IMPACT OF TRADE OPENNESS ON TECHNICAL EFFICIENCY: AGRICULTURAL SECTOR OF THE EUROPEAN UNION

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ABSTRACT

This thesis examines the impact of trade openness (TOP) on technical efficiency (TE) in the agricultural sector of the European Union (EU). The hypothesis is that TOP, the share of agricultural imports and exports relative to agricultural GDP, can increase TE. The objective is to add to the limited number of studies focused on the impact of TOP on TE by inspecting an unexamined group of countries, the EU. Results show that TOP leads to an increase in TE over time. However, an instantaneous decrease in efficiency is observed. This outcome contributes to the mixed results found when examining the relationship between TOP and TE in the agricultural sector, industrial sector, and aggregate GDP. Past studies examining the agricultural sector have not found a significant impact of TOP on TE, a result indicative of the benefits the Common Agricultural Policy (CAP) provides for member states of the EU.

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INTRODUCTION

Trade is considered as a primary means for increasing a country's productivity; productivity growth, however, can be measured by two distinct, mutually exclusive parts. It is important to distinguish these two components: Technological Change (TC) and Technical Efficiency Change (TEC). TC is a shift in the Production Possibility Frontier (PPF), whereas TEC is the movement towards or away the PPF. That is, TEC measures the difference between potential and actual outputs. Trade can typically lead to only positive TC, but either positive or negative TEC (Iyer, Rambaldi, and Tang, 2008). The effect of trade openness on TEC is uncertain, and it is the aim of this study is to address this issue for the agricultural sector of the European Union (EU).

The EU stands as the world's largest trading partner, and has created a system such that each of its member states operate in an open market with each other. Therefore this study should be of particular interest for policy makers in countries considering open trade agreements. Specifically, this research should be of significance to the United States as they are currently discussing a free trade agreement with the EU. Details of the agreement may be finalized in the next few years, and policy makers will need to decide whether or not to include agriculture in this transatlantic deal. Trade liberalizers have the widely held belief that productivity increases as does TEC due to trade openness. However, economists argue that this is not always the case, and that such benefits cannot be assumed to be true.

Whether or not trade openness impacts TEC is a point of economic debate. This debate exists because there are no systematic theories linking trade policy to technical efficiency (Rodrik, 1992). If trade openness does indeed impact TEC, it can actually have a positive or negative effect. No papers have specifically examined the impact of trade openness on TEC in the agricultural sector of the EU, and therefore the findings of the relationship should be of great significance to trade economists.

Several papers have examined TEC and trade openness to see if there is a potential relation. Studies of the industrial sector and national level have led to varying positions, establishing no solid conclusion (Iyer, Rambaldi, and Tang, 2008; Shafaeddin, 2005; Milner and Weyman-Jones, 2003; Lall, Featherstone, and Norman, 2000). In 2008, Iyer, Rambaldi, and Tang determined that trade openness does not have equal effects on both technological change and technical efficiency change. Technological change will be positive, but technical efficiency change can be either positive or negative. Only two studies have been completed which examine the relationship between TEC and trade openness for the agricultural sector an economy. Shaik and Miljkovic (2011) examined U.S. agriculture and Miljkovic, Miranda, and Shaik (2013) researched Brazilian agriculture. Both studies found no significant relationship.

This study contributes to the issue of whether or not trade openness impacts technical efficiency by investigating a case thus far unconsidered, the agricultural sector of the EU. Theoretically, this research provides another source which documents the debated impact of trade openness on TEC. Namely, the study expands the study of trade openness in agricultural sector, which few papers have addressed. For trade policy makers, the study provides evidence as to whether or not the agricultural sector should be included in future free trade agreements.

Stochastic frontier analysis (SFA) has been used widely to estimate technical efficiency and production functions. SFA can be applied to the agricultural sector of the EU to investigate the relationship between trade openness and technical efficiency. Specifically, the method used in this study is the Battese and Coelli (1993) model which uses SFA to estimate the relationship between inputs and outputs via two separate functions: production and efficiency. Factor inputs are used in the frontier production function, and trade openness variables are used in the efficiency model. This specific model is chosen because it signifies the determinants of inefficiency using a one-stage approach; the traditional two-stage approach has been shown to create a bias in the results. This model has been the most frequently used in closely related papers, making it the ideal candidate for this study.

EUROPEAN UNION REVIEW

The European Union currently is composed of 28 countries. Nations have become members through several expansions over the course of fifty years. Becoming a member of the EU entitles a country to the trade benefits all members receive, but also requires the nation to adhere to the EU's rules and regulations. It is important to briefly examine the history of the organization, the goals the EU pursues, and the Common Agricultural Policy (CAP) followed by member nations.

Economic cooperation between Belgium, Germany, France, Italy, Luxembourg, and the Netherlands in 1951 via the European Coal and Steel Community led to the eventual creation of the EU. In 1957, the Treaty of Rome joins these nations in what was then called the European Economic Community, also referred to as the Common Market. The group was formed following World War II in order to foster economic cooperation; Europe had been facing agricultural shortages, and the hope was to subsidize farmers and to allow goods and services to flow freely between countries.

During the 1960s, EU countries terminated charging custom duties when trading amongst each other, and applied equal import tariffs to goods from nonmember nations. This resulted in the EU becoming the world's largest trading partner. They also started the CAP, creating a surplus of agricultural produce by agreeing to joint control of food production and equal prices for produce paid to farmers. During this time, the EU began making strides to help developing nations; they did so by providing assistance to former colonies in Africa. Since then, the EU has remained the largest supporter of developing countries.

Plans for a common currency, which eventually culminated in what is the euro today, began in the 1970's; the exchange rate mechanism was installed to stabilize exchange rates between member nations. The CAP first adopted measures to address environmental safety in the 1970's; similar measures are now one of the primary focuses of the EU. In 1973, the EU realized its first expansion with the addition of Denmark, Ireland, and the United Kingdom.

Expansion continued in the 1980's with the addition of Greece in 1981 and Spain and Portugal in 1986. Custom duties were eliminated in 1986; however there was not free trade between members yet. Thus in 1986 the Single European Act was signed in hopes of forming the Single Market where there could be a free-flow of trade across borders. The Single Market program came to fruition in 1993, enacting four freedoms: movement of goods, services, people, and money across borders. A year earlier, the Treaty on European Union was signed, establishing guidelines for a future single currency as well as renaming the 'European Community' as the 'European Union'. In 1995, the EU saw the addition of member states Austria, Finland, and Sweden.

The first employment of the Euro occurred in 1999, with Austria, Belgium, Finland, France, Germany, Greece (in 2001), Ireland, Italy, Luxembourg, the Netherlands, Portugal, and Spain adopting the currency. Initially, it was used strictly for commercial and financial transactions; Euro notes and coins were not introduced until 2002. The EU expanded to include many Eastern European countries in 2004 with the addition of the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, and Slovenia; the Mediterranean islands of Cyprus and Malta also joined the same year. Three years later, candidate countries Bulgaria and Romania joined the EU. The same year, the Treaty of Lisbon was signed with major goals of environmental safety and sustainable development.

Croatia just recently acceded to the EU, bringing the total member countries to 28 as of 2013. There are several other countries still on the road to membership in the EU. Former Yugoslav Republic of

Macedonia, Iceland, Montenegro, Serbia, and Turkey are candidate countries, and Albania, Bosnia, and Herzegovina are potential candidates. Table 1 lists the years of accession for each of the 28 members of the EU.

Table 1. EU Accession History

Year	Countries
1952	Belgium, France, Germany, Italy, Luxembourg, Netherlands
1973	Denmark, Ireland, United Kingdom
1981	Greece
1986	Portugal, Spain
1995	Austria, Finland, Sweden
2004	Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia
2007	Bulgaria, Romania
2013	Croatia

Today the EU continues to work toward its original goal of economic cooperation between European nations, and has succeeded by creating a single market in which most goods, services, and money are exchanged openly between countries. Accounting for nearly 20% of world trade, the EU has become the world's largest trading partner, and aims to grow even more through further trade liberalization; implications of this include a large amount of competition and direct investments in other nations. Problems, however, have presented themselves through the differing levels of productivity and competitiveness among member nations. The Europe 2020 strategy aims to address these issues through structural reforms, hopefully leading to further economic development. Recently, the EU has been forming free-trade agreements with other nations based on competitiveness. Along with these negotiations, the EU eliminated tariff quotas on some imports in 2009 from least developed countries. Another goal has been to reduce the role of CAP in the EU through the "Health Check" CAP, which was agreed upon in 2008 by the EU agriculture ministers.

CAP is a form of farm policy in the EU, and it is meant to address environmental issues, assist rural communities, and ensure sufficient production. Originally the aim of CAP was to address the food shortages faced by post-war Europe. This was accomplished by providing production subsidies and by purchasing surpluses from farmers to support prices. Now the goal has expanded by setting high-quality standards for food, contributing to diversified economic development in rural areas, and establishing guidelines for environmental care and animal welfare. To satisfy these standards, agricultural firms face the need for much technological change, which proves to be an expensive endeavor; however, this is heavily funded by the CAP subsidization program. This has also resulted in the shift from a labor intensive to a capital intensive agricultural market; the percentage of the workforce employed in agriculture fell from 7.8% in 1998 to 5.6% in 2009. CAP has also established safety nets to farmers by providing relief from emergencies that could devastate entire sectors of the rural economy. Supplements provided to farmers under CAP are contingent on food, animal, and environmental standards that must be meet. However, it has been proposed that by 2013 all such subsidies be discontinued. Future CAP instead focuses on the preservation of natural resources and landscapes, enhancement of animal welfare, and assistance to rural communities.

In 1958, Ministers of Agriculture, along with other representatives, from the six founding countries of the EU met in Italy to discuss plans for what would become CAP. Two years later, their proposals were unveiled, setting goals to have free agricultural trade between member nations and universal market prices for goods, among other objectives. Decisions on these proposed policies were made in 1962, and the European Agricultural Guidance and Guarantee Fund was established in order to finance the guaranteed prices to farmers as well as the subsidies placed as incentives to produce.

CAP expenditure proved to be extremely high, and towards the end of 1960's reforms were proposed to cut spending. This was to be done by redistributing land so as to increase average farm size and guarantee incomes for the remaining farmers; however, this would have displaced almost five million farmers from their occupations, thus the idea was rejected. The only legislation approved in the next few years were bills that would aim to improve the technology used and the training provided on farms. Initiatives in the late 1970's were passed to provide more assistance to farmers in harsher geographical areas, as well as enact penalties for over production in the dairy sector.

There was an overall failure to reduce CAP spending in the 1970's, and although this goal remained in the 1980's, the decade brought new objectives as well. The EU became successful in producing enough agricultural products to remain self-sufficient; however there was also a great deal of surpluses. This resulted in an increase in budget spending as well as a distortion of prices in the world market; these left negative consequences for tax payers, farmers, and consequences. Another rising issue was the concern for environmental safety. Plans to address the issue of excess production were made in the early 1980's, and reform proposals ensued. A quota system was enacted in order to limit the surplus of sugar and milk in 1984. A commission met in 1985 to address these issues as well as the environmental concerns of the public, and the 'Green Paper' was compiled to list the options the EU could take combat the problems. Then in 1988, a reform was passed to reduce CAP spending through budget stabilizers. These stabilizers acted as maximum ceilings for the quantity of which farmers could receive financial support for production.

In 1992, the MacSharry reform was introduced, which aimed to further shift support to farmers away from price guarantees and towards income subsidies. Goals of this measure were to increase competitiveness and stability in the agricultural market, increase product diversification, promote environmental protection, and to reduce CAP expenditure. The act was successful in the sense that producers began receiving direct payments from the EU instead of price support, and funds were created for environmental programs, product differentiation, and even early retirement for farmers. The next major reform was Agenda 2000, which aimed to increase competition, improve the safety and quality of food, control producer incomes, address environmental issues, and advance rural farms. The latter was accomplished by creating a second pillar of the CAP, which focused entirely on providing assistance to rural farmers in order to increase diversity and competitiveness.

