Investigation of the factors influencing adoption of GM crops at country level

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Abstract

With the possible exception of nuclear technology, few scientific breakthroughs have generated the level of emotive debate that has surrounded the roll-out of agricultural biotechnology. Initial discussion about the environmental impacts of agricultural genetic modification, are now frequently juxtaposed with counter-claims that the technologies could actually be part of a wider global environmental solution in relation to climate change mitigation and food shortages. This study tests whether there are any consistent messages on why some countries seem to be advancing adoption of the technology, while others are not. We consider the range of claims in existing literature on adoption tendencies and then use structural equation modelling to test and estimate these a priori determinants of GM adoption. We found that being an exporter of maize and soybeans, agricultural area, participation in the Responsible Care Program of the Chemical Manufacturer's Association, having the EU and/or Japan as main trading partners, and participation in international environmental agreements, significantly influence decisions about whether or not to adopt GM crops at the country-level. In addition, there are two variables that are indirectly related to adoption decisions at country-level, namely technological readiness and government effectiveness.

Keywords: Genetically modified crops; structural equation model; global adoption.

1. Introduction

Debates about genetically modified (GM) crops are as polarised as ever, with continuing claims and counterclaims over the risks and benefits of adoption of the technology, the role of institutions, including government regulation and multinational power, and whether consumers should have the right to choose. Recent developments in global environmental debates have advanced GM technology as a potential solution to both global climate change and food shortages. These arguments suggest that the risk / benefit picture may need to factor in wider benefits in terms of greenhouse gas mitigation and food supply. On the other hand, opponents suggest that adoption of GM technologies could have global consequences that are too complex to foresee with current information, and thus, the only option is to adopt a precautionary stance. The result is that high profile, direct action in several countries has been highly persuasive to governments and farming communities that are wary of jeopardising fragile relationships with powerful supply chains, and thus have adopted a precautionary stance towards the technology.

This debate does not give rise to a consistent picture on the formulation of international biotechnology policies or suggest why some countries have adopted, while others have not. In fact it is difficult to see how the current stalemate can be broken. As Artuso (2003) states, developments in the market for GM crops point to the need for analysis of the interaction between market expansion, regulatory policy, and consumer risk perceptions, all of which have been analysed separately. This paper analyses the interaction between adoption (market expansion) and a number of factors that might explain why some countries are adopters of the technology. The paper aims to inform international policy debates about the future of GM technology in global agriculture.

2. Determinants of GM adoption

Much of the GM adoption literature relates to individual farm-level adoption. Here we review literature relating to country-level adoption decisions.

Agricultural variables. There is a range of variables that may have some influence on the decision to adopt (or not) GM crops at a country level. A number of agricultural variables are important, since different countries have different production environments, and hence potential profitability from any given modification will vary country by country.

Consumers, NGOs, risk perceptions, trust in government: factors affecting adoption in developed countries. From the point of view of farmers and agri-businesses in developed countries, it could be expected that key concerns and priorities influencing adoption decisions would be the extent to which new technologies lead to greater economic efficiency and improved business performance (Otsuka, 2003). However, in fact, one of the main factors influencing the decision of developed countries to authorise GM crops, is the level of resistance of consumers, consumer groups and the activities of NGOs in that country (Chen & Chern, 2002). Thus, understanding the factors that influence consumer attitudes to GM crops is critical, and the public's perception of the risks of GM technology is central to its (non-)acceptance.

If we accept that the commercial development of GM crops in developed countries will largely depend on acceptance by consumers and environmentalists, it follows that they must have confidence in the legislative framework regulating the technology.

Ultimately, the acceptance of GM foods in developed countries is likely to depend on consumer attitudes and perceptions of risks and benefits. A key part of these perceptions relates to environmental concerns about the technology and a growing awareness of the importance of environmental issues. Trust in the regulatory system, a key part of government effectiveness, is also an important determinant of consumer acceptance. Thus, scientific, economic, and technical factors may be insufficient to lead a country to adopt GM crops. Social issues, such as trust in institutions and people's values and attitudes, notably towards the environment, are likely to be equally important (Purchase, 2005).

