

DISSERTATION PROPOSAL WORKSHOP COVER PAGE

STUDENT NAME: **FRANTIŠEK BRÁZDIK**

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TENTATIVE CHAIR NAME: **MICHAL KEJAK**

I CONFIRM THAT I HAVE READ THE PROPOSAL AND FIND IT SUITABLE FOR THESIS PROPOSAL DEFENCE.

SIGNATURE: _____

MARK CONTENT PARTS

- THE GENERAL SUBJECT OF THE PROPOSED DISSERTATION
- THE PRINCIPAL BODY OF SOURCE MATERIALS TO BE USED
- A SURVEY OF LITERATURE RELEVANT TO THE CHOSEN TOPIC
- THE TECHNIQUES, METHODS AND DATA TO BE USED
- A LIST OF FOUR (4) PROPOSED DISSERTATION COMMITTEE MEMBERS
- IF DEEMED SUITABLE, WHEN, WHERE AND WHY HE OR SHE WOULD LIKE TO PARTICIPATE IN A STUDY MOBILITY ABROAD (MOST TYPICALLY IN WESTERN EUROPE OR NORTH AMERICA)

Essays on Shocks in Economy
Dissertation proposal

František Brázdík*

Abstract

This paper proposes my future research on monetary policy effects for European countries that will access the European Monetary Union in the close future. I propose to examine monetary policies effects on the volatility of output and inflation during the process of common currency adoption by the Central European transition countries. The further research focuses on incorporation of the Harrod-Balassa-Samuelson effect into the model of two open economy countries with asymmetric shocks.

The second part of the proposal presents my contribution to theoretical development of models for Stochastic Data Envelopment Analysis. I elaborate on the orientation of the stochastic models and their linearization.

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1 Introduction

I propose research in two different fields of economic research: monetary economics of European Union accession countries and productivity analysis. These two different fields of my research proposal are linked together by the presence and role of shocks in the economic environment.

In the second section, that is devoted to macroeconomic stability I am proposing research on the volatility properties of output and inflation series during the country accession to monetary union in the open economy environment with asymmetric shocks. The knowledge of volatility properties and its policy implications is important for conducting monetary authority policy. Further, I propose research on international transmission of country specific shocks in environment with implemented production of tradable and non-tradable goods to introduce deviations from power purchasing parity.

The third proposal section presents my motivation for the productivity analysis research. In the presented work, I develop non-parametric models for productivity frontier search in noisy environment. This work is presented in Appendix section. In the last three proposal sections, administrative issues related to future work on my dissertation, dissertation committee, a research time line and mobility proposal are presented.

2 Monetary regimes and Economic stability

Decades ago, western European countries started their integration into common political and economic environment by creating various treaties and organizations that peaked with the creation of the European Union (EU). Nowadays, past enemies to death are joining their political and economic forces in EU to create wealth and powerful multinational state. Due to the economic and political power of the EU in Europe, the transition countries of Central and Eastern Europe want to join the EU that they believe, will deliver to their countries economic stability and a standard of living that is observable among the EU countries.

The EU accession treaty brought the first wave of accessing countries under obligation to enter the European Monetary Union (EMU) after they fulfill the conditions of Maastricht treaty. For accessing countries, it means that in the future they will abandon their national currencies, join the Euro currency area and will transfer their management of monetary policy to the European Central Bank (ECB). At the beginning of EMU accession process national monetary authorities conduct its monetary policies independent of ECB, then the national currency is pegged to common currency and at the

final accession stage the national currencies are first replaced by Euro banknotes and coins, and then cease to be legal tender.

May 1st, 2004, marks a new milestone in the history of 10 European countries¹ that will enter the European Union and start to drive monetary policies towards common currency adoption. Although, at this day, the EU's population will rise by as much as 20% to over 450 million in 2004, European Union's GDP will grow by no more than 5%.² This documents large differences between the EU members and EU accession countries that will expose EMU to asymmetric economic shocks.