Due to demands from the public, the CAP went under a great amount of reform once again in 2003. Although much restructuring took place, the fundamental goals widely remained the same; the 2003 reform focused on increasing agricultural competition, promoting sustainable production, and improving rural development via changes in funding and policy. Changes in 2005 had a different goal; due to multiple reforms aimed at improving food safety and quality, as well as ensuring environmental protection, producers were faced with an abundance of rules. Thus a proposal was created to simplify the CAP, making policies more understandable and rules easier to follow. The effectiveness of the 2003 reform was addressed in 2007 to see what adjustments were necessary for the near future. The results was the 2008 CAP "Health Check," which removed many restrictions farmers faced, allowing them to adapt better to shifts in market demand, global warming and climate change, water usage, and alternative clean energy choices.

CAP has undergone constant and significant change over the past sixty plus years in order to adapt to the economic and environmental needs faced by the EU. Currently there are plans for further reform towards the year 2020. Changes are due to take place in 2013 in order to advance the effectiveness of policy measures, further develop rural farms, and promote cleaner and more sustainable agricultural market. Along with these goals, the budget of the CAP remains in issue, and subsidies for producers are likely to be reduced or eliminated.

The EU has expanded over the past 55 years into a 28 member nation conglomeration, and become the world's greatest trading partner. The organization currently demonstrates some of the most progressive steps towards openness, and plans to expand liberalization in the future. Agricultural policies in the EU have been implemented and reformed for over sixty years in an attempt to appease the demands of member nations as the organization has greatly expanded throughout Europe. Therefore the impact of trade openness on technical efficiency, as well as membership, in the EU should come as great interest to policy makers in any country.

LITERATURE REVIEW

Productivity growth is composed of two mutually exclusive and exhaustive components, Technological Change (TC) and Technical Efficiency Change (TEC). TC is a shift in the Production Possibility Frontier (PPF), whereas TEC is the movement towards or away the PPF. That is, TEC measures the difference between potential and actual outputs. Trade can typically lead to only positive TC, but either positive or negative TEC (Iyer, Rambaldi, and Tang, 2008). Thus TEC is of particular interest since the effect of trade openness on it is uncertain.

Agricultural production in Europe was in need of a boost prior to the signing of the Treaty of Rome due to instability in prices, underdeveloped technology, suboptimal utilization of resources, and widespread shortages. Thus the Treaty of Rome set objectives to combat these shortcomings and the European Economic Committee was formed. In order to address the shortages, advances in production became a primary goal of the CAP. The idea was to increase agricultural productivity by making advances in technological progress and utilizing factors of production more optimally (Zobbe, 2001). These goals set the path for modern day Europe, and they remain integral aspects of production theory.

Factors of production have changed in the EU, shifting from a labor intensive agricultural sector to one more prominently driven by the use of technology. Specifically, the use of labor as a factor input in agricultural production has declined greatly in the past several decades. This shedding of labor has been observed as a shift of labor use from the agricultural sector and to services in the European Union. Additionally, it has been found that the reduction in labor has led to an increase in productivity and technical efficiency. That is, agricultural productivity growth has been driven by labor shedding (Alam, Casero, Khan, and Udomsaph, 2008). Further evidence of this trend has been discussed by Timmer and Szirmai in 2000, Caselli and Tenreyro in 2004, and Lenain and Rawdanowicz in 2004.

In addition to the shift of labor from agriculture to services, capital equipment has been found to be highly substitutable for unskilled labor (Arpaia, Pérez, and Pichelmann, 2009). That is, the elasticity of substitution for labor is very high. This is because the agricultural sector of the EU is highly intensive; there is very heavy use of technology. Another elasticity of substitution of interest is land in exchange for other factors. Land has a very low rate of substitution; its elasticity of substitution for other production factors has been estimated at about 0.07 in Europe (Laborde, 2011). The same study calculated the elasticity of substitution between fertilizer/feedstuff and land to be extremely small as well, estimated at 0.11 in developed European nations and 0.20 in developing European countries. This suggests that land is complementary to other inputs in EU agriculture, thus the addition of land would yield no additional production without extra capital, labor, and fertilizer inputs as well. Productivity, however, can increase through means other than improvements in technology or increases in factor inputs, which is to say through trade.

The original study of open trade by Smith in 1937 was based on an expansion of the division of labor; this led to the conclusion that trade openness increases productivity. That theory is still believed to be true today. International trade has an economically and statistically significant and positive effect on productivity (Alcalá and Ciccone, 2004). Countries that are more productive due to trade do not necessarily have higher openness, but countries with open trade do have a higher level of aggregate productivity. For the case of the US, Markheim suggested that trade liberalization is in the nation’s best interest in 2007. Trade liberalization since 1985 has resulted in significant benefits to the American economy. According to the Office of the U.S.

Trade Representative, 2006, growth in U.S. exports accounted for 25 percent of U.S. economic growth in the 1990s and 20 percent in 2005. Agricultural exports were at record high in 2005, accounting for 926,000 jobs. Free trade policies have led to innovation, better products, higher wages, new markets, and increased savings and investment (Markheim, 2007). Although trade openness increases productivity, it has not been determined whether or not it improves technical efficiency.

In 1957, Farrell defined the concept of technical efficiency as the distance of the observation from the PPF, as measured by a firm's output, i.e., given the level of technology, the ability of a firm to transform inputs into outputs. Previously, efficiency had been measured as the average productivity of labor, ignoring all other inputs. However, Farrell noted that a set of inputs should be considered as well as factors such as climate and location must be included. Also inputs should be weighted proportional to prices, so as to portray a firm's ability to adapt to different sets of factor prices. In order to analyze a firm's efficiency, it must be compared to the efficiency levels of other firms. Until 1993, there had been no theoretical stochastic frontier functions that explicitly formulated a model for the inefficiency effects. This is when Battese and Coelli developed a stochastic frontier production function that included firm-specific effects and time effects in the model of inefficiency. They concluded that it was difficult to determine whether or not their model, in which inefficiency effects were specified as a linear function of firm-specific variables and time, together with an additive stochastic error which is independent over time and among firms, provides a best model for the data involved. However, their model has become a standard for measuring the impact of technical efficiency on trade openness.

There are no systematic theories linking trade policy to technical efficiency (Rodrik, 1992), forcing the debate as to whether or not trade openness has an impact on TEC. Several papers have examined this topic to see if there is a potential relation. Studies of the industrial sector and national level have led to varying positions, establishing no solid conclusion (Iyer, Rambaldi, and Tang, 2008; Shafaeddin, 2005; Milner and Weyman-Jones, 2003; Lall, Featherstone, and Norman, 2000). In 2008, Iyer, Rambaldi, and Tang determined that trade openness does not have equal effects on both technological change and technical efficiency change. Technological change will be positive, but technical efficiency change can be either positive or negative.

Rodrik described the relation between trade liberalization and technical efficiency as fundamentally ambiguous in 1988. Policy makers are told that trade liberalization will force firms to modernize production techniques in order to compete with foreign producers. On the other hand, the theory exists that trade liberalization increases the income of exporters, allowing them to relax technological efforts and produce less efficiently. However, there is also the argument of economies of scale which suggests that trade liberalization forces inefficient firms out of the market. Rodrik went on to find that the larger the firm's market share, the greater its investment in productivity-enhancing technology. With a larger scale of output, there are greater benefits to the firm from a reduction in costs. Therefore trade liberalization reduces the incentive to improve technical efficiency. In the case of an oligopoly, firms compete aggressively, resulting in an over investment in technology, resulting in worse technical efficiency due to openness.

Krugman identified scale economies as a rationale for trade liberalization in 1979. Sachs, 1987, stated that trade liberalization is not driven by economics, but rather ideology. That is, it is difficult to prove that trade liberalization improves technical efficiency since fiscal policy is the greater focus. In 1992, Tybout found support from Chilean industrial census data for the theory that trade liberalization improves technical efficiency by causing less efficient plants to exit the market. Theoretically, trade openness should improve technical efficiency through economies of scale; exports improve potential productive capacity, and imports encourage domestic firms to become more efficient in order to remain competitive (Lall, Featherstone, and Norman, 2000).

This paper addresses the agricultural sector, however, and only two studies to date have researched the relationship between openness and TEC in this field. These results have been consistent, concluding that trade openness does not have a significant impact on technical efficiency (Shaik and Miljkovic, 2011; Miljkovic, Miranda, and Shaik, 2013). These two papers pertained to U.S. agriculture and Brazilian agriculture, respectively. The studies used SFA to measure technical efficiency. Specifically, the Battese and Coelli model was used. A positive, significant, coefficient was found for the time trend variable suggesting that there was a .02 percent yearly increase in the output index, also the aggregate factor had a positive and significant impact. However, the model showed no impact from trade openness on technical efficiency. To reconfirm this result, a second model with disaggregate inputs was used. Once again, it was found that trade openness did not have a statistically significant impact on technical efficiency. It was found that increasing protection on exports had no impact on technical efficiency. Neither of these papers, however, examined the impact of foreign direct investment (FDI) on technical efficiency

When determining the impact of trade openness on TEC, it is important to consider FDI as well. Excluding FDI can lead to a bias in the estimation of the growth impact of trade openness, or an underestimation of the growth effects of general outward orientation (Hejazi and Safarian, 1999). Iyer, Rambaldi, and Tang found that models which contained only FDI or openness were empirically rejected. Also, they found that countries which did not have policies to develop domestic absorptive capacity were unable to capture the efficiency gains from FDI inflows; FDI outflows were found to increase inefficiency, but it was noted that these outflows are normally perceived as conduits of foreign technology and that further research was needed.

The EU stands as the world's largest trading partner, and no study for this group on the impact of trade liberalization on TEC has been performed, making it a prime case for this paper. There may be a disparity in the effects of FDI on technical efficiency due to the differing economic strength of the countries examined; not every country has the absorptive capacity to realize efficiency gains from foreign capital investment. Due to a shift from labor to capital in the agricultural sector, development economic theory should be considered when analyzing the behavior of the production function. There has been no consensus as to the impact of the trade openness on technical efficiency, and the agricultural sector of the EU has yet to be examined. This study on the EU should also come of particular interest to policy makers in any country because the group currently demonstrates some of the most progressive steps towards openness, and has plans to expand liberalization in the future.

MODEL AND DATA

Stochastic frontier analysis (SFA) is used to estimate the relationship between a country's production resources and agricultural output, as well as to determine the technical efficiency of a country. SFA constructs an efficient frontier by imposing a common production technology across all countries in the sample. The Battese and Coelli (1993) SFA model, which measures output quantity as an exponential function of input quantities and time and error as represented by inefficiency and noise (Iyer, Rambaldi, and Tang, 2008), is used in this paper. This allows the process to be done in a one-stage approach instead of the two-stage which has been shown to bias results due to under-dispersed technical efficiency measures in the first-step (Wang and Schmidt, 2002).

The model is separated into two functions, production and efficiency. The production function is (Eq. 1) is defined as:

$$y = f(\boldsymbol{x}; \beta) \qquad \text{(Eq. 1)}$$

where $\boldsymbol{x}$ is a vector of independent variables consisting of input factors, dummy variables, and time which act as the decision variables affecting output y, and β is input parameter coefficients. Constraints v and u are introduced to the production function to form the production function (Eq. 2) used in the SFA:

$$y = f(\boldsymbol{x}; \beta) \cdot v - u \qquad \text{(Eq. 2)}$$

where v is country or time specific random error, i.e., noise component, that is assumed to be independently and identically distributed normally with mean zero and variance σ_v^2, and u is technical efficiency which is assumed positive, normally distributed, and has mean zero and variance σ_u^2.

Next the trade equation introduces a group of trade openness variables consisting of inefficiency determinants, dummy variables, and time to determine technical inefficiency. (Eq. 3) is defined as:

$$u = f(\boldsymbol{z}; \gamma) \cdot \varepsilon \qquad \text{(Eq. 3)}$$

where $\boldsymbol{z}$ is a vector of trade openness variables acting as deterministic variables impacting technical inefficiency u, and ε is random error assumed as normally distributed with mean zero and variance σ_ε^2.