Institutional capacity, trade relations: Factors affecting adoption in developing countries. There is a number of variables that are particularly significant to developing countries and their decisions about whether or not to adopt GM crops. Many developing countries lack in-country educational capacity and the capacity to undertake independent research. Further, many developing countries lack the institutional capacity required for addressing legal issues such as intellectual property rights and ethics. The systems in place relating to bio-safety approval and monitoring will affect whether or not a country can give its farmers authorisation to adopt GM crops (Cohen & Paarlberg, 2004; Gonsalves et al, 2007).

There is concern that consumers in developed, food-importing countries, such as Europe and Japan, will reject imports from any country that plants GM crops (Paarlberg 2002; Cohen & Paarlberg, 2004; Gonsalves et al, 2007; Berg et al, 2003; Pekaric-Falak et al, 2001).

Overall, it is suggested that even where there are clear technological, production and economic benefits to be gained from the introduction of GM crops, these may not be sufficient to overcome the internal factors relating to a lack of institutional capacity at all levels, or the external factors such as import country restrictions and precautionary positions. As Gonsalves *et al* (2007) state, for many developing countries overcoming these challenges will prove to be significant, should they wish to adopt GM crops.

3. Method

3.1 Data

Central to the empirical analysis in this paper is a cross-section database containing data on several variables that we hypothesised, based on *a priori* information from the literature, could be determinants of GM adoption behaviour at country level. The data was collected for 112 countries from several established databases (FAOSTAT, WTO, International Council of Chemical Associations (ICCA), Yale Center for Environmental Law and Policy, World Economic Forum, ISAAA). The size of the sample of countries was determined by the data available. Among these 112 were the 24 current adopters.

The purpose was to test whether certain variables could be shown to be related to whether or not a country was an adopter of GM crops.

The eight variables included in the analysis are 'agricultural area' (agriland), 'maize and soybean exports' (exports), 'participation in the Responsible Care Program of the Chemical Manufacturer's

Association' (rescare), 'EU and/or Japan main trade partners' (tradpart), 'participation in international environmental agreements' (envpart), 'government effectiveness' (goveff), 'technological readiness' (techread) and 'GM adoption behaviour' (GM). Table 1 presents a series of descriptive statistics for these variables.

Table 1. Descriptive statistics

	Mean	Std. Deviation
agriland (agricultural area)	1.61	.66
exports (maize and soybean exports)	1.65	.97
rescare (participation in the Responsible Care Program of the Chemical Manufacturer's Association)	.38	.49
tradpart (EU and/or Japan main trade partners)	1.18	.52
envpart (participation in international environmental agreements)	.72	.16
goveff (government effectiveness)	.11	.95
techread (technological readiness)	1.79	.82
gm (gm adoption)	.21	.41

'Agriland' represents the agricultural area in the specific country for the year 2003 (source: FAOSTAT, 2008). 'Agriland' is a categorical variable taking the value 1 if the agricultural area is less than 10 million ha; value 2 if the agricultural area is between 10 and 100 million ha; and value 3 if the agricultural area is above 100 million ha.

'Exports' represents the level of a country's exports of maize and/or soybeans (source: FAOSTAT, 2008). 'Exports' is a categorical variable taking value 0 if the country is not an exporter of maize or soybeans; value 1 if the country's exports of maize and/or soybeans are between 1 and 2,000 thou. US$; value 2 if the country's exports of maize and/or soybeans are between 2,000 and 60,000 thou. US$; value 3 if the country's exports of maize and/or soybeans are above 60,000 thou. US$. Our hypothesis here was that being a large exporter of maize and/or soybeans would increase the likelihood of a country being an adopter of GM crops, as these are the major GM crop types.

