2 LITERATURE REVIEW

The literature review is divided into two sections. In the first section, empirical applications of frontier models are reviewed with the example of developing country cases. The emphasis is placed on policy variables which influence production efficiency. In the Appendix, a table illustrates a summary of the studies that includes the country of application, crops under investigation, methodologies used and obtained efficiency scores. In the second section, the shortcomings of the existing methods and techniques are specified and new methodological developments (parametric and non-parametric approaches) are described.

2.1 REVIEW OF EMPIRICAL EFFICIENCY STUDIES

2.1.1 The Debate on Farm Size and Efficiency

The extent of inefficiency in the utilization of farm resources and a discussion of the causes of efficiency differentials took sizeable attention in the efficiency literature related to transition economies. One of the immensely debated relationships was between farm size and *TE*. Mathijs and Swinnen (1998) and Rizov et al. (2001) illustrated mixed results. The authors noted that farm restructuring and land tenure reforms greatly influenced farm size distribution in transition economies. Gorton and Davidova (2001) argued that larger farms were more efficient than smaller farms in relation to resource utilization. Earlier work by Curtiss (2000) and Morrison (2000) also reported the affirmative relationship between *TE* and farm size in the case of Czech and Slovakian crop producing farms. Thus, policy recommendations in these directions included consolidating farming entities. On the contrary, Koester and Striewe (1999) favored smaller sized farms in the case of transition countries. They argued that countries in transition suffer from diseconomies of scale.

Developing country experiences also illustrated varied results on this topic for more than four decades. Sen (1962) investigated the link between productivity and the size of the farm in India. This is one of the earlier studies in productivity analysis. A shortcoming of this study is that the relationship is based on total output and farm size. Hence, it disregards other production factors and is accepted as a partial efficiency measurement.

Relationships between relative efficiency and farm size gained huge interest starting in the 1970s. Yotopoulos and Lau (1973) discovered a negative association between efficiency and farm size in the example of Indian agriculture. The authors concluded that, given the fixed factors of production and under the observed prices of resource endowments and output, small farms achieved greater *AE* and *TE* levels. They also emphasized that the managerial role of the farm's head was crucial in reaching larger levels of economic efficiency (*EE*). Studies conducted by Cornia (1985) and Verma and Bromley (1987) also supported this relationship and found that small–scale farms were operationally more practical and profitable. They also observed that these farms intensely used agricultural land for growing several crops.

Squires and Tabor (1991) investigated farms in Indonesia that grew a variety of crops (e.g. wet rice, peanuts, cassava, and mung beans) and found that smaller farms were much more efficient in resource utilization. They explained their findings by the fact that smaller farms had more control over their agronomic activities and exploited the economically beneficial land cultivation pattern and resource allocation. Balcombe et al. (2007) employing the Bayesian approach, also found proof of decreasing returns to farm size among rice producing farmers in Bangladesh. Okoye et al. (2009) concluded that small farms were more productive in land use and had larger efficiency levels in the production of Cassava in Nigeria. Other authors who got an inverse relationship in their efficiency analysis were Barrett (1996), Peterson (1997), Heltberg (1998) and Amara et al. (1999).

The inverse relationship was questioned by Feder et al. (1985), on the basis of imperfections in land and capital markets. Authors who favored a positive relationship between farm size and efficiency argued that farms with larger sizes gained from diminished land prices, higher educational levels, and easier access to credit and extension services. Coelli and Battese (1996) found a positive relationship between farm size and *TE* and explained that smaller farmers had alternative income sources and farming was only necessary for subsistence. Alene and Hassan (2003) using a *SFM*, found that larger farms were more efficient and successful in using improved maize production technology in Western Ethiopia. Fandel (2003) employed the *DEA* model in an investigation of corporate farms in Slovakia and calculated technical and scale efficiencies. They also found that *SE* improved with farm size. In Nigeria, Alene et al. (2006) in the case of cowpeas, and Adewumi and Adebayo (2008) in the case of sweet potatoes, showed that increasing the farm size had a tendency of reducing the inefficiency level. Murthy et al. (2009) used the *DEA* approach and estimated the technical and scale efficiencies of tomato-producing farms in the example of three groups of farms. They illustrated that most of the farms had inefficiency problems, irrespective of the size of the farm. Khan and Maki (1979), Curtiss (2000), Jha et al. (2000), Latruffe and Fraser (2002) and Dlamini et al. (2010) found a positive association between efficiency levels and the size of the farm.

