	1.000	1.000	0.879	1.000	1.000
Observations	522	229	293	524	230	294

AR = Auto regression;

Notes: Numbers in parentheses are the t values. ***, **, and * represent significances of 1%, 5%, and 10%, respectively.

The first three columns relate to H2. The last three columns relate to H4.

Table 6: Comparison among Direct and Indirect Impacts

Effect		β'	β''	Absolute effect ($\beta' \times \beta''$)	Relative effect (%)
Developed & Developing countries					
	Direct	-0.193	1	-0.193	108.048
	Indirect				
	Agri. Protection	0.092	-0.045	-0.004	2.318
	Food import	-0.001	-18.516	0.019	-10.366
	Total			-0.179	100.000
Developed countries					
	Direct	NS	1	NS	NS
	Indirect				
	Agri. Protection	0.158	-0.059	-0.009	100.000
	Agri. Protection	NS	-9.482	NS	NS
	Total			-0.009	100.000
Developing countries					
	Direct	-0.370	1	-0.370	105.939
	Indirect				
	Agri. Protection	NS	0.069	NS	NS
	Agri. Protection	-0.003	-6.914	0.021	-5.939
	Total			-0.349	100.000

NS = Not significant

Figure 1: Direct and Indirect Impacts of Land Endowment on Fertiliser Use Intensity

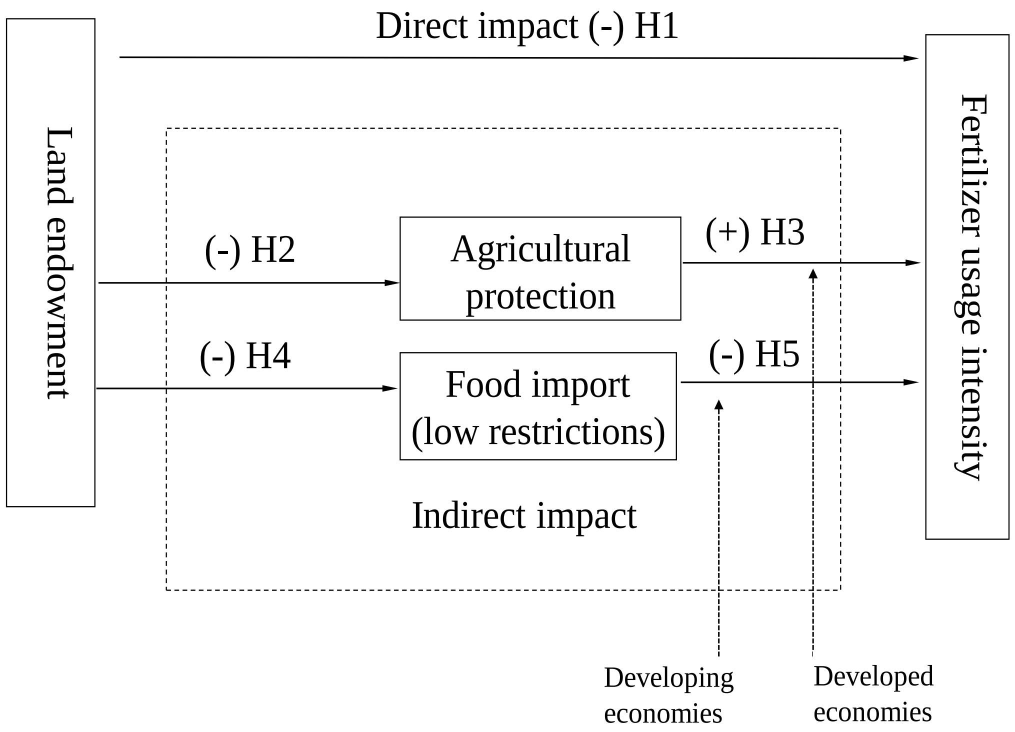


Figure 2: Relation between Fertiliser Use Intensity and Gross National Income (GNI) per Capita