'Rescare' represents country's participation in the Responsible Care Program (RCP) of the Chemical Manufacturer's Association, which sets environmental, health and safety performance standards across the chemical industry (ICCA, 2003). 'Rescare' is a dichotomous variable taking value 0 if the country is not a member of the RESCARE and value 1 if the country is a member of the RESCARE. The expectation here was that being a participant in RCP would increase the likelihood of adopting GM crops because membership demonstrates a highly developed and technological intensive industrial agricultural system, with strong involvement of the chemical industry in agricultural production. To a large extent, the agri-chemical companies are also highly involved in the development of GM crops.

'Tradpart' represents whether the country's main trading partners trade include the EU and/or Japan (source: WTO, 2007). 'Tradpart' is a categorical variable taking value 0 if neither EU nor Japan are amongst the country's main trade partners; value 1 if either EU or Japan are amongst main trade partners; value 2 if both EU and Japan are amongst main trade partners. We hypothesised that having the EU and/or Japan as main trading partners would reduce the likelihood that a country would be an adopter of GM crops.

'Envpart' represents the country's participation in international environmental agreements (source: Esty *et al*., 2005). 'Envpart' is a continuous variable taking values between 0 and 1 depending on the degree of participation (based on Esty *et al*., 2005, p. 329[1]). The expectation here was that greater involvement in environmental agreements could mean less likelihood of being an adopter.

'Goveff' represents government effectiveness, measuring perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies (source: Esty *et al*., 2005). 'Goveff' is a continuous variable taking values between 0 and 1 depending on the degree of government effectiveness (methodology for building this indicator is given in Esty *et al*., 2005, p. 344). Our hypothesis in this case, drawn strongly from claims presented in the literature, was that a higher degree of government effectiveness would suggest a greater likelihood of GM adoption.

'Techread' represents technological readiness, measuring the ease with which an economy adopts existing technologies to enhance the productivity of its industries (source: World Economic Forum, 2008). 'Techread' is a categorical variable taking value 1 if the original value[2] of the indicator was below 3; value 2 if the original value of the indicator was between 3 and 4; value 3 if the original value of the indicator was above 4. We hypothesised that a higher technological readiness would suggest a greater likelihood to adopt GM crops. Both 'goveff' and 'techread' relate to institutional development, as discussed in the literature review.

[1] "For each convention, protocol, and amendment points were allocated as follows: 1 point for signature, accession, and ratification without signature. An additional point for ratification with signature, acceptance, approval, or succession. The maximum number of points achievable is: 2 points for UNCCD, 12 points for Vienna Convention, Montreal Protocol, and its Amendments, 2 points for CITES, 4 points for UNFCCC and the Kyoto Protocol, 2 points for the Basel convention, 4 points for UNCBD, and 4 points for the Ramsar convention and the Cartagena Protocol. Due to the varying allocation of points, the observed value for each convention/protocol was rescaled from 0-1 by dividing the observed points by the maximum number of points achievable. The re-scaled values were then aggregated using equal weights of 1/7 each. Countries or territories not listed under the list of parties to a convention/ protocol/ amendment were assigned 0 points for the respective convention/ protocol/ amendment".

[2] The original values of the indicator ranked from 2.1 to 5.87 depending on the degree of technological readiness (detailed methodology in World Economic Forum, 2008).

‘GM’ represents the country’s GM adoption behaviour (James, 2007). ‘GM’ is a dichotomous variable taking value 0 if the country has not adopted GM technology and value 1 if the country has adopted GM technology.

3.2 Structural equation model

To test the factors influencing GM adoption behaviour at country level we employ a structural equation model (SEM) with observed variables. SEM is a statistical technique for testing and estimating relationships amongst variables, using a combination of statistical data and qualitative causal assumptions. “It is generally agreed that no one ‘invented’ SEM. […] modern SEM evolved out of the combined efforts of many scholars pursuing several analytical lines of research. Bollen (1989) proposed that SEM is founded on three primary analytical developments: (1) path analysis, (2) latent variable modelling, and (3) general covariance estimation methods” (Golob, 2003, p. 5). While the idea of causality may be controversial (Mueller, 1996), SEM is not intended to discover causes but to assess the soundness of the causal relationships researchers formulate.