The frontier production function and trade equation are estimated with national output and technical inefficiency as endogenous variables. These functions are combined to form a two function, one-staged model, with production function (Eq. 4), and technical inefficiency function (Eq. 5):

$$y = f(\boldsymbol{x}; \beta) \cdot v - u \qquad \text{(Eq. 4)}$$

$$u = f(\boldsymbol{z}; \gamma) \cdot \varepsilon \qquad \text{(Eq. 5)}$$

The trade equation u must be positive as it defines the inefficiency that is subtracted from the production function. The γ term is used to determine the appropriateness of the SFA model. It is calculated as $\frac{\sigma_u^2}{\sigma_u^2+\sigma_v^2}$. If γ approaches 0, then there is no inefficiency in the model, thus OLS is the correct functional form. If γ approaches 1, then the frontier is deterministic. This implies that there is no noise, just inefficiency.

Specifically, the production function estimates agricultural GDP using inputs of arable land, labor, capital, fertilizer, and time. Agricultural GDP is given in millions of constant USD (2005 prices); arable land is measured in 1000 Ha, labor in 1000 workers, gross capital stock in constant USD million, and fertilizer as total metric tons of plant nutrient consumed. The natural logarithms of agricultural GDP, land, labor, capital, and fertilizer are used in the model in order to obtain elasticities of the variables. Country dummy variables are also included in the production function in order to create a one-way fixed effect SFA model to account for the cross-sectional effects. The efficiency equation contains variables which depict the outward orientation of each nation's economy. These variables include FDI inflow and outflow, trade openness, time, EU dummy, World Trade Organization (WTO) dummy, and regional dummies. FDI is taken as a percentage relative to total GDP. Openness is measured as the amount of imports and exports, in 1000 USD, as a percentage of agricultural GDP; imports and exports are combined in the measurement due to the high collinearity of the two (Iyer, Rambaldi, and Tang, 2008). FDI inflow and outflow variables, as well as the trade openness measurements, are lagged one year in order to remove problems of endogeneity. The EU and WTO dummy variables signify membership for the corresponding year. The two regional dummies separate the countries from the formerly Communist nations. The second regional dummy is a signifier of being a part of southern Europe due to the difference in agricultural climate; this group consists of Spain, Portugal, and Italy. A time trend is incorporated in both the frontier function and the inefficiency equation of the SFA model in order to account for shifts in the PPF over time. The data ranges from 1980-2007; land, capital, fertilizer, exports, and import information are gathered from the Food and Agricultural Organization of the United Nations, whereas labor, FDI, and agricultural GDP data are collected from the United Nations Conference on Trade and Development. Due to data availability, only 16 of the 28 EU members are examined.

Frontier Version 4.1, developed by Tim Coelli, is the computer program used to estimate the stochastic frontier production. For a description of the program and list of instructions, see the appendix, which is copied directly from the user guide for the program (Coelli, 1996). Only the segment of the instruction files that pertains directly towards the model used in this paper is included. The program generates the ordinary least squares regression equation for the given data, as well as the combined production and inefficiency functions. Panel data is used with 16 cross-sections, representative of countries, and 28 years.

For the production function, each input variable is expected to have a positive sign, due to the theory of production functions. However, a negative sign could result due to an increase in technology that requires a different set of resource endowments, and therefore results in a shift of resource consumption, as is the theory of development economics. United Kingdom is set as the base case for the country dummy variables, thus negative signs are expected for countries less productive than the United Kingdom, and positive signs are expected for more productive nations. The efficiency equation measures the amount of inefficiency, thus a negative sign implies that a variable decreases inefficiency. It is expected that openness variables, time, and FDI inflow be negative. The expected effect of FDI outflow is ambiguous, as that the reduction of capital supply may result in domestic firms utilizing factor inputs more efficiently, but on the other hand, it could result in the depletion of the capital market thereby lowering efficiency (Iyer, Rambaldi, and Tang, 2008).

A Cobb-Douglas functional form is chosen over a Translog format based on the rejection of the Translog production frontier. The log-likelihood ratio test is used to evaluate the Cobb-Douglas and Translog models. When testing the Translog format, the various models examined either had gamma terms indicating that SFA is inappropriate, that is either $\gamma = 0$, implying no inefficiency, or $\gamma = 1$, implying no noise, or the estimated equations failed the log-likelihood ratio test. A hybrid functional form was also attempted, but was rejected for the same reasons. It should be noted that using a system of equations where each input variable is a separate function of the other input variables and lagged GDP could give valuable insight to the production side of the study; however this is not done as the main focus of this paper is technical efficiency. Using autoregressive spatial matrix weights instead of a fixed effects models and accounting for temporal autocorrelation are other looming issues, but also stray from the main intent of the study.

The initial Cobb-Douglas function considered includes land, labor, capital, and fertilizer as inputs and the country dummy variables in the production function. The inefficiency equation includes FDI inflow and outflow, trade openness, and WTO, EU, and two regional dummy variables. The second function incorporates a time trend in the production function, and the third includes a time trend in both the production and inefficiency functions. To account for the relationship between the input variables and time, an extended Cobb-Douglas function is examined which includes a time interaction variable for each input in the production function; the final model incorporates the time interaction variable for each input in the production function, as well as each of the non-dummy variables in the inefficiency equations.

For each model considered, a simple OLS regression is run first to obtain the coefficients for the inputs of the production function. These are then compared to the SFA results in order to ensure robustness. The gamma error value is examined for each model to ensure the estimations adhere to SFA. A likelihood ratio test is performed to test whether or not each model is to be rejected.

RESULTS

The models are estimated using logarithms, thus the results are in the form of elasticities. The results of the OLS and the Battese and Coelli SFA for the basic Cobb-Douglas functional form can be seen in Tables 2 and 3, respectively. Labor, labor, capital, and the country dummy variables Denmark, France, Ireland, Italy, Netherlands, Portugal, Spain, and Sweden are statistically significant for both OLS and SFA results. Land, capital, and fertilizer coefficients are positive, whereas labor is negative. Fertilizer is only significant for SFA at the 5% level, and the significance of country dummy variables differs greatly between OLS and SFA results. Additionally, the signs of each of the input factors are consistent with land, capital, and fertilizer

Table 2. Cobb-Douglas OLS Results

Variable	OLS	
Production function	Coefficient	t-Value
Intercept	0.9116	0.8543
Land	0.1854**	2.0518
Labor	-0.3344**	-8.5821
Capital	0.7738**	11.1219
Fertilizer	0.0395	1.5529
Austria	-0.2124	-1.3851
Bulgaria	-0.2832**	-2.2581
Denmark	-0.8316**	-7.4855
Finland	-0.0712	-0.5921
France	0.5257**	4.9205
Germany	0.0696	0.8797
Hungary	0.0554	0.4712
Ireland	-0.4751**	-2.8267
Italy	0.9668**	16.2183
Netherlands	0.9053**	4.5144
Poland	0.1003	1.2064
Portugal	0.4521**	2.7448
Romania	0.1011	1.5652
Spain	0.7850**	9.9514
Sweden	-0.3847**	-3.5861

5% critical value = 1.9569, 10% critical value = 1.6486
** Significant at the 5% level

Table 3. Cobb-Douglas SFA Results

Variable	SFA	
Production function	Coefficient	t-Value
Intercept	-0.9226	-1.2490
Land	0.2885**	5.6933
Labor	-0.4078**	-14.6175
Capital	0.8946**	17.1386
Fertilizer	0.0520**	3.0953
Austria	-0.0111	-0.1156
Bulgaria	0.1135	1.2974
Denmark	-0.3704**	-4.5644
Finland	0.0743	0.9157
France	0.3475**	5.1795
Germany	0.0104	0.1841
Hungary	0.4623**	5.4147
Ireland	-0.2490**	-2.4364
Italy	0.9234**	24.0058
Netherlands	1.3430**	10.9172
Poland	0.2012**	3.2702
Portugal	0.7151**	6.4974
Romania	0.2327**	5.1898
Spain	0.6829**	14.6745
Sweden	-0.2504**	-3.3575
Inefficiency function		
Intercept	-0.0745	-1.1497
FDI Inflow	3.4187**	6.0247
FDI Outflow	-5.7899**	-11.0889
Openness	0.2173**	11.2198
WTO	-0.1280**	-3.4808
EU	0.1458**	2.2485
Region 1	-0.9459**	-9.1397
Region 2	-1.1615**	-7.8272
Sigma-squared	0.0473**	6.6664
Gamma	0.9400**	62.0490

5% critical value = 1.9569, 10% critical value = 1.6486

** Significant at the 5% level

being positive and labor being negative. As for the significant country dummy variables in the SFA model, France, Hungary, Italy, Netherlands, Poland, Portugal, Romania, and Spain are more productive than the United Kingdom. In the inefficiency model, FDI inflow, openness, and EU dummy variable are positive and significant at the 5% level, and FDI outflow, WTO, region 1, and region 2 dummy variables are negative and significant at the 5% level. The gamma value is less than 1, thus the model complies with SFA.

The results for the OLS regression and the Battese and Coelli SFA models incorporating the time trend can be seen in Tables 4 and 5. Table 5 shows the results of when time is only included in the production function on the left, and when it is included in both production and efficiency functions on the right. Time, land, capital, and fertilizer are each positive and significant in each model at the 5% level. Labor is only significant in the OLS results at the 5% level. When significant, the signs of the country dummies are consistent with the previous models with the exceptions of Hungary, Ireland, Poland, and Romania which each switch signs

Table 4. Cobb-Douglas OLS with Time Trend Results

Variable	OLS	
Production function	Coefficient	t-Value
Intercept	0.1212	0.1279
Time	0.0202**	10.9073
Land	0.2211**	2.7616
Labor	0.2115**	3.4793
Capital	0.4336**	6.2791
Fertilizer	0.0665**	2.9378
Austria	-0.0037	-0.0268
Bulgaria	-0.5811**	-5.0819
Denmark	-0.3577**	-3.3267
Finland	0.2125*	1.9400
France	0.3235**	3.3554
Germany	-0.1835**	-2.4881
Hungary	-0.3817**	-3.4221
Ireland	-0.0601	-0.3914
Italy	0.5537**	8.5227
Netherlands	0.9170**	5.1644
Poland	-0.9198**	-7.7265
Portugal	-0.0130	-0.0853
Romania	-0.6505**	-7.2641
Spain	0.3108**	3.7782
Sweden	-0.0526	-0.5278

5% critical value = 1.9569, 10% critical value = 1.6486
* Significant at the 10% level, ** Significant at the 5% level

Table 5. Cobb-Douglas SFA with Time Trend Results

Variable	Prod. time Trend SFA		Prod. & Ineff. Time Trend SFA	
Production function	Coefficient	t-Value	Coefficient	t-Value
Intercept	-2.5884**	-3.3586	-2.3513**	-3.0759
Time	0.0138**	8.0376	0.0125**	6.9267
Land	0.4148**	7.1020	0.3848**	6.2082
Labor	-0.0442	-0.8691	-0.0664	-1.2619
Capital	0.7180**	13.3087	0.7312**	13.0579
Fertilizer	0.0468**	2.6871	0.0499**	2.8653
Austria	0.3192**	2.9606	0.2706**	2.4637
Bulgaria	0.0245	0.2655	0.0108	0.1185
Denmark	0.0404	0.4141	0.0145	0.1493
Finland	0.4200**	4.6570	0.3800**	4.2131
France	0.0980	1.2480	0.1342	1.7100
Germany	-0.2143**	-3.4805	-0.1924**	-3.1310
Hungary	0.2580**	2.7791	0.2645**	2.8732
Ireland	0.2898**	2.2640	0.2226*	1.6815
Italy	0.6000**	10.8484	0.6257**	11.3072
Netherlands	1.5723**	11.2080	1.5232**	10.9077
Poland	-0.5264**	-4.7528	-0.4731**	-4.3397
Portugal	0.5722**	5.0186	0.5617**	4.8779
Romania	-0.2945**	-3.6872	-0.2597**	-3.1934
Spain	0.3065**	4.4486	0.3445**	4.9205
Sweden	0.0772	0.9393	0.0461	0.5598
Inefficiency function				
Intercept	-0.0760	-1.0374	0.0190	0.2928
FDI Inflow	2.0417**	4.4638	1.9239**	3.6293
FDI Outflow	-4.2909**	-8.7501	-4.2842**	-9.0193
Openness	0.2075**	9.1822	0.2066**	9.0576
Time			-0.0125**	-3.2312
WTO	-0.0045	-0.1419	0.1479**	2.5738
EU	0.0790	1.3734	0.1461**	2.3114
Region 1	-0.9335**	-8.6473	-0.9542**	-7.8227
Region 2	-0.6831**	-6.9857	-0.7270**	-5.9186
Sigma-squared	0.0353**	7.1363	0.0341**	5.4970
Gamma	0.9162**	52.2063	0.9141**	41.5551

5% critical value = 1.9569, 10% critical value = 1.6486

* Significant at the 10% level, ** Significant at the 5% level

once the time trend is introduced. Once again, FDI inflow and openness are positive and significant at the 5% level in the efficiency model; FDI outflow, region 1, and region 2 dummy variables are still negative when significant, and WTO and EU are not consistently significant. Additionally, the WTO variable is positive and significant in the model with a time trend in the inefficiency equation, which is inconsistent with the previous model. The gamma value is less than 1 for both models, thus they both comply with SFA.