2.1.2 Land Fertility, Water Availability and Technical Efficiency

Agricultural sustainability is constrained by degrading soil fertility and water scarcity problems. As complementary substitutes for widespread growth are wilting, focus is, at present, on factor productivity improvement and resource use efficiency. In this regard, land fertility and water related variables play an important role explaining productivity differentials among crop producing farms. In the efficiency literature, several authors found that, in the fertile lands, the efficiency of farmers was very high. For example, Kebede (2001) used a geographic location dummy as a proxy for land fertility. He reported that, in the provinces where soil fertility was high, output per ha and farmer's resource use efficiency was also high. Sherlund et al. (2002) found a similar result in the production of rice in Cote Devoir. Rahman (2003) also reported a similar finding in the case of Bangladesh; he emphasized that a strategy, like efficient soil fertility management, had to be promoted. Latruffe et al. (2004), Binam et al. (2004) and Kiatpathomchai et al. (2009) found that farmers who utilized better quality land were much more efficient in resource use. Binam et al. (2004) and Kiatpathomchai et al. (2009) also emphasized that efforts had to be started to enhance soil conditions in Cameroon and Thailand, respectively. Rahman (2009) recommended that technological proposals be aimed at measures to discover lower soil fertility areas so the intrinsic soil rooted productivity constraint could be decreased.

In traditional production models, the water variable is included as a conventional input in the production function. As is suggested in the literature, water use also dependent on several factors and had to be included as an efficiency explaining factor in the frontier models. In our approach, we use a dummy variable for water. One of the dummy variables used in efficiency studies is easy access to irrigation, which plays an important role in increasing *TE*. For crop producing farms in Shri-Lanka, Ekayanake (1987) investigated the access to irrigation water and efficiency variables by separating farmers into two locations. The first group consisted of farmers who were located in the “head” and the rest in the “tail.” Author discovered no significant results of the *TE* with “head” farmers during the wet season. Since there was enough water in the good season, *TE* differentials were not different from zero. However, “tail” farmers suffered greatly from *TI*, even when there was enough water. Author explained this finding by the fact that these farmers were situated in a disadvantaged location and the farmers located in the “head” used to take water illegally from the water source due to their favorable location. Based on these results, this study emphasized that different managerial decision skills of farmers, agronomic methods and the appropriate timing of water delivery had to be developed.

Ali et al. (1996) estimated *EE* for several crops in Pakistan using a stochastic translog cost function. They considered expenses in irrigation as an important variable, but dropped it from the analysis, because it was very similar across farms. They did not obtain any significant results. Other studies included information related to irrigation water as a dummy variable in the regression analysis. For example, Tian and Wan (2000), in a study of survey data from China, estimated the crop specific *TE* of rice, wheat and corn. Results from their model illustrated that efficiency was positively related to the irrigation and drainage variables. With these findings, they supported the recommendation of Wan and Anderson (1990) and stressed that policy recommendations had to include support for improving the irrigation systems’ management in China.

Croppenstedt (2005) investigated Egyptian wheat producing farms' *TE* using a *SFM* and included knowledge of irrigation as a dummy in the regression analysis. Author found that those who had a good knowledge of improved irrigation techniques were technically efficient and increased production of wheat by 14%. Khanna (2006) employed the *SFM* to estimate Indian sugar cane farmers' *TE* by differing water user categories. Khanna found that farmers who owned the tube-well had a much larger *TE* than those who paid for the delivery of water to irrigate their fields. It was explained that farmers who owned a tube-well had better access to irrigation water and were able to control the resource use in a timely manner.

2.1.3 Crop diversification, Production Characteristics and Efficiency

Studies on crop diversification in the empirical literature investigated its relationship on the level of income or production output. Guvele (2001) found that income variability lessened in Sudan due to crop diversification. Kar et al. (2004) found that crop diversification in the upland rice area of India was beneficial for drought alleviation and yield stabilization with improved rainwater zone efficiency. Mkhabela (2005) concluded that crop diversification programs in South Africa were successful in the geographic locations where access to irrigation was easy. Van den Berg et al. (2007) concluded that crop diversification towards cash crops improved the income levels of Chinese farms. Sannikova and Bokusheva (2007) found some constraints for adopting crop diversification strategies in Russian farms. They emphasized that current production practices were not adjusted to the existing climatic conditions. Solis et al. (2009) highlighted the importance of crop diversification and stated that crop diversification would influence the production structure and decision-making of farmers.