Therefore, macroeconomists have to examine if EMU accession and common currency adoption will deliver to the accessing countries promised economic advantages like: transaction cost reduction, dismissal or reduction of exchange rate and monetary fluctuations. The research on currency unionization before the creation of the EMU was focused on examination of degree of country economic integration because as Bayoumi and Eichengreen (1997), Mundell (1961) and McKinnon (1963) conclude higher degree of integration increases the readiness for common currency area membership.³ Recently, the research interest is shifting to examination of monetary unionization effects for countries involved in the monetary unionization.

I would like to contribute to research on the European currency areas, because it receives relatively less attention than the research on the American currency areas. Specifically, I would like to examine the macroeconomic stability of Central European countries, in terms of macroeconomic series volatility, during their EMU accession process. My research interest in the macroeconomic stability is motivated by the lack of studies that analyze the spread of country specific shocks effects between the EMU members and accession countries. The knowledge of international effects of country specific shocks under alternative monetary regimes matters for the ECB and the accessing countries' monetary authorities when conducting their monetary policies that drive them toward the adoption of common currency. The application for Central European countries is the main research contribution because as Collard and Dellas (2002) state the present business cycles literature offers insufficient information on actual economies performance under various monetary regimes.

¹Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovak Republic, Slovenia

²According to the EU's web page: http://www.ecdel.org.au/eu_guide/enlargement/.

³See literature review for more information on currency areas where works by Bayoumi and Eichengreen (1997), Mundell (1961) and McKinnon (1963) are reviewed.

My further research, will introduce more specific focus on macroeconomic stability during the second stage of accession process when a country accessing currency union has to maintain fixed exchange rate with the union currency. The research will be conducted in within advanced environment where the international productivity differences in production of tradable and non-tradable goods have effects on real exchange rate between the EMU members and accession countries. This further research will contribute to identification of monetary policy maker's problems because most of the studies just sketch the problems that can occur during monetary union accession when the business cycles of EMU accessing countries are not enough synchronized with business cycles of EMU countries.

The following subsection states and focuses my research questions. The second subsection briefly summarizes literature related to proposed research questions. The third subsection sketches the two open economy country framework originated by Obstfeld and Rogoff (1995) that will be extended for my research purposes. This methodology subsection presents the major features of two country model and proposes the research procedure. The data subsection describes sources that can provide data for proposed research.

2.1 Research questions

The first part of macroeconomic stability research will be focused on the Central European transition countries that will access to the EMU in the close future. The effects of various monetary policies, that drive accessing countries towards the EMU, on the volatility of output and inflation series will be examined. The case of Germany and France suggest unequal distribution of macroeconomic stabilization for these countries during accession to European Monetary Union, therefore I will ask if EMU accession will deliver ultimate macroeconomic stability to the group of accession countries or will these new EMU members face a tradeoff in their output and inflation series volatility? Subsequently, I call for identification of the main source of macroeconomic volatility in presence of the country specific shocks that are complicating monetary authority policy making process.

The second part of the proposed macroeconomic research focuses on the exchange rate properties during second stage of the EMU accession. Empirical works show that the deviations from purchasing power parity are present among CEECs. Works by Ballasa (1964) and Samuelson (1964) on international trade suggest that productivity differences between tradables and non-tradables are capable to explain the deviations from purchasing power

parity.⁴ The purchasing power parity deviations induce distortions to monetary authority policy when fixing the exchange rate, therefore I will incorporate the productivity differences into the model and I will ask what amount of macroeconomic stability in terms of macroeconomic series volatility will be in exchanged for required exchange rate stability. The valuation of these costs is important because the high costs of exchange rate stability can discourage the accessing country from entering the currency unification process. Also, the high costs of exchange rate stability may give the rationale for the skip of second stage of currency union accession process.