The next models in consideration are the extended Cobb-Douglas functional forms. They include a time trend interaction variable for each of the inputs in the production function, as well as each of the factors in the inefficiency function. The first model only includes the time trend interaction variable in the production function, whereas the second includes the interaction variable in both the production and inefficiency equations. The OLS results for the two models can be seen in Table 6. The Battese and Coelli SFA results can be found in Table 7. In the OLS model, only the input variables labor and capital are positive and significant at the 5% level and only the interaction term labor*time is negative and significant at the 5% level. The rest of the input and interaction terms are insignificant. The time trend is found to be insignificant as well. The signs of the country dummy variables are consistent with previous OLS results when significant with France, Italy, Netherlands, and Spain being positive and significant at the 5% level, while Bulgaria, Denmark, Hungary, Ireland, Poland, and Romania are negative and significant. Both SFA models have gamma values of less than 1 thus they adhere to SFA requirements.

Results from the model with the interaction terms included only in the production function are consistent with the previous models, with the exception of the time trend. For the production function, land, capital, and capital*time are each positive and significant at the 5%

level. Time and labor*time are negative and significant at the 5% level. Other input and interaction terms are found to be insignificant. Finland, France, Italy, the Netherlands, Portugal, and Spain are each positive and significant, Poland and Romania are negative and significant, and the other country dummy variables are insignificant. These results are relatively consistent with the signs of dummy variables from previous models, suggesting that the results are robust. As for the inefficiency model, FDI outflow, time, and region 1 and region 2 dummy variables are each negative and significant, implying that they decrease inefficiency. Openness, FDI inflow,

Table 6. Extended Cobb-Douglas OLS Results

Variable	OLS	
Production function	Coefficient	t-Value
Intercept	1.4341	1.3369
Time	-0.0189	-1.5969
Land	-0.0033	-0.0290
Labor	0.2695**	3.4397
Capital	0.4931**	4.0217
Fertilizer	0.0383	1.0281
Land*Time	0.0022	1.1613
Labor*Time	-0.0064**	-3.9098
Capital*Time	0.0032	1.6473
Fertilizer*Time	0.0020	1.1902
Austria	-0.2110	-1.3288
Bulgaria	-0.5432**	-3.9453
Denmark	-0.4626**	-3.6917
Finland	0.0947	0.7796
France	0.4624**	4.0834
Germany	-0.1260	-1.5008
Hungary	-0.2871*	-1.9131
Ireland	-0.3443*	-1.7570
Italy	0.5913**	7.6568
Netherlands	0.6562**	3.3779
Poland	-0.7417**	-4.1302
Portugal	-0.1058	-0.6680
Romania	-0.5288**	-3.8668
Spain	0.4504**	3.9671
Sweden	-0.1273	-1.1516

5% critical value = 1.9569, 10% critical value = 1.6486

* Significant at the 10% level, ** Significant at the 5% level

Table 7. Extended Cobb-Douglas SFA Results

Variable	Extended Prod.		Extended Prod. & Ineff.	
Production function	Coefficient	t-Value	Coefficient	t-Value
Intercept	0.0426	0.0498	-0.6572	-0.8269
Time	-0.0312**	-3.3630	-0.0162*	-1.7699
Land	0.2357**	2.6885	0.2559**	3.1390
Labor	-0.0092	-0.1595	-0.0845	-1.3195
Capital	0.6021**	6.4958	0.6457**	6.6477
Fertilizer	0.0441	1.4249	0.0824**	2.3816
Land*Time	-0.0003	-0.2009	0.0026*	1.6890
Labor*Time	-0.0027**	-2.2067	0.0000	-0.0065
Capital*Time	0.0050**	2.8468	0.0013	0.6846
Fertilizer*Time	0.0008	0.6294	-0.0005	-0.3220
Austria	0.0003	0.0024	0.0829	0.7153
Bulgaria	-0.1626	-1.6097	-0.1123	-1.0483
Denmark	-0.1513	-1.4193	-0.1123	-1.0893
Finland	0.1759*	1.7896	0.2133**	2.3161
France	0.3127**	3.4548	0.2650**	3.2102
Germany	-0.0572	-0.8212	-0.0986	-1.5373
Hungary	0.1002	0.8899	0.1665	1.3984
Ireland	-0.0877	-0.5354	-0.0019	-0.0126
Italy	0.6749**	10.8808	0.7110**	11.5918
Netherlands	1.1740**	7.8953	1.2749**	9.2511
Poland	-0.4067**	-2.7768	-0.3165**	-2.2050
Portugal	0.3180**	2.7965	0.4386**	3.8785
Romania	-0.2341**	-2.1501	-0.1835*	-1.6657
Spain	0.4667**	5.0969	0.4550**	5.2280
Sweden	-0.1125	-1.2741	-0.0760	-0.9174
Inefficiency function				
Intercept	0.0227	0.3398	-0.1291	-1.4069
FDI Inflow	1.4046**	2.6447	1.5253	0.5519
FDI Outflow	-4.1932**	-7.7552	-3.7942	-1.0245
Openness	0.2115**	9.2032	0.2436**	9.2863
FDI Inflow*Time			-0.0441	-0.3180
FDI Outflow*Time			0.0397	0.1984
Openness*Time			-0.0061**	-5.8690
Time	-0.0158**	-4.4324	0.0097**	2.0213
WTO	0.1740**	3.1096	0.0922*	1.7057
EU	0.0513	0.7185	-0.0265	-0.4480
Region 1	-0.8251**	-6.3615	-0.5888**	-5.4459
Region 2	-0.6115**	-4.6328	-0.4443**	-4.3779
Sigma-squared	0.0347**	5.8978	0.0211**	5.7173
Gamma	0.9286**	58.1977	0.8794**	29.2941

5% critical value = 1.9569, 10% critical value = 1.6486

* Significant at the 10% level, ** Significant at the 5% level

and WTO are positive and significant at the 5% level, implying that they increase inefficiency. The EU dummy variable is insignificant. The sign of the WTO dummy variable is inconsistent with previous models. The gamma value is smaller than 1, thus the model adheres to SFA.

The final model considered includes interaction terms in the inefficiency function in addition to the production function. This is done in an attempt to explain the positive sign of openness in the model. Land, capital, fertilizer, and land*time are positive and significant; time is negative and significant. The remaining input and interaction terms are insignificant. The signs of significant country dummy variables are fairly consistent with the previous model; Finland, France, Italy, Netherlands, Portugal, and Spain are positive and significant, Poland and Romania are negative and significant, and the rest insignificant. Openness, time, and WTO are positive and significant in the inefficiency model, implying they increase inefficiency. Openness*time, time, and region 1 and region 2 dummy variable are each negative and significant, indicating that the variables decrease inefficiency. The gamma term is not equal to 1, thus it is consistent with SFA modeling requirements.

Table 8. Likelihood Ratio Statistics

Model	Log Likelihood Function	LR Test
Cobb-Douglas	408.8262	266.8453
Cobb-Douglas with time trend (Prod. only)	435.7269	210.5388
Cobb-Douglas with time trend (Prod. and Ineff.)	438.6196	216.3240
Extended Cobb-Douglas (Prod. only)	452.2727	218.1235
Extended Cobb-Douglas (Prod. And Ineff.)	470.2233	254.0248

The log likelihood function and LR test statistic of each model which complies with the SFA requirement of a small gamma is shown in Table 8. The highest statistics are associated with the extended Cobb-Douglas model which includes the interaction terms between time and the inefficiency non-dummy variables. Thus the model provides the best fit for the data.

For the production function, it can be seen that land, capital, and fertilizer are consistently positive when significant, implying that these resources increase production; time is inconsistent, this is likely due to the inclusion of the time interaction variables. Land*time is found to be positive and significant. This may indicate a more productive use of arable land in recent years. This is consistent with CAP reforms of the 1980's and 1990's aimed at limiting production so as to reduce surpluses. Rye and sugar beet acreage are also noted to drop in 2005 and 2006 due to CAP reforms; lower subsidies are another cause of decreasing farm acreage (Polet, 2009). There is evidence to support the claim that arable land has decreased in recent years as seen in Figure 1.

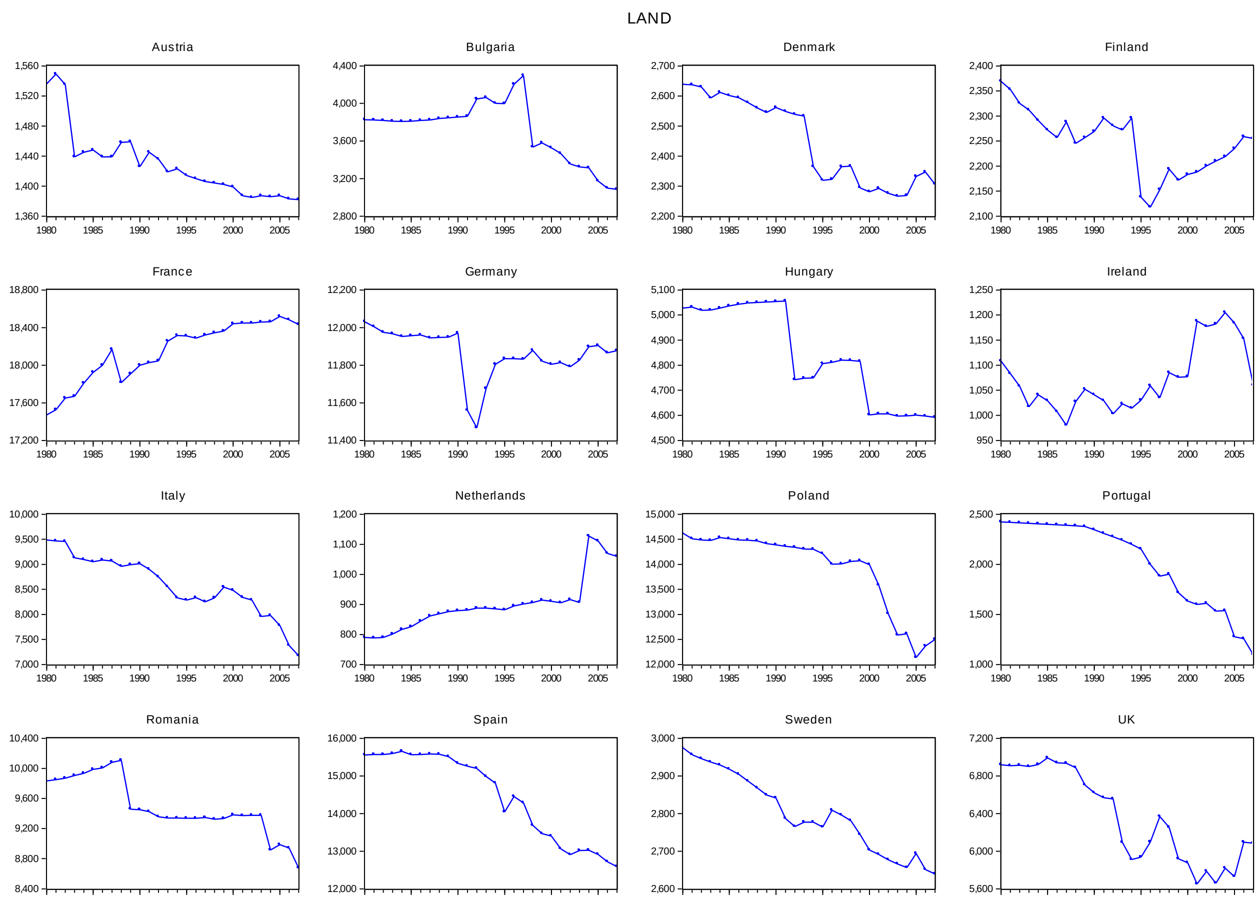

Figure 1. Arable Land Graphs

Figure 1 shows the arable land of each country for the years of 1980-2007; there is a notable negative trend in the amount of arable land for several of the countries, and this may imply that marginal land in terms of quality of productivity is being added to production, leading to higher productivity of the resource in recent years.