The critical worry for the characterization of policy is whether there is any association between crop diversification and plot level efficiency. There is no uniform relationship among them, as is the case of farm size. For instance, Rahman and Rahman (2009) in the case of Bangladesh, found that crop diversification positively influences the resource economy and *TE*. These findings are in line with the results of Coelli and Fleming (2004), Uaiene

(2008), and Asadullah and Rahman (2009), who stated that diversification increases the efficiency of farmers in resource use in Papua New Guinea, Mozambique and Bangladesh, respectively. Haji and Andersson (2006), Binici et al. (2006), Amaza et al. (2006) and Llewelyn and Williams (1996), however, concluded that crop diversification significantly reduced the production efficiency of farmers in Indonesia, Turkey, Nigeria and Ethiopia, respectively. Kassali et al. (2009) found non-significant results between crop diversification and *TE* in Nigeria.

Previous studies also demonstrated that some of the production variables were included as an efficiency explaining factor in the efficiency analysis. We have already discussed some of the production variables, such as irrigation and land fertility, which were included in the inefficiency regression model. There were also many studies in which the production characteristics were included as possible sources of inefficiency.

Manevska-Tasevska et al. (2011) included production characteristics, including resource endowments (e.g., total area, irrigated area, machinery value, yields, materials and labor costs), in the inefficiency regression model. They found positive significant results between *TE* and irrigated areas, as well as material and labor costs. Wouterse (2010) also found a positive impact between the value of farm equipment and *TE*. Olson and Vu (2009) and Larsen (2010) included hired labor in the inefficiency regression model to establish the relationship between the production factor and production efficiency. Sauer et al. (2006) and Sauer and Tchale (2009) also included weeding frequency as an efficiency influencing factor in the analysis.

2.1.4 Socio-Economic and Demographic Determinants of Efficiency

Gorton and Davidova (2004) emphasized the importance of production efficiency and farmers' involvement in non-farm activities. One of the indicators used to investigate this relationship was the off-farm work variable. Its impact on production efficiency was revealed in many *EE* studies. The literature review illustrated that small farms, mono-cropping farms and highly educated farmers were engaged in off-farm activities. As it was observed, when a farmer was involved in off-farm work, production efficiency decreased due to less time spent on farming activities. Brümmer (2001) mentioned that farmers who devoted all of their time to crop activities were more efficient than those who were involved in non-farm activities. Joshi et al. (2006) showed that farmers who had off-farm incomes did not diversify their crop production, because of time limits and skills. Many studies, such as Llewelyn and Williams (1996) in the case of Indonesia, Coelli et al. (2002) and Rahman (2003) in Bangladesh, Bozoglu et al. (2006) in Turkey, Aye and Mungatana (2010) in Nigeria, also found low production efficiencies with those farmers that reported that they were involved in off-farm work. Since it was difficult to obtain data related to the income of the farmer, due to confidentiality or difficulty in calculations, most of the authors used dummy variables for income in the regression analysis.

A farm manager's age and agricultural experience was widely discussed in the literature. Stefanou and Saxena (1988) found that education and experience had significant positive effects on the level of efficiency and concluded that, in some cases, these two variables could be treated as substitutes in explaining farm performance. Seyoum et al. (1998) employed a translog *SFM* and estimated maize producing farms' *TE* in eastern Ethiopia. The authors reported that older farmers were much more inefficient than younger farms. There is a vast amount of literature confirming these results.

A range of demographic factors determine the *TE* of farms (Coelli and Battese, 1996; Wilson et al., 1998). These results are not new. Kalirajan and Shand (1985) and Stefanou and Saxena (1988) concluded that there was a positive effect of farming experience on farm productivity. Mathijs and Vranken (2000) and Munroe (2001) considered age as a proxy for farming experience and found a positive relationship with *TE* in samples of Hungarian and Polish crop farms, but a negative effect in Bulgarian crop farms. Amaza and Maurice (2005) also found similar results for rice producing farms in Nigeria. These results were also confirmed in Ajibefun et al. (2006).

Researchers have tried to see whether there is an influence of farmer's education on efficiency levels. Educated farmers were well aware of ways of obtaining new information, especially with regards to prices and new technologies. So far, however, mixed results were obtained.