Figure 3a: Trends of Land Endowment and Fertiliser Use in Developed Countries

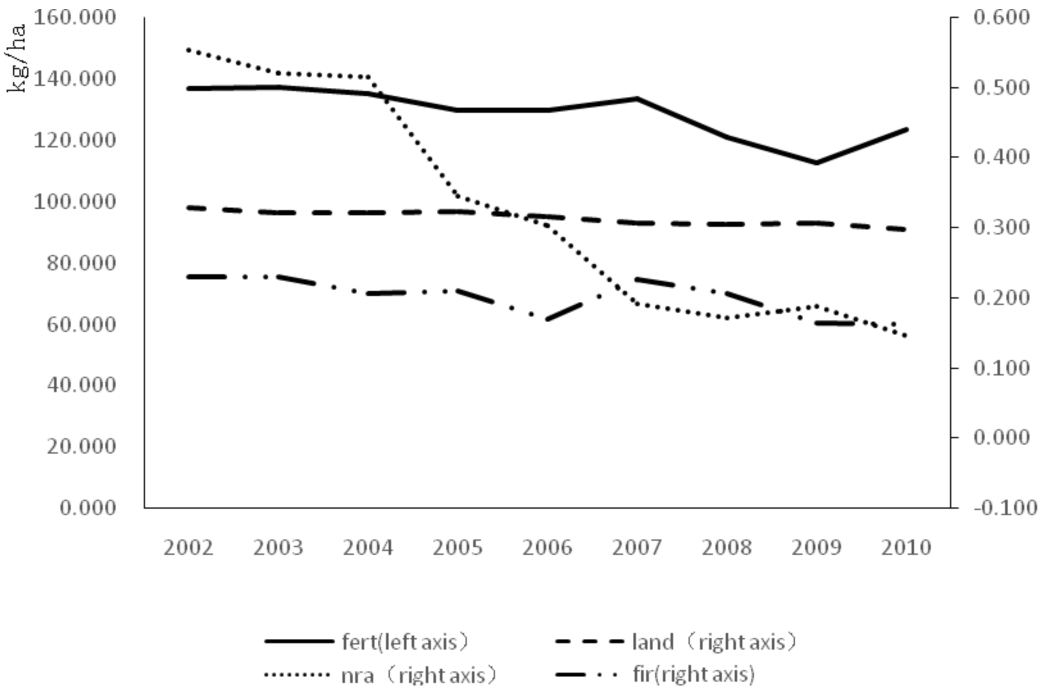


Figure 3b: Trends of Land Endowment and Fertiliser Use in Developing Countries

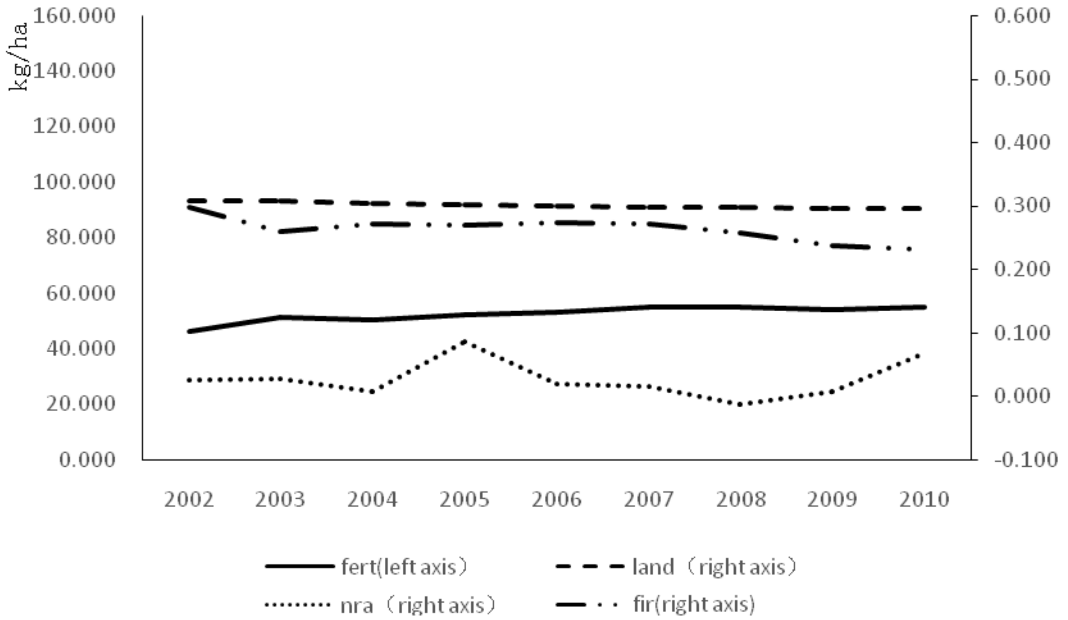


Figure 3c: Trends of Land Endowment and Fertiliser Use in the Poorest Countries

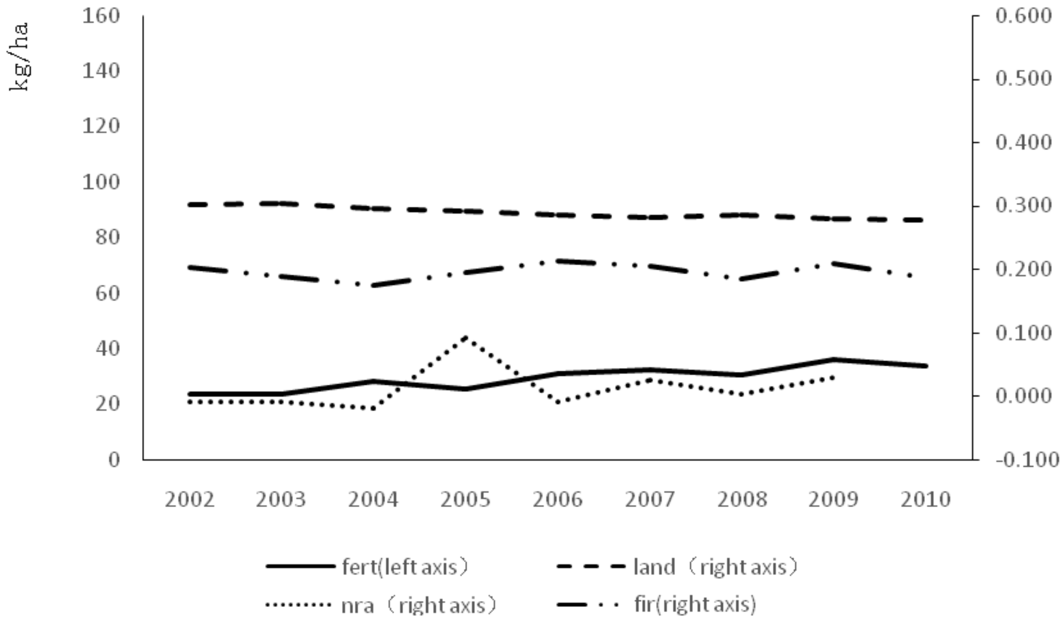
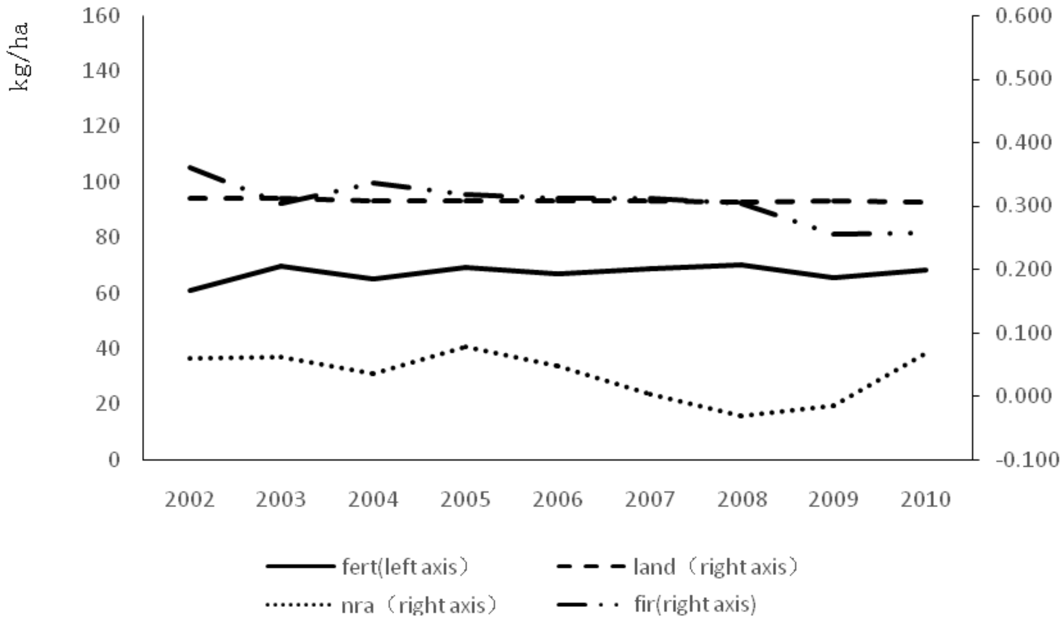


Figure 3c: Trends of Land Endowment and Fertiliser Use in the Poor Countries



Appendix A: Countries Included in the Empirical Analysis

29 developed countries		43 developing countries		
Australia	Japan	Argentina	Indonesia	Russia
Austria	South Korea	Bangladesh	Kazakhstan	Senegal
Canada	Lithuania	Benin	Kenya	South Africa
Cyprus	Netherlands	Brazil	Latvia	Sri Lanka
Czech	Norway	Bulgaria	Madagascar	Sudan
Denmark	Poland	Burkina Faso	Malaysia	Tanzania
Estonia	Portugal	Cameroon	Mali	Thailand
Finland	Slovakia	Chile	Mexico	Togo
France	Slovenia	Colombia	Morocco	Turkey
Germany	Spain	Dominican Republic	Mozambique	Uganda
Greece	Sweden	Ecuador	Nicaragua	Ukraine
Hungary	Switzerland	Egypt	Nigeria	Vietnam
Ireland	UK	Ethiopia	Pakistan	Zambia
Israel	USA	Ghana	Philippines	
Italy		India	Romania	