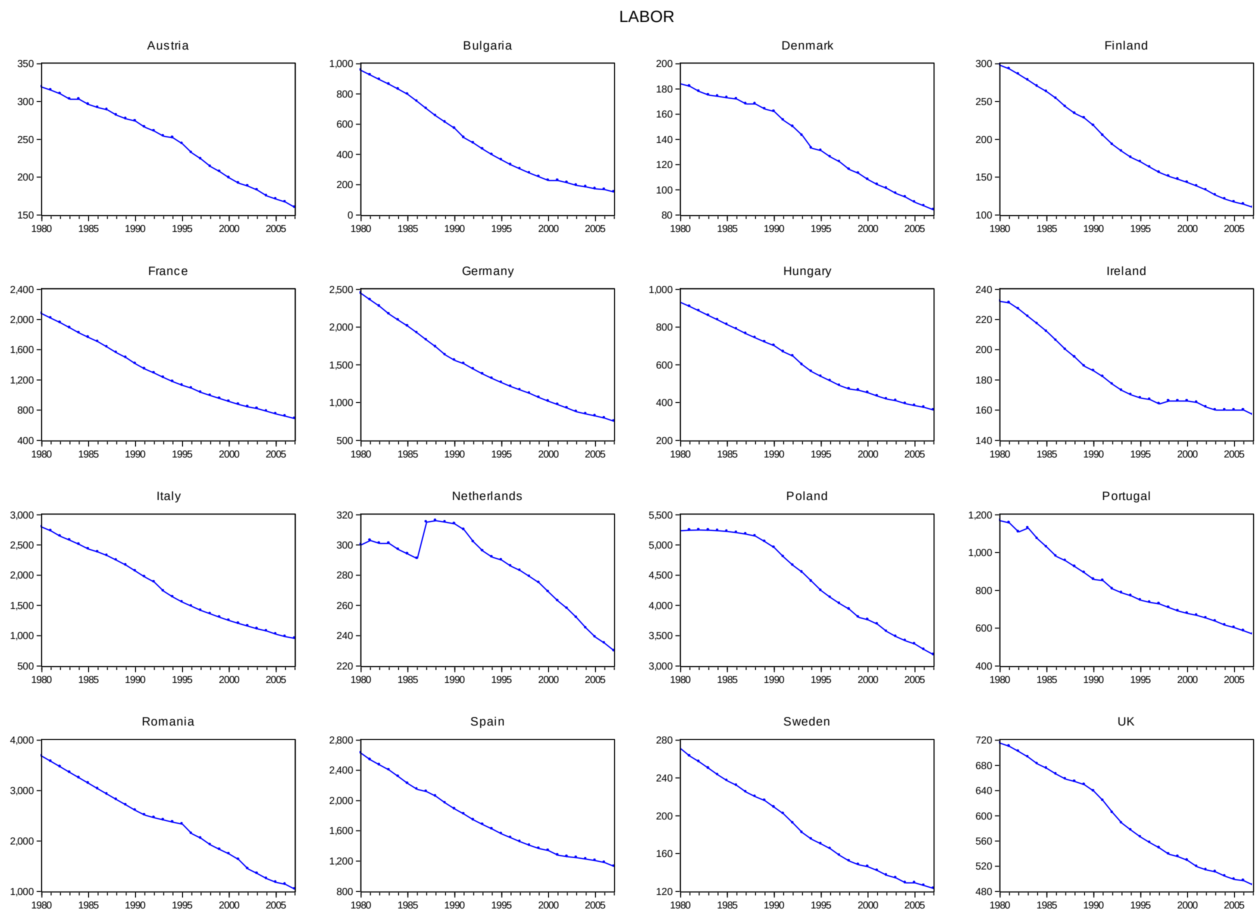

Figure 2. Labor Graphs

The sign for labor is positive in the first model, but insignificant in each of the other models; these results are likely due to labor shedding. That is to say, the decline in the use of labor in favor of capital is improving production and efficiency. Labor*time is negative and significant, further solidifying the theory that a shift of resources has recently taken place. Additional evidence for this is found in the positive sign of capital*time, suggesting more productive use of the resource in recent years. Graphs of labor and capital can be seen in Figures 2 and 3. There is a definitive negative trend in labor, solidifying the theory of labor shedding. A decline in capital is observed in most of the countries, and this tied with the positive sign of capital and capital*time suggests that the resource has been used more productively in recent years. Fertilizer has a positive impact on production, and there has been a decline in the use of the input. Figure 4 graphs the fertilizer consumption of each country; with the exception of Poland, each country has observed a decrease in fertilizer use since 1980. This suggests that countries have been able to more effectively gauge the amount of the resource required.

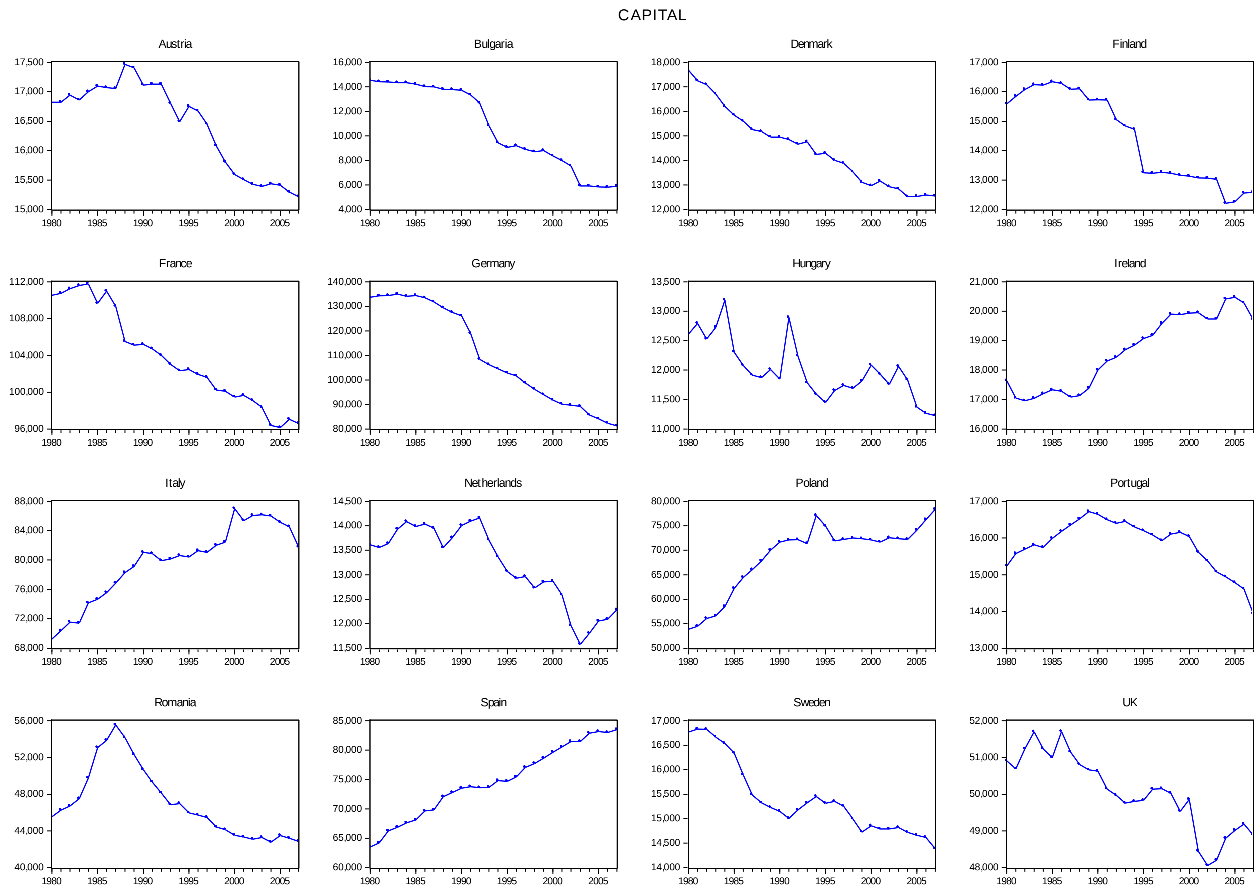

Figure 3. Capital Graphs

For the efficiency function, it was found that FDI outflow consistently decreased inefficiency. This suggests countries initially are able to cope with decreases in capital and