Ali and Flinn (1989) investigated the role of education in Pakistan on profit efficiency levels and found significant positive results. Findings of Ali and Flinn were confirmed in Seyoum et al. (1998) in China, and Young and Deng (1999) in Ethiopia. Wadud and White (2000) in Bangladesh, Battese and Coelli (1995) in India, and Llewelyn and Williams (1996) in Indonesia, could not find any significant results. Lockheed et al. (1980) emphasized that the influence of the farm education variable changed, depending on whether modernized or traditional methods of cultivation were utilized in crop production. It was also quite possible that educated farmers might be involved in off-farm activities fairly regularly, which might reduce production efficiency. Mathijs and Vranken (2000) also included education in their analysis and found a positive connection between education and *TE*, in the case of Hungary. Sotnikov (1998) illustrated that a degree in agriculture for Russian farmers did not increase the farm managers' ability to use resources efficiently.

Another important policy variable which influences production efficiency is institutional credit. Easy access to credit helps farmers increase *TE* by purchasing the necessary inputs on time. Credit, therefore, can assist farmers to increase *TE*, while credit constraints decrease the efficiency of farmers by limiting the adoption of high-yielding varieties and the acquisition of information needed for increased productivity. This was proven in several studies in the efficiency literature.

Abdulai and Eberlin (2001) investigated the bean and maize producing farmers' *TE* in Nicaragua and found that formal credit increased production efficiency. However, Parry and Carter (1989) mentioned that if credit was considered savings, then it had no influence on production efficiency. Ahmad et al. (2002) also emphasized that credit had to be offered in advantageous terms; only then would it reduce farm inefficiencies. Alemu et al. (2009) discouraged the use of agricultural credit for consumption. They also found that access to credit reduced farm inefficiencies in Ethiopia.

Atis (2006) mentioned that agricultural credit could also be provided for conservation practices which, in turn, would increase the *TE* of cotton producing farms in Turkey. Binam et al. (2004) emphasized that farmers might not have ready cash in the cropping season, and thus, access to credit might increase farmers' production efficiency.

2.1.5 Economic Efficiency and the Frontier

As mentioned previously, *EE* describes the overall efficiency and consists of *AE* and *TE*. The policy inferences of *EE* infuse both the micro- and the macroeconomic level (Lau and Yotopoulos, 1971). Extensive empirical research was conducted to examine the *EE* of crop producing farms in the developing country literature. Studies reporting *AE* and *EE* illustrated varying scores of efficiency indicators.

Huang et al. (1986) adopted a stochastic profit function approach to investigate the *EE* of small and large farms in two States in India. The variability of farm effects was highly significant and individual farm economic efficiencies tended to be greater for large farms than small farms (the average economic efficiencies being 0.84 and 0.80 for large and small farms, respectively). Ali and Flinn (1989) utilized the profit frontier model and found the *EE* score of 0.69 in the case of Basmati rice producers in Punjab.

Evenson (1993) contributed to the productivity literature in developing country agriculture by quantifying the level of efficiency for a sample of peasant farmers from Eastern Paraguay. He found a mean *EE* of 40.1% for cotton and 52.3% for cassava. In the case of Dominican peasant farmers, Bravo Ureta and Pinheiro (1997) reported *AE* and *EE* scores of 0.44 and 0.31, respectively. Based on their results, they recommended substantial cost decreases with the given technology. Ogundari and Ojo (2007) reported *AE* and *EE* scores of 0.872 and 0.684, respectively, for Nigerian small-holder croppers. Osborne and Trueblood (2006) found that the overutilization of fuel was the largest source of *AI* in Russian corporate farms.

In recent years, directional distance functions became popular in the estimation of *EE* in different fields as an extension of the data envelopment non-parametric methods. For example, Färe et al. (2009) used the directional distance function to estimate the efficiency of salmon farming. Picazo-Tadeo and Reig-Martínez (2005) analyzed firm performance by considering the influence of environmental regulations on firm operations. Bellenger and Herlihy (2009) decomposed the environmental index. Costa et al. (2010) measured the efficiency of animal health control. Singbo and Lansink (2010) measured the profit inefficiency of different farming systems in Benin. One of the important contributions of this methodology is the derivation of shadow prices for market and non-market inputs.