2.2 Literature review

Currency unionization is not such as new research topic as many people think because of present focus on Europe's unionization.⁵ The currency areas and their properties were described more than forty years ago by Mundell (1961) and McKinnon (1963). These two papers usually occur as references in the majority of works devoted to currency areas. As Mundell (1961) suggested there was a lack of systematic attempts to define characteristics of the optimum currency area (OCA). Therefore Mundell (1961) searched for economic properties of the OCA and he described shock transmission under various exchange rate systems. Mundell (1961) advises that countries with highly correlated business cycles should decide to implement an exchange rate peg or common currency. The idea of currency area optimality was further developed by McKinnon (1963) when he focused on resource mobility. In spite of these papers influence, the research interest should be focused on the newer empirical works that are trying to operationalize the currency areas theory.

Bayoumi and Eichengreen (1997) operationalize Mundell's OCAs theory by examining bilateral trade among the Western European countries. Bayoumi and Eichengreen (1997) used the standard deviation of the change in the logarithm of the end-year exchange rate of national currency with German Mark as the country's index of monetary union readiness. A low index value means high synchronization of the country's business cycle with the German one. The authors forecasted index values and according to these readiness index values, they split the country sample into countries that are

⁴The Harrod-Balassa-Samuelson effect is used to explain international deviations from purchasing power parity. The Harrod-Balassa-Samuelson effect is based on the differences in productivity of tradable and nontradable goods. It is observed that countries with higher production of tradables relatively to nontradables have higher price levels.

⁵Rose and Engel (2000) identified 60 countries that are member of a currency union.

ready for monetary union, converging to a state of entry readiness and those that do not exhibit convergence in the readiness index. Remarkably, France's readiness index value reveals a low level of synchronization, this supports the view that the French desire for monetary unionization is rather political than economic consideration.

In contrast to Bayoumi and Eichengreen (1997), the paper by Frankel and Rose (1996) relates country's extent of international trade and cross-country business cycle correlation for 22 countries to create criteria for currency union member.⁶ Frankel and Rose (1996) based on "Lucas critique" point out that even a poor candidate, based on historical data, may enter the currency union, because of the union's influence on the candidate's international trade. Their logic behind this point explains that accession into monetary union can deliver impulses for trade international expansion therefore the accessing country may satisfy the criteria for currency union ex ante.

Fidrmuc and Korhonen (2001) follow the work by Frankel and Rose (1996) to test if the Central and Eastern European countries (CEECs) belong to the same OCA as the current EMU members. The framework of aggregate demand and supply model is used for reconstruction of the country specific shocks. The VAR model of GNP and unemployment series is applied to recover the supply and demand shocks from data. Fidrmuc and Korhonen (2001) examined the correlation of national shocks with the EU area aggregate shocks and they conclude that the group of the CEECs is less homogeneous than the group of the EU countries in terms of shock correlation. This is the only one general empirical result about the CEECs in the paper. Regardless of different degrees of shocks correlations across accession countries, the increasing effort in integration can change the results over time and the CEECs' business cycles can become more homogenous.

The aforementioned empirical studies stressed the role of business cycles correlation, also I will employ real business cycles models of the international economy for my research. The following part of the literature review summarizes the work done up to date in the two country framework that I will use to answer my research questions. In the survey of open economy macroeconomics by Lane (2001), we can read that Obstfeld and Rogoff (1995) initiated a new wave of models and research in open macroeconomic fields by introducing their Redux model. The major feature of the Redux general equilibrium model are two countries interactions. The initial version of the Redux model set up two countries populated by a continuum of farmers with separable money in the utility function. Each farmer-consumer makes his de-

⁶According to the gravity model by Rose (1999) countries with common currency trade three times more than the same countries without a common currency.

cisions on labor supply and consumption in a environment without shocks. Labor is the only production factor in the farmer-producer production function. The farmer does not face any trade barriers for his goods but his labor is immobile. Prices are set one period in advance to induce nominal price rigidities. This goods price setting mechanism is the only source of nominal rigidities in the model. Obsfeld and Rogoff (1995) used this framework to analyze welfare effects of unanticipated shock effects in the steady state in the linearized form of the model. Since 1995, the Redux model has been extended in many different ways, e.g., shocks were added, sticky prices were replaced by price staggering and capital was introduced.⁷