We consider a structural equation model with observed variables. The model is defined by the following equation in matrix terms (Jöreskog and Sörbom, 2001):

$$\eta = B\eta + \Gamma\xi + \zeta$$

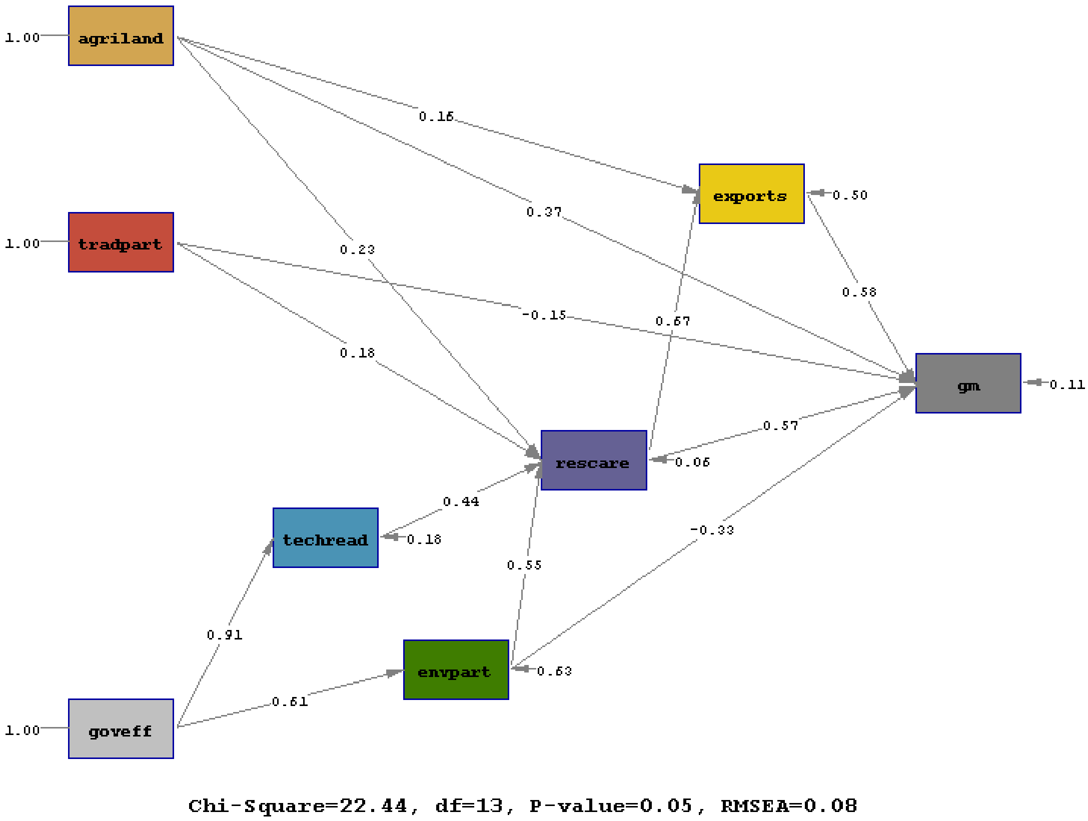
Where: η is an mx1 random vector of endogenous variables; ξ is an nx1 random vector of exogenous variables; B is an mxm matrix of coefficients of the η variables; Γ is an mxn matrix of coefficients of the ξ variables; ζ is an mx1 vector of equation errors.

SEM takes into account both direct and indirect causal relations between variables, which means that one causal relation may be reinforced or counteracted by another. We undertake SEM with categorical and continuous variables using the statistical package Lisrel 8.50 (Jöreskog and Sörbom, 2001). The recommended method consistent with the sample size (n=112) is the normal-theory maximum likelihood (MLE) method (Bollen, 1989).