2.2 REVIEW OF THE THEORETICAL CONCERNS IN EFFICIENCY ESTIMATIONS

This section draws attention to a number of essential weaknesses of current efficiency estimation techniques, when parametric and non-parametric approaches are followed. While agricultural producers' resource use efficiency is an important topic for policy-makers and researcher alike, the methodological deficiencies will leave most empirical findings biased. Therefore, closer consideration in the empirical work is required. This section is divided into three separate parts. In the first part, existing problems with estimations of a *SFM* are discussed in detail. In the second part, a drawback of the two stage traditional *DEA* methodology is debated and the significance of bootstrapping is emphasized. In the third part, an advantage of employing the directional distance function is shown.

2.2.1 Consistency of Stochastic Frontier Production Models

The *SFM* is commonly used in agricultural and production economics fields to estimate efficiency levels and factors determining efficiency differentials. However, a majority of the studies did not incorporate the theoretical properties specified in microeconomic theory (Sauer et al., 2006). The key motive for not adopting certain theoretical properties is in the complexity of incorporating the basic microeconomic assumptions in econometric models. It is important to note that this leads to some biased results. In the empirical work, the robustness and practicality of the results deeply depend on precisely estimated efficiency levels. Imposing certain constraints in the frontier models has its certain advantages and makes frontier models attractive in terms of robustness.

Estimating models with the imposition of non-linear constraints on the parameters are as old as the literature on flexible functional forms (Wolff et al., 2010). They have been utilized in the empirical microeconomic non-frontier models for the last 30 years. Gallant and Golub (1984) directly imposed inequality by restricting the eigenvalues of the Hessian matrix with respect to prices. Lau and Wu (1987) and Diewert and Wales (1987) utilized the Cholestky decomposition of the Hessian to impose inequality constraints. More recent work emphasized a non-classical approach implemented by Chalfant et al. (1991), Koop et al. (1994), and Wolff et al. (2010) who used Bayesian methods to impose certain restrictions.

Microeconomic theory assumes that production functions increase monotonically in all factors of production. It is easy to execute this linear inequality constraint by employing a linear programming optimization model. However, it is challenging to impose it when utilizing conventional econometric methods.

The quasiconcavity assumption, in addition to the monotonicity assumption, requires a convex input set. It has to be imposed at each data point. It is only possible to conduct it in non-linear programming. It is very cumbersome to incorporate it in the traditional econometric techniques.

Henningsen and Henning (2009) argued that non-negative marginal products (*MP*) at each evaluation point do not make a model fully theoretically consistent. One reason is that there might be non-monotonic intervals between the data points over a given sample. These non-monotonic intervals misrepresent the efficiency results, endogenous in frontier models. This is demonstrated in Figure 2-1, where we see that Farm A is efficient and Farm B is inefficient, according to their location in the frontier. We do notice, however, that Farm B utilizes more inputs than Farm A and produces the same output as

Farm A. This leads to bias efficiency results and does not correspond to theoretical properties (e.g., monotonicity). We also notice that there are some non-monotonic intervals between the (*a*) and (*b*) data points.