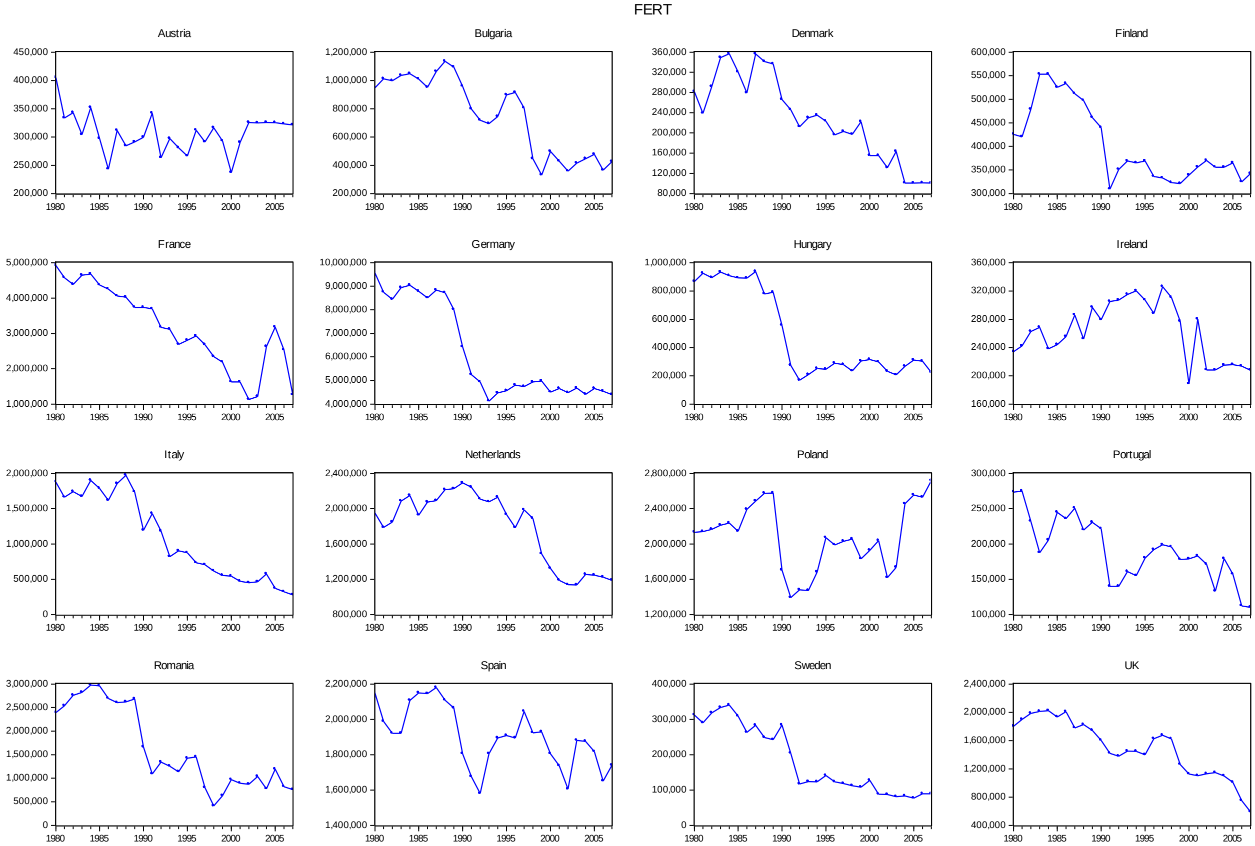

Figure 4. Fertilizer Graphs

utilize their resources more efficiently. However, it is possible that eventually domestic capital becomes depleted resulting in a decrease in efficiency, but perhaps not enough lags are introduced in the model to reflect this phenomenon. FDI inflows, on the other hand, are found to decrease efficiency. This can be attributed to the absorptive capacity of countries; poorer nations do not have the ability to fully utilize investments received from other countries. This results in an inefficient use of resources received via FDI. Figures 5 and 6 show the graphs of FDI outflows and inflows respectively. It can be seen that there is a spike in both at the year 2000, then a sharp drop in the subsequent years. This is consistent with the average annual efficiency scores, as lower TE is observed in 2000, followed by an increase throughout 2001-2007. The time trend is negative and significant when there are no time interaction variables in the

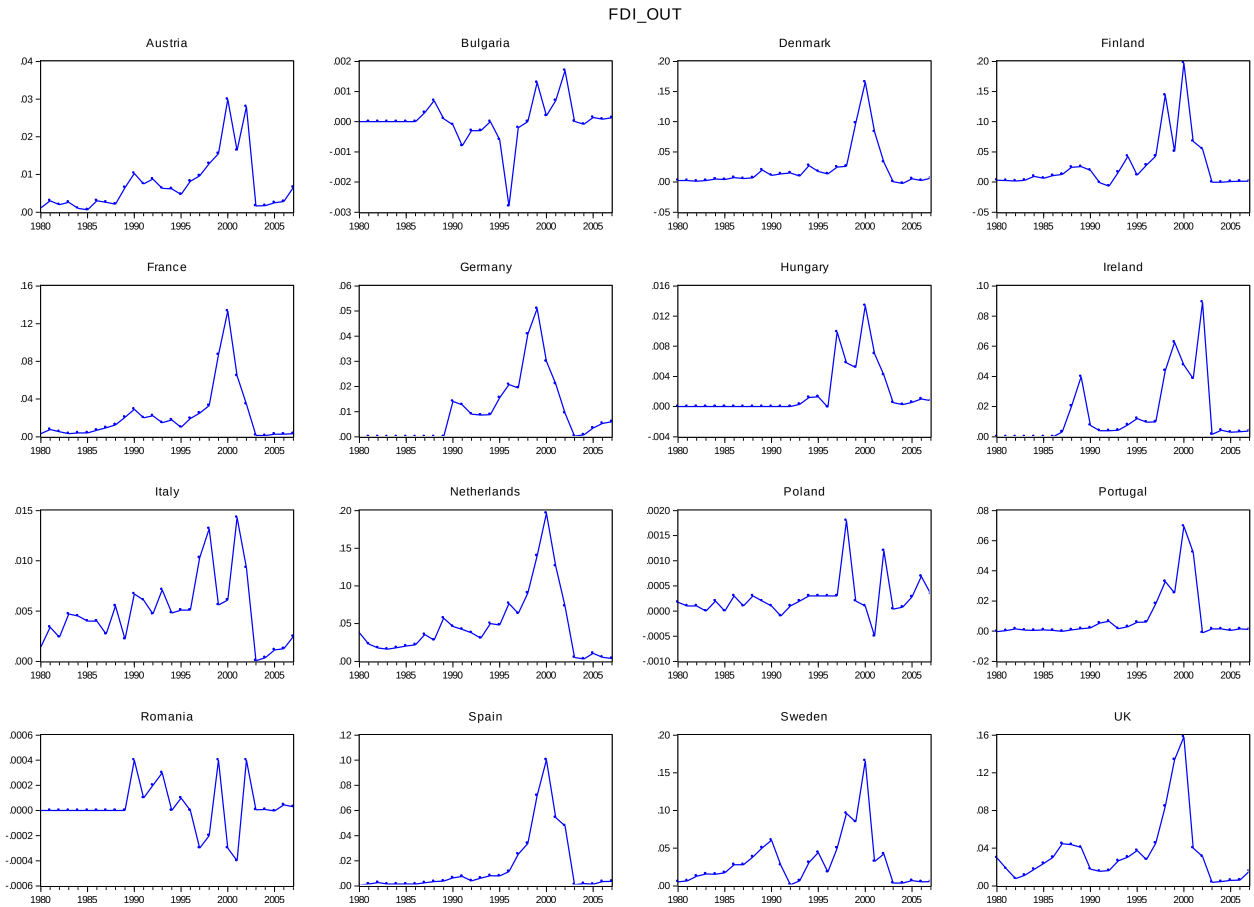

Figure 5. FDI Outflow Graphs

inefficiency equation, suggesting that countries in the EU have become increasingly efficient. This trend is intuitive, as improvements in technology are likely to result in improved efficiency. However, once the interaction terms are introduced, the time variable becomes positive. Thus the result is not robust. The EU dummy positive when significant, but often insignificant thus it is not robust. However, the decrease in efficiency due to EU membership could be pointed towards the environmental and food safety regulations member nations must adopt in order to engage in trade. These strict guidelines may force countries to modify an otherwise more efficient production process. The sign of the WTO is also inconsistent, thus a conclusion cannot be drawn of the benefits its membership.

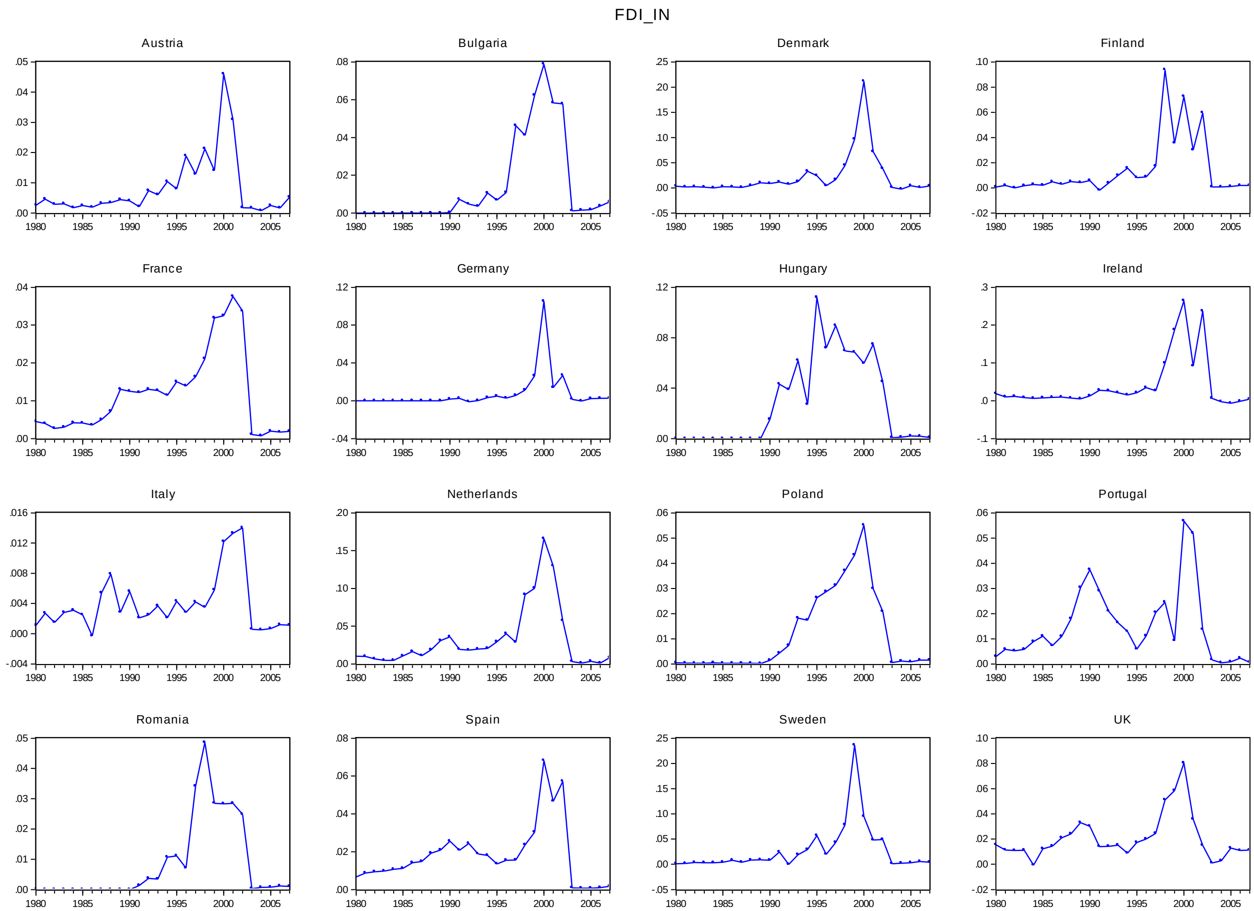

Figure 6. FDI Inflow Graphs

Countries belonging to region 1 are Austria, Denmark, Finland, France, Germany, Ireland, Netherlands, Sweden, and the United Kingdom; countries belonging to region 2 are Italy, Spain, and Portugal, and the remaining countries Bulgaria, Hungary, Poland, and Romania, serve as the base group. The second group is separated based on climate differences, and the third group is formerly Communist nations. The region 1 dummy variable is consistently negative when significant, as is the region 2 dummy variable throughout the models. Therefore, it is evident that not being a formerly Communist nation is related to having lower technical inefficiency. Considering the transformation from publicly owned farms to privately owned, which would likely result in immediate losses of efficiency, this result is consistent with what is to be expected.