4. Results and discussion

Based on the existing literature it was reasonable to assume a certain amount of underlying causality amongst the variables in the model. Hence we tested the model described in figure 1, which presents the path diagram for the estimated model.

Figure 1. Path diagram for the estimated model (standardised solution)



The estimated model includes three *exogenous variables*, namely 'agricultural area' as predictor of 'maize and soybean exports', 'participation in RESCARE' and 'gm adoption behaviour'; 'EU and/or Japan main trade partners' as predictor of 'participation in RESCARE' and 'gm adoption behaviour'; and 'government effectiveness' as predictor of 'participation in international environmental agreements' and 'technological readiness'.

'Technological readiness', 'participation in international environmental agreements', 'participation in RESCARE' and 'maize and soybean exports' are *variables with alternating roles*, namely *endogenous* in some equations ('technological readiness' predicted by 'government effectiveness'; 'participation in international environmental agreements' predicted by 'government effectiveness'; 'participation in RESCARE' predicted by 'agricultural area', 'EU and/or Japan main trade partners', 'technological readiness', and 'participation in international environmental agreements'; 'maize and soybean exports' predicted by 'agricultural area' and 'participation in RESCARE') and *exogenous* in some others ('technological readiness' as predictor of 'participation in RESCARE'; 'participation in international environmental agreements' as predictor of 'participation in RESCARE' and 'gm adoption behaviour'; 'participation in RESCARE' as predictor of 'maize and soybean exports' and 'gm adoption behaviour'; and 'maize and soybean exports' as predictor of 'gm adoption behaviour').

The behavioural variable, 'gm adoption behaviour' is *endogenous* as predicted directly or indirectly by all the other variables.

The model has an adequate fit according to the measures of absolute, incremental and parsimonious fit (Hair *et. al.*, 2006). The low chi-square value of 22.44 together with the acceptably high p-value of 0.05 for the chi-square test confirm no statistically significant differences between the covariance matrices of the observed sample and estimated model. The normed chi-square value of 1.73 is within the recommended interval of 1 to 3. The root mean square error of approximation (RMSEA) value of 0.08 is below threshold maximum value of 0.10, therefore indicating acceptable fit. The standardised root mean residual (SRMR) value of 0.032 lower than the threshold of 0.08 indicates good fit. The comparative fit index (CFI) value of 0.98, incremental fit index (IFI) value of 0.98, non-normed fit index (NNFI) value of 0.95, goodness of fit index (GFI) value of 0.95, adjusted goodness of fit index (AGFI) value of 0.86 are all (except AGFI with a slightly lower value) above cut-off values for fit indices, the 'magic 0.90 or 0.95' (Hair *et. al.*, 2006).

Additional testing of the appropriateness of the model was achieved by comparing the estimated model with three other models using a nested model approach. The results across all types of goodness-of-fit measures favoured the estimated model in all cases.

Next we examined the structural standardised coefficients for both practical and theoretical implications. Table 2 shows that all five structural equations contain statistically significant coefficients.

Table 2. Standardised parameter estimates for the structural model. Structural equation coefficients (t values in parentheses)

Endogenous variables	Endogenous variables					Exogenous variables			Structural equation fit (R^2)
	exports	rescare	envpart	techread	gm	agriland	tradpart	goveff	
exports	0.0	0.67 (8.28)	0.0	0.0	0.0	0.16 (2.01)	0.0	0.0	0.50
rescare	0.0	0.0	0.55 (9.65)	0.44 (7.17)	0.0	0.23 (4.72)	0.18 (3.45)	0.0	0.94
envpart	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.61 (6.98)	0.37
techread	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.91 (14.87)	0.82
gm	0.58 (7.14)	0.57 (3.42)	-0.33 (-2.49)	0.0	0.0	0.37 (5.79)	-0.15 (-1.97)	0.0	0.89