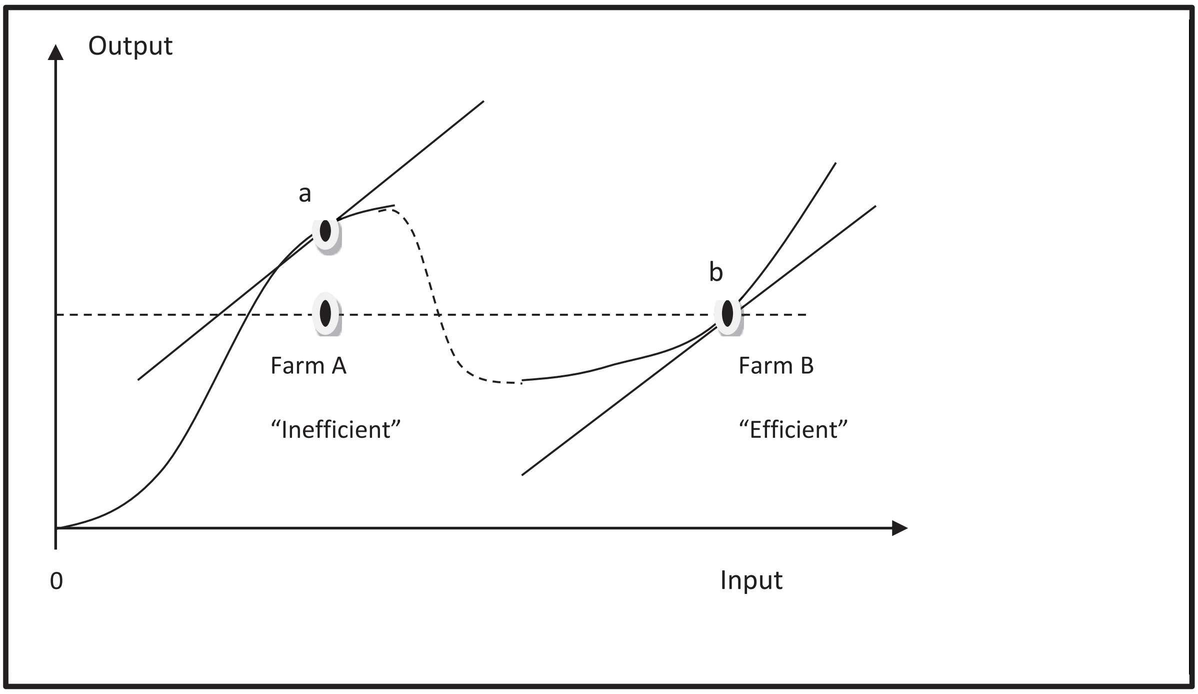

Figure 2-1: Demonstration of the Non-Monotonic Frontier

Source: Adapted from Henningsen & Henning (2009), with kind permission from Springer Science and Business Media.

Only a small number of empirical studies considered assumptions in microeconomics and developed theoretically consistent models. Kumbhakar (1989) Christopoulos and Tsionas (2001) and Sauer and Frohberg (2007) used a symmetrically generalized McFadden (*SGM*) cost function. It does account for input-specific inefficiencies using dummy variables. However, it is not based on the traditional frontier model. O'Donnell (2002) and O'Donnell and Coelli (2005) used the Bayesian method (e.g., *MCMC*) to impose restrictions on frontier models. This is an ideal approach, but it is empirically very laborious. Bokusheva and Hockmann (2006) employed the restricted maximum likelihood (*ML*), but only imposed constraints locally at the sample mean. Most other studies made use of simple models without introducing any constraints. Henningsen and Henning (2009) suggested a better way of dealing with this problem. They used optimization and econometric models jointly and imposed monotonicity, both locally, at a given evaluation point, and regionally, at a connected region of data points. Chapter Five applies the three step methodology offered by Henningsen and Henning (2009) in the case of cotton producing farms in Uzbekistan and estimates a theoretically robust and consistent *SFM*.

2.2.2 The Conventional Two-Step Data Envelopment Analysis

Wadud and White (2000), Coelli et al. (2002) and Chavas and Bromley (2005) examined the efficiency differentials among crop producing farms. They concurrently attempted to investigate causes of variations in the efficiency results. A frequently utilized methodology involves the incorporation of regression models in the *DEA* in the second stage. This is called the two stage approach, as the *DEA* is used to calculate efficiency scores in the first step. These scores are then used as a dependent variable in the second stage.

Simar and Wilson (2007) presented an extended literature review that used two-stage *DEA* methods to measure efficiency with a different set of data. They emphasized that efficiency scores are serially correlated. They stated that the two-stage practice does not take into account the properties of the *DEA* estimator, shedding distrust on the interpretation of exogenous variables, which explains efficiency differentials. As such a typical inference, the procedures that are utilized in the traditional two-step *DEA* are statistically unacceptable. As demonstrated by Simar and Wilson (2007), biased results are achieved in any two-step procedure, if only the point estimate of the efficiency value is utilized. In the output orientation approach, *DEA* efficiency scores are biased toward the score of one.

In order to analyze the *DEA* estimator's property, a data generating process (DGP) is identified as necessary for model selection. Simar (1996) and Simar and Wilson (1998) elaborate on a range of assumptions necessary for model selection. The *DGP* that authors illustrate is suitable for the two-stage procedure, because it censors the dependent variable. They bootstrap the entire model to approximate the asymptotic distribution and obtain consistent efficiency scores. Up to now, this is the only likely tactic available to assess the inference around the *DEA* efficiency results. This will help to reasonably examine the effect of different factors on efficiency scores in the second stage. It is worth noting that Simar and Wilson (2007) provided a double bootstrapping method and suggested not using the naive bootstrapping method offered in traditional statistical packages. These statistical packages are criticized by Simar and Wilson (1999), Simar and Wilson (2000a,2000b) and Kneip et al. (2003). Chapter 6 makes use of this non-parametric approach and double bootstrapping the *TE* scores in the example of wheat, potato and melon growing farms.