The average technical efficiency for each of the 16 countries examined can be seen in Table 9. It can be noted that Finland had the highest technical efficiency, followed by Italy, Austria, and Sweden. The lowest countries were Denmark, Hungary, Bulgaria, and Poland, each formerly Communist nations with the exception of Denmark. The annual average technical efficiencies are found in Table 10. Here it can be seen that the scores fluctuate slightly throughout the years in question, however peaks are observed in 1984, 1990, and 2004; the 2004 spike is followed by a dramatic decrease the subsequent three years. This result is similar to that found in the study by Akande in 2012, which observed a decrease in efficiency for the agricultural sector of the EU-15 in 2002, followed by a sudden increase from 2003-2004, then another drop off in 2004-2007. In order to explain this, Akande examined total factor productivity using DEA; this revealed that the period of 1999-2002 was driving be technical

Table 9. Average Technical Efficiency 1980-2007

Country	Average Technical Efficiency
Denmark	0.7098
Hungary	0.7851
Bulgaria	0.8052
Poland	0.8174
Netherlands	0.8336
Romania	0.8595
Germany	0.8786
Ireland	0.9092
United Kingdom	0.9399
Spain	0.9520
Portugal	0.9523
France	0.9582
Sweden	0.9622
Austria	0.9636
Italy	0.9649
Finland	0.9671

Table 10. Average Annual Technical Efficiency 1980-2007

Year	Average Technical Efficiency
1980	0.8778
1981	0.8783
1982	0.8979
1983	0.8912
1984	0.9086
1985	0.8940
1986	0.8920
1987	0.8785
1988	0.8958
1989	0.8929
1990	0.9097
1991	0.8960
1992	0.8946
1993	0.9016
1994	0.8849
1995	0.8922
1996	0.8828
1997	0.8921
1998	0.8908
1999	0.9002
2000	0.8852
2001	0.8963
2002	0.8846
2003	0.8830
2004	0.9305
2005	0.8847
2006	0.8753
2007	0.8593

change, and 2003-2004 was driven by efficiency change. That is to say that the technological to utilize the technology, and improve technical efficiency from 2003-2004. The key difference changes in 1999-2002 resulted in a decline in efficiency, but EU countries were able to catch up, here is that Akande's study does not include the Eastern European nations considered here; both Poland and Austria acceded to the EU in 2004, and could very well contribute to the observed phenomenon. Additionally, these two nations along with Bulgaria and Romania, which acceded in 2007, may augment the changes in annual efficiency due to their substantially lower efficiency scores. It is possible that efficiency increases in 1984 and 1990 due to catch up to technological advancements, but analysis on total factor productivity growth would need to be completed.

Table 11 lists the average levels of capital, labor, land, and fertilizer for each country considered. The level of labor relative to capital is much higher for Bulgaria, Hungary, Poland, Portugal, and Romania than any of the other EU members. With the exception of Portugal, these countries have some of the lowest efficiency levels of the nations in question. This shows that countries which have a labor intensive resource endowment are less efficient.

Table 11. Average Resources 1980-2007

Country	Land	Labor	Capital	Fertilizer
Austria	1429.57	244.61	16437.53	303375.00
Bulgaria	3714.86	479.89	10708.71	820789.00
Denmark	2448.93	137.64	14505.82	253175.78
Finland	2246.64	193.29	14450.49	414830.70
France	18139.04	1284.14	103741.46	3363191.30
Germany	11862.43	1446.71	109990.21	6541431.39
Hungary	4841.86	611.93	12009.46	541992.04
Ireland	1072.25	183.57	18651.69	273504.35
Italy	8587.04	1785.11	79747.49	1231078.65
Netherlands	899.43	283.96	13185.28	1910748.43
Poland	13921.89	4401.79	68845.95	2015473.96
Portugal	2020.21	825.18	15819.89	202254.74
Romania	9486.89	2334.43	47068.27	1782063.39
Spain	14460.00	1742.18	74615.42	1927775.30
Sweden	2799.50	186.89	15402.48	204230.22
UK	6358.07	594.50	50053.17	1619121.74

Table 12. Average Technical Efficiency by Group

Group	Technical Efficiency
EU	0.8912
Formerly Communist	0.8168
Remainder of Europe	0.9025
Southern Europe	0.9564

Table 12 lists the average technical efficiency of each group of countries considered: the formerly Communist nations, southern Europe, and the remaining EU nations. It can be seen that countries which fell under a Communist regime in the past are subject to the lowest efficiency levels of EU member nations. Southern European nations, on average, have the highest technical efficiency scores relative to the remainder of the EU.

Openness, the primary variable in question, is found to be positive and significant. Important to note, however, is that openness*time is negative and significant. This indicates that openness leads to decreased efficiency instantaneously, however a long run adjustment occurs resulting in an increase in efficiency; that is, trade openness results in efficiency gains over time. There is a necessary time period for the consumers and producers to adjust to the imports and exports which result from trade openness. When a country increases exports due to trade

Figure 7. Trade Openness Graphs

liberalization, it is immediately unclear what the demand for their products may be in the foreign nation. As for increases in imports due to trade openness, foreign agricultural goods may be superior to domestic EU products, thus adjustments must be made domestically. These adjustments are trade induced technology innovation, which causes an immediate decrease in efficiency, but a long term increase. The graphs for each country's annual trade openness can be seen in Figure 7. It can be seen that most countries have lower degrees of openness in the early 1980's, the time period in which technical efficiency levels are the lowest with the exception of 2006-2007.

CONCLUSIONS

Past studies have had conflicting results on the impact of trade openness on technical efficiency. Only two papers have been written for the case of the agricultural sector on this subject, and each of those papers found no significant impact. The results from this study, however, have shown that trade openness does indeed impact technical efficiency in the EU agricultural sector. The findings were that trade openness has an immediate, negative impact on efficiency. Over time, however, trade openness does increase efficiency. This occurrence could be explained in a variety of ways. This could imply that countries in the EU initially are less efficient when foreign countries enter their market, due to the need for an improvement in technology in order to remain competitive. Also, when entering a foreign market, countries in the EU may not necessarily know what the demand for their agricultural products are, leading to inefficiency. Over time though, countries are able to adapt to increased competition and larger world markets, allowing efficiency to increase.

To expand on this phenomenon, many importing countries are unable to compete with foreign goods; this leads to a race to advance technology. Many producers are not financially prepared to do this, thus weaker firms and farms are often forced or bought out of the expanded market. Additionally, the chance for further exports may lead a country to expand certain aspects of production and reduce others. This could result in a shift in resources between sectors, and an instantaneous decline in inefficiency. Indeed the evidence in support of labor shedding was extremely prevalent, thereby supporting this conclusion. Furthermore, due to the diversity of capital endowed versus developing countries in the EU, primarily the former Communist countries, shifts in production are sure to occur. Well-endowed nations are likely to increase the production of capital intensive goods, whereas developing nations are likely to increase the production of labor intensive goods when trade liberalization occurs due to their respective comparative advantages. Hypothetically, this redistribution of production would occur in the long-term as countries shift their resources to more productive uses following trade liberalization; initially a decline in inefficiency may occurs as weaker farms struggle to compete with the larger market. Over time however, once less competitive firms and farms have exited the market, only the more efficient producers would remain. This would be reflected as an increase in efficiency over time, followed by the initial decrease; such is the case for the countries observed in this study. The long term versus instantaneous effects of trade openness on technical efficiency has not been extensively researched, and is a point that should be addressed as policy makers continue to work towards trade liberalization.

Another rationale for the results observed is that trade liberalization does improve technical efficiency, but the trade openness measurement cannot accurately capture the efficiency change. In this study, openness is measured as agricultural exports plus imports as a percentage of agricultural GDP. Although many barriers to trade are removed for member nations, thereby allowing for cheaper trade between countries, the amount of trade between countries may be independent of trade restrictions. Some member countries may have a particular agricultural product that is in high demand by other nations, or perhaps are incapable of producing a given agricultural good. If this is the case, a country's trade openness may experience little or no change when trade barriers are lifted due to membership in the EU. In such instances, the trade openness measurement used might not truly reflect the positive effects of liberalization.

The impact of FDI on technical efficiency in the EU is important to note. The interpretation of the results is quite ambiguous as that the FDI outflows decrease inefficiency.

Thus suggests that an initial reduction in capital supply forces EU nations to utilize other factor inputs more efficiently, but there is the unexamined potential that over time the depletion of capital results in a decrease in efficiency. The interpretation of the results for FDI inflows may initially seem counterintuitive. Presumably a country that receives foreign investments should be able to increase their efficiency. However, a nation's ability to utilize these funds is dependent on the technology gap between them and the remainder of the world market. That is, the absorptive capacity of a country determines their ability to increase efficiency using foreign investment. In order to truly understand the impact of FDI inflows, the amount a country dedicates in research and development, human capital, and other foreign investments must be examined. Another impact on technical efficiency is geographic location of EU members. Eastern, formerly Communist, nations are found to have the lowest technical efficiency scores whereas Southern European nations have the highest efficiency. Interestingly, there is no link found between EU membership and higher efficiency results, suggesting that subsidies received through the CAP and other trade and production benefits membership entails to are likely offset by the health safety and environmental restrictions sanctioned by the EU.

The study could potentially be expanded to include the entire global market in order to find a conclusive relationship between trade liberalization and technical efficiency. The cause for the EU being different from the US or Brazil could be due to the CAP that member nations adhere to, or due to the higher competition faced due to so many countries engaging in open competition. Nonetheless, it can be concluded that trade liberalization over time, despite an immediate decline in efficiency, does significantly decrease a nation's technical inefficiency.

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APPENDIX. THE FRONTIER PROGRAM

The FRONTIER Program

FRONTIER Version 4.1 differs in a number of ways from FRONTIER Version 2.0 (Coelli, 1992), which was the last fully documented version. People familiar with previous versions of FRONTIER should assume that nothing remains the same, and carefully read this document before using Version 4.1. You will, however, find that a number of things are the same, but that many minor, and some not so minor things, have changed. For example, Version 4.1 assumes a linear functional form. Thus if you wish to estimate a Cobb-Douglas production function, you must log all of your input and output data before creating the data file for the program to use. Version 2.0 users will recall that the Cobb-Douglas was assumed in that version, and that data had to be supplied in original units, since the program obtained the logs of the data supplied to it. A listing of the major differences between Versions 2.0 and 4.1 is provided at the end of this section.

Files Needed

The execution of FRONTIER Version 4.1 on an IBM PC generally involves five files:

1) The executable file FRONT41.EXE

2) The start-up file FRONT41.000

3) A data file (for example, called TEST.DTA)

4) An instruction file (for example, called TEST.INS)

5) An output file (for example, called TEST.OUT).

The start-up file, FRONT41.000, contains values for a number of key variables such as the convergence criterion, printing flags and so on. This text file may be edited if the user wishes to alter any values. This file is discussed further in the Appendix. The data and instruction files must be created by the user prior to execution. The output file is created by FRONTIER during execution.[1] Examples of a data, instruction and output files are listed in Section 4.

The program requires that the data be listed in a text file and is quite particular about the format. The data must be listed by observation. There must be 3+k[+p] columns presented in the following order:

1)	Firm number (an integer in the range 1 to N)
2)	Period number (an integer in the range 1 to T)
3)	Y_{it}
4)	$x1_{it}$
	:
3+k)	xk_{it}
[3+k+1)	$z1_{it}$
:	
3+k+p)	zp_{it}].

The z entries are listed in square brackets to indicate that they are not always needed. They are only used when Model 2 is being estimated. The observations can be listed in any order but the columns must be in the stated order. There must be at least one observation on each of the N firms and there must be at least one observation in time period 1 and in time period T. If you are using a single cross-section of data, then column 2 (the time period column) should contain the value "1" throughout. Note that the data must be suitably transformed if a functional form other than a linear function is required. The Cobb-Douglas and Translog functional forms

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[1]Note that a model can be estimated without an instruction file if the program is used interactively.

are the most often used functional forms in stochastic frontier analyses. Examples involving these two forms will be provided in Section 4.

The program can receive instructions either from a file or from a terminal. After typing "FRONT41" to begin execution, the user is asked whether instructions will come from a file or the terminal. The structure of the instruction file is listed in the next section. If the interactive (terminal) option is selected, questions will be asked in the same order as they appear in the instruction file.

The Three-Step Estimation Method

The program will follow a three-step procedure in estimating the maximum likelihood estimates of the parameters of a stochastic frontier production function.[2] The three steps are:

1) Ordinary Least Squares (OLS) estimates of the function are obtained. All β estimators with the exception of the intercept will be unbiased.

2) A two-phase grid search of γ is conducted, with the β parameters (excepting β_0) set to the OLS values and the β_0 and σ^2 parameters adjusted according to the corrected ordinary least squares formula presented in Coelli (1995). Any other parameters (μ, η or δ's) are set to zero in this grid search.

3) The values selected in the grid search are used as starting values in an iterative procedure (using the Davidon-Fletcher-Powell Quasi-Newton method) to obtain the final maximum likelihood estimates.