In the first relationship, the variables ‘agricultural area’ and ‘participation in RESCARE’ are predictors of ‘maize and soybean exports’. We found that the higher the agricultural area the higher the level of a country’s exports of maize and soybean. Also, the country’s participation in RESCARE influences the level of the country’s exports of maize and soybean. Maize and soybean are two of the major global agricultural commodities hence the countries that are the global producers have both vast areas of agricultural land and highly regulated production systems complying with environmental and health standards. The relationship between ‘agricultural area’ and ‘maize and soybean exports’ was found to be significant (t-value of 2.01) with a parameter estimate of 0.16. The relationship between ‘participation in RESCARE’ and ‘maize and soybean exports’ was also found to be significant (t-value of -8.28) with a high parameter estimate (0.67). The combined effect of the variables ‘agricultural area’ and ‘participation in RESCARE’ gives an R^2 value of 0.50.

In the second relationship, the variables ‘participation in international environmental agreements’, ‘technological readiness’, ‘agricultural area’ and ‘EU and/or Japan main trade partners’ are predictors of ‘participation in RESCARE’. The relationship between ‘participation in international environmental agreements’ and ‘participation in RESCARE’ was found to be significant (t-value of 9.65) with a high parameter estimate of 0.55. The relationship between ‘technological readiness’ and ‘participation in RESCARE’ was found to be significant (t-value of 7.17) with a high parameter estimate (0.44). The relationship between ‘agricultural area’ and ‘participation in RESCARE’ was significant (t-value of 4.72) with a parameter estimate of 0.23. The relationship between ‘EU and/or Japan main trade partners’ and ‘participation in RESCARE’ was significant (t-value of 3.45) with a parameter estimate of 0.18. The combined effect of the variables ‘participation in international environmental agreements’, ‘technological readiness’, ‘agricultural area’ and ‘EU and/or Japan main trade partners’ achieves an R^2 value of 0.94. We found that participation in international environmental agreements has the highest impact on the likelihood of a country’s participation in RESCARE. The more active is the country as regards environmental protection and compliance with environmental standards, the more likely it is that the country will participate in RESCARE. The higher the country’s technological readiness level, the more likely it is that the country will participate in RESCARE as it would be more able to adopt the RESCARE standards. A larger agricultural producer will be more likely to participate in RESCARE as it would be more likely to practice widespread fertiliser and pesticide use and thus be heavily involved with the chemical industry. Having the EU and/or Japan as main trading partners would make a country more likely to participate in RESCARE because of the need to comply with EU and Japanese production and regulatory standards.

In the third relationship, the variable ‘government effectiveness’ is a predictor of ‘participation in international environmental agreements’. The relationship between ‘government effectiveness’ and ‘participation in international environmental agreements’ was found significant (t-value of 6.98) with a high parameter estimate of 0.61. The effect of the variable ‘government effectiveness’ achieves an R^2 value of 0.37. The higher the country’s level of government effectiveness, the more likely it is that the country will take an active role in environmental protection.

In the fourth relationship, the variable ‘government effectiveness’ is a predictor of ‘technological readiness’. The relationship between ‘government effectiveness’ and ‘technological readiness’ was highly significant (t-value of 14.87) with a high parameter estimate of 0.91. The effect of the variable ‘government effectiveness’ achieves an R^2 value of 0.82. The higher a country’s level of government effectiveness, the more likely it is that the country will have a high level of technological readiness.

In the fifth relationship, the variables ‘maize and soybean exports’, ‘participation in RESCARE’, ‘agricultural area’, ‘participation in international environmental agreements’ and ‘EU and/or Japan main trade partners’ are predictors of ‘gm adoption behaviour’. The combined effect of the variables ‘maize and soybean exports’, ‘participation in RESCARE’, ‘participation in international environmental agreements’, ‘agricultural area’ and ‘EU and/or Japan main trade partners’ achieves an R^2 value of 0.89. ‘Maize and soybean exports’ and ‘participation in RESCARE’ have the highest influence on ‘gm adoption behaviour’, while ‘EU and/or Japan main trade partners’ have the lowest (but still significant) impact.