2.2.3 Directional Measurement of Economic Inefficiency

Several non-radial efficiency indices are offered in the theoretical literature as an alternative to the traditional radial index. In the early 1990s, a non-radial estimation gained a lot of attention with the work of Luenberger (1992,1995), who defined the benefit and shortage functions in consumer theory as novel technology representations (Färe and Primont, 2006). Inspired by Luenberger's work, Chambers et al. (1996) utilized it in production theory. It became known as a directional distance function with input and output orientation. As correctly stated and emphasized by Färe and Primont (2006), these can be considered additive substitutes for Shephard's radial approach and have been very popular over the last 40 years.

While the theory behind the directional distance functions is described in Chapter 3, it is worth mentioning a few points here which illustrate the important difference of this method from traditional ones, as well as the one offered by Tone (2002). In the *DEA* framework, for instance, Tone (2002) illustrates the paradox when it comes to measuring *EE* and describes it in detail. The author states that if different prices are given two different farms, then the farms with the larger costs are thought as efficient farms. The directional distance function, which has an additive structure, rather than multiplicative, avoids this sort of problem. Furthermore, since the last empirical chapter is concerned with the *EE* of inputs, the radial approach only provides one index for all inputs. Hence, it does not permit identifying as to which inputs are distorted the most. Duality between the *DIDF* and the cost function permits an additive decomposition of cost inefficiency or the overall *EI* of each used input. As can be seen, employing the directional distance function is a necessity, rather than another choice for an efficiency measurement.

2.3 RESEARCH GAPS AND THE OBJECTIVES OF THE STUDY

Given the various agricultural programs implemented to enhance farmers' efficiency, it is essential to quantitatively measure the current level of, and determinants of, efficiency. This is complex, because decision-making in crop production depends on a number of unpredicted aspects. It is, therefore, much easier to conduct a crop specific efficiency analysis. It provides clear insight to properly comprehend the plot level of decision-making in the production of a particular crop. This chapter has drawn attention to a number of significant matters related to the frontier efficiency analysis, as it is associated with policy analysis for sustainable agricultural development. The literature review revealed several parametric and non-parametric empirical models which have been integrated in quite a few stylized factors in explaining different efficiency levels. No efficiency study was found that was carried out under the conditions of institutional rigidity in a transitional country. This study will be a good addition to fill in the gap on that perspective. It makes it interesting to see how policy variables, described in different studies, will change under the conditions of the quota system. In terms of theoretical methodology, an area still lacking in efficiency models, is that most of the studies ignore the basic microeconomic assumptions.

The literature review pointed out the disadvantages of a two staged *DEA* estimation, which was used intensively in non-parametric models. It is also found that deriving the *AE* using traditional methods in the regulated input and output markets (in the example of the public sector) may provide inconsistent results. And all in all, there is no recorded research on crop specific efficiency estimations in the case of *CA* countries in the empirical literature. Therefore, this research is conceptually based on filling the gap with regard to methodology and empirical application to the case of crop producing farms in Uzbekistan. It contributes to the existing frontier efficiency literature by integrating basic microeconomic concepts into an econometric model. The research further contributes by integrating the semi-parametric approach into *DEA* with the purpose of achieving robust results.

This study also includes other important policy indicators not utilized as a possible explanation to efficiency differentials. A recent methodological development, the directional duality theory, is applied to measure the *AE* and *EE* of crop producing farms and to derive related shadow prices of resource endowments. As it was earlier specified, the overall aim of the thesis was to examine the *TE* and *AE* of crop producing farms in Uzbekistan. However, in light of the previous discussions, this study has refined the objectives, which consist of five important steps:

- Provide an overview of the crop production system and institutional environment, as well as consequences of agricultural reform policies;

- Estimate *TE* of cotton producing farms in the Khorezm and Fergana provinces of Uzbekistan by developing theoretically consistent stochastic frontier model;

- Estimate and compare the *TE* and *SE* of wheat, potato and H-W melon growing farms employing a semi-parametric approach and determine factors causing variation in efficiency levels;

- Evaluate *EE* in input spending using the directional input distance function for vegetable producing farms and derive shadow prices of Land and Labor in the existence of production inefficiencies;