[2]If starting values are specified in the instruction file, the program will skip the first two steps of the procedure.

Grid Search

As mentioned earlier, a grid search is conducted across the parameter space of γ. Values of γ are considered from 0.1 to 0.9 in increments of size 0.1. The size of this increment can be altered by changing the value of the GRIDNO variable which is set to the value of 0.1 in the start-up file FRONT41.000.

Furthermore, if the variable, IGRID2, in FRONT41.000, is set to 1 (instead of 0) then a second phase grid search will be conducted around the values obtained in the first phase. The width of this grid search is GRIDNO/2 either side of the phase one estimates in steps of GRIDNO/10. Thus a starting value for γ will be obtained to an accuracy of two decimal places instead of the one decimal place obtained in the single phase grid search (when a value of GRIDNO=0.1 is assumed).

Iterative Maximization Procedure

The first-order partial derivatives of the log-likelihood functions of Models 1 and 2 are lengthy expressions. These are derived in appendices in Battese and Coelli (1992) and Battese and Coelli (1993), respectively. Many of the gradient methods used to obtain maximum likelihood estimates, such as the Newton-Raphson method, require the matrix of second partial derivatives to be calculated. It was decided that this task was probably best avoided, hence we turned our attention to Quasi-Newton methods which only require the vector of first partial derivatives be derived. The Davidon-Fletcher-Powell Quasi-Newton method was selected as it appears to have been used successfully in a wide range of econometric applications and was also recommended by Pitt and Lee (1981) for stochastic frontier production function estimation. For a general discussion of the relative merits of a number of Newton and Quasi-Newton methods see Himmelblau (1972), which also provides a description of the mechanics (along with Fortran code) of a number of the more popular methods. The general structure of the subroutines, MINI, SEARCH, ETA and CONVRG, used in FRONTIER are taken from the appendix in Himmelblau (1972).

The iterative procedure takes the parameter values supplied by the grid search as starting values (unless starting values are supplied by the user). The program then updates the vector of parameter estimates by the Davidon-Fletcher-Powell method until either of the following occurs:

a) The convergence criterion is satisfied. The convergence criterion is set in the start-up file FRONT41.000 by the parameter TOL. Presently it is set such that, if the proportional change in the likelihood function and each of the parameters is less than 0.00001, then the iterative procedure terminates.

b) The maximum number of iterations permitted is completed. This is presently set in FRONT41.000 to 100.

Both of these parameters may be altered by the user.

Program Output

The ordinary least-squares estimates, the estimates after the grid search and the final maximum likelihood estimates are all presented in the output file. Approximate standard errors are taken from the direction matrix used in the final iteration of the Davidon-Fletcher-Powell procedure. This estimate of the covariance matrix is also listed in the output.

Estimates of individual technical or cost efficiencies are calculated using the expressions presented in Battese and Coelli (1991, 1995). When any estimates of mean efficiencies are reported, these are simply the arithmetic averages of the individual efficiencies. The ITE variable in FRONT41.000 can be used to suppress the listing of individual efficiencies in the output file, by changing its value from 1 to 0.

Differences between Versions 2.0 and 4.1

The main differences are as follows:

1) The Battese and Coelli (1995) model (Model 2) can now be estimated.

2) The old size limits on N, T and K have been removed. The size limits of 100, 20 and 20, respectively, were found by many users to be too restrictive. The removal of the size limits have been achieved by compiling the program using a Lahey F77L-EM/32 compiler with a DOS extender. The size of model that can now be estimated by the program is only limited by the amount of the available RAM available on your PC. This action does come at some cost though, since the program had to be re-written using *dynamically allocatable arrays*, which are not standard Fortran constructs. Thus the code cannot now be transferred to another computing platform (such as a mainframe computer) without substantial modification.

3) Cost functions can now be estimated.

4) Efficiency estimates can now be calculated when the dependent variable is expresses in original units. The previous version of the program assumed the dependent variable was in logs, and calculated efficiencies accordingly. The user can now indicate whether the dependent variable is logged or not, and the program will then calculate the appropriate efficiency estimates.

5) Version 2.0 was written to estimate a Cobb-Douglas function. Data was supplied in original units and the program calculated the logs before estimation. Version 4.1 assumes that all necessary transformations have already been done to the data before it receives it. The program estimates a linear function using the data supplied to it. Examples of how to estimate Cobb-Douglas and Translog functional forms are provided in Section 4.

6) Bounds have now been placed upon the range of values that μ can take in Model 1. It is now restricted to the range between $\pm 2\sigma_U$. This has been done because a number of users (including the author) found that in some applications a large (insignificant) negative value of μ was obtained. This value was large in the sense that it was many standard deviations from zero (e.g. four or more). The numerical accuracy of calculations of areas in the tail of the standard normal distribution which are this far from zero must be questioned.[3] It was thus decided that the above bounds be imposed. This was not viewed as being too restrictive, given the range of truncated normal distribution shapes which are still permitted. This is evident in Figure A1 which plots truncated normal density functions for values of μ of -2, -1, 0, 1 and 2

7) Information from each iteration is now sent to the output file (instead of to the screen). The user can also now specify how often (if at all) this information is reported, using the IPRINT variable in FRONT41.000.

8) The grid search has now been reduced to only consider γ and now uses the corrected ordinary least squares expressions derived in Coelli (1995) to adjust σ^2 and β_0 during this process.

9) A small error was detected in the first partial derivative with respect to η in Version 2.0 of the program. This error would have only affected results when η was assumed to be non-zero. The error has been corrected in Version 4.1, and the change does not appear to have a large influence upon estimates.

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[3]A monte carlo experiment was conducted in which μ was set to zero when generating samples, but was unrestricted in estimation. Large negative (insignificant) values of μ were obtained in roughly 10% of samples. A 3D plot of the log-likelihood function in one of these samples indicated a long flat ridge in the log-likelihood when plotted against μ and σ^2. This phenomenon is being further investigated at present.

10) As a result of the use of the new compiler (detailed under point 2), the following minimum machine configuration is needed: an IBM compatible 386 (or higher) PC with a math co-processor. The program will run when there is only 4 mb RAM but in some cases will require 8 mb RAM.

11) There have also been a large number of small alterations made to the program, many of which were suggested by users of Version 2.0. For example, the names of the data and instruction files are now listed in the output file.

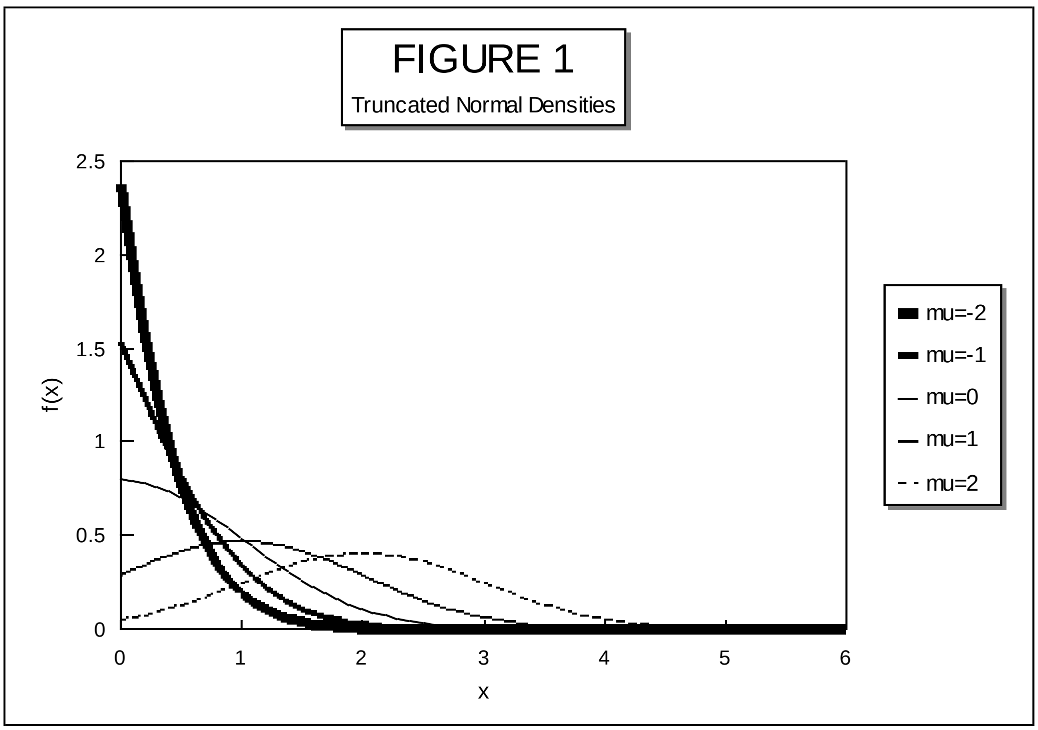

Figure A1. Truncated Normal Densities

The Battese and Coelli (1995) Specification (Model 2)

In this example we estimate the full model defined by (3) and (4) with the z vector containing a constant and one other variable (which incidentally is a time trend in this simple example). Thus the data file EG5.DAT (refer Table A1) contains one more column (the z variable), than the data file in the previous example. The SHAZAM instructions (refer Table

A2) are similar to those in first example, except that data on the z variable must be read in and read out. The FRONTIER instruction file (EG5.INS) differs in a number of ways from the previous example: the model number on line one has been set to “2”; the question regarding δ_0 has been answered by a yes (line 10) and the number of z variables has been set to 1 (line 11).

Table A1. Listing of Data File EG5.DAT

1.	1.	15.131	9.416	35.134	1.000
2.	1.	26.309	4.643	77.297	1.000
3.	1.	6.886	5.095	89.799	1.000
	.				
	.				
	.				
13.	4.	23.314	9.329	87.124	4.000
14.	4.	22.737	7.834	60.340	4.000
15.	4.	22.639	5.621	44.218	4.000

Table A2. Listing of Shazam Instruction File EG5.SHA

```
read(eg5.dat) n t y x1 x2 z1

genr ly=log(y)

genr lx1=log(x1)

genr lx2=log(x2)

file 33 eg5.dta

write(33) n t ly lx1 lx2 z1

stop
```

Table A3. Listing of Data File EG5.DTA

1.000000	1.000000	2.716746	2.242410	3.559169
1.000000				
2.000000	1.000000	3.269911	1.535361	4.347655
1.000000				
3.000000	1.000000	1.929490	1.628260	4.497574
1.000000				
.				
.				
.				
13.00000	4.000000	3.149054	2.233128	4.467332
4.000000				
14.00000	4.000000	3.123994	2.058473	4.099995
4.000000				
15.00000	4.000000	3.119674	1.726510	3.789132
4.000000				

Table A4. Listing of Instruction File EG5.INS

```
2          1=ERROR COMPONENTS MODEL, 2=TE EFFECTS MODEL
eg5.dta      DATA FILE NAME
eg5.out      OUTPUT FILE NAME
1          1=PRODUCTION FUNCTION, 2=COST FUNCTION
y          LOGGED DEPENDENT VARIABLE (Y/N)
15          NUMBER OF CROSS-SECTIONS
4          NUMBER OF TIME PERIODS
60          NUMBER OF OBSERVATIONS IN TOTAL
2          NUMBER OF REGRESSOR VARIABLES (Xs)
y          MU (Y/N) [OR DELTA0 (Y/N) IF USING TE EFFECTS MODEL]
1          ETA (Y/N) [OR NUMBER OF TE EFFECTS REGRESSORS (Zs)]
n          STARTING VALUES (Y/N)
          IF YES THEN     BETA0
                    BETA1 TO
                    BETAK
                    SIGMA SQUARED
                    GAMMA
                    MU          [OR DELTA0
                    ETA            DELTA1 TO
                                DELTAK]
```

NOTE: IF YOU ARE SUPPLYING STARTING VALUES AND YOU HAVE RESTRICTED MU [OR DELTA0] TO BE ZERO THEN YOU SHOULD NOT SUPPLY A STARTING VALUE FOR THIS PARAMETER.