The relationship between ‘maize and soybean exports’ and ‘gm adoption behaviour’ was found to be significant (t-value of 7.14) with a high parameter estimate of 0.58. As we hypothesised, and as discussed in the literature (Gonsalves, 2007; Franks, 1999), agricultural factors such as crop type are important variables in the adoption decision. Here it is shown to be the major producers of maize and soybean, two of the most significant GM crops that are more likely to adopt GM crops at the country level. The relationship between ‘participation in RESCARE’ and ‘gm adoption behaviour’ was found to be significant (t-value of 3.42) with a high parameter estimate (0.57). As hypothesised, it is the countries with highly technological agricultural production systems, specifically those where the agrichemical industries are major players that are more likely to be adopters of GM crops. The relationship between ‘agricultural area’ and ‘gm adoption behaviour’ was also found to be significant (t-value of 5.79) with a parameter estimate of 0.37. This finding demonstrates the link between the scale of agricultural production in a country and the likelihood of GM adoption, thus it is the countries where there is a large amount of land in agricultural production that are the most likely adopters.

The relationship between ‘participation in international environmental agreements’ and ‘gm adoption behaviour’ was significant (t-value of -2.49) with a parameter estimate of -0.33. This suggests that participation in environmental agreements means that the country is less likely to be a GM adopter, hence that those countries with a high degree of political interest in environmental agreements, and by implication an active environmental NGO sector, are less likely to be GM adopters. The position of consumers and NGOs has been highly significant to the adoption decisions of some developed countries (Chen & Chern, 2002). Further, the relationship between 'EU and/or Japan main trade partners' and 'gm adoption behaviour' was found to be significant (t-value of -1.97) with a parameter estimate of -0.15. This underlines the importance of public perceptions of the risks and benefits of GM technology. EU countries and Japan have experienced the most resistance to the technology and thus, those countries that have important trade relations with them are most likely to demonstrate greater wariness of GM adoption.

The model takes into account both direct and indirect causal relationships between variables, which signifies that one causal relationship may be reinforced or counteracted by another. What this means is that those 24 countries included in the sample that have adopted GM technology have been influenced not only by the factors significant in the 'GM adoption behaviour' equation, but also by the factors found significant in the other equations in the model. These include technological readiness and government effectiveness, both important to country-level GM adoption decisions.

5. Conclusions

The research has tested and estimated the relationships between GM adoption and a number of *a priori* determinants in an attempt to illustrate why countries may make different decisions when faced with the question of whether or not to adopt GM crops. First, there are a number of variables directly related to the structure of agricultural production in that country, namely, whether or not they are major producers of maize and soybean, the extent of agricultural land in the country, and the significance of the agri-chemical industry in the country. Significantly, the model highlights the importance of public perceptions of the risks and benefits of GM technology, mainly through the variable relating to whether or not the EU and/or Japan are major trading partners. Another variable shown to be directly related to whether or not a country is likely to be an adopter of GM or not, is the participation of that country in international environmental agreements. Thus those countries with greater participation are less likely to be GM adopters. There are also a number of important variables shown to be indirectly related to country-level adoption decisions, through their influence on the variables that have a direct influence. These are technological readiness and government effectiveness.

If the aim is to promote the adoption of GM crops in more countries, the implications of these findings are numerous. First, the development of the technology into a broader selection of crops, of relevance to additional countries, would be required. Second, the issue of public resistance and suspicion of the technology remains to be addressed. Third, the apparent contradictions in the claims about environmental benefit versus environmental harm must be addressed if countries where positive environmental behaviour is considered the priority are to be convinced that GM technology is the correct path to follow. Finally, the strengthening of government institutions in developing countries is key.

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