The use of all of these additional features leads to the creation of very complex models that can quite well reproduce the behavior of real economies. The two country general equilibrium model framework became so popular that almost all present research on exchange rate regimes is conducted using it. Dellas (2003b) used the two country model to analyze the welfare effects of monetary policies in situations when the monetary authority does not possess perfect information on current shocks. In the model by Dellas (2003b), countries are perfectly symmetric and there are no country specific shocks, so each country faces the same technology, money demand and government spending shock. The welfare analysis of six monetary policies (flexible and fixed exchange rate regimes with different Taylor rule targets) are conducted. Dellas (2003b) conclude that there are not significant welfare effects of the examined monetary policies and volatility effects should be taken into account.

Dellas (2003a) enriches the aforementioned two country framework by introducing capital (in form of perishable good) into the intermediate good production function. Dellas (2003a) compares six monetary policies (flexible or bilateral peg with targeting on interest rate, money supply and nominal wage) and again as in (Dellas 2003b) the welfare effects are found to be not significant, therefore the effects on volatility of output, employment and price level are calculated. The author considers as the best monetary policy one under which the costs of volatility in terms of steady state consumption are minimal. This criterion favors money supply targeting, but the choice of exchange rate regime is not so straightforward. To find the optimal exchange regime, Dellas (2003a) decomposed the series variance on shocks and showed that 90% of employment variation is driven by money demand shocks. This fact explains why money supply targeting rules successfully stabilize employment. The author identifies that the maximum stabilizing effect is reached

⁷Obsfeld and Rogoff (1996) present a detailed description of the derivation and Redux model properties.

under the fixed exchange rate regime.

The two previously mentioned open economy frameworks are derived from two equal size country version of neoclassical, exogenous growth model with money and government spending by Collard and Dellas (2002).⁸ In this complex model, the representative household decides on its money, bond holding, consumption and labor supply. The Cash-in-advance constraint is used when purchasing the consumption bundle and it is assumed that each country is specialized in the production of country specific internationally tradable good. Because the model is not distinguishing between internationally tradable and non-tradable goods the Harrod-Balassa-Samuelson effect is omitted. Firms in this model setting produce intermediate goods and the final domestic good that is consumed by domestic consumers. The agents in the Collard and Dellas (2002) model version are facing totaly 6 country specific shocks and one common supply shock. Country specific supply, fiscal and money shock are the source of asymmetries that complicate monetary authority policy making. Collard and Dellas (2002) used this rich model to estimate the effects of different stages of regimes used in transformation towards the common currency for Germany and France. Collard and Dellas (2002) concluded that Germany faced a trade off when the German output volatility was significantly increased during the exchange rate pegging period and even further under single currency and at the same time German inflation volatility was reduced.

2.3 Methodology

I will answer my research questions in the framework of the RBC cycles model used in the works by Dellas (2003a) and Collard and Dellas (2002) that are extensions of original model by Obsfeld and Rogoff (1995). As was mentioned in the literature review, this framework is a very fashionable approach for modelling international economics, because the qualitative implications are consistent with the existing empirical evidence. The two country framework with asymmetric shocks reproduces the main features of series that characterize the business cycles.

In each of the simulated countries 5 agents are present: representative household, intermediate and final good firms, government and monetary authority.⁹ Firstly, I will describe the agents' behavior in models by Dellas

⁸The description of the two open economy country framework is presented in the methodology section.

⁹Variables with the star index are for the foreign country. To distinguish home and foreign country goods subscripts H and F will be used. To distinguish households and

(2003b) and Dellas (2003a) and economy equilibrium will be defined. The general equilibrium description is followed by the description of the proposed research methodology.

Household's problem Each country is populated by an infinitely living representative household, that consumes final good and provides labor. Households in both countries can borrow and lend through internationally traded bonds. The home country representative household maximizes its lifetime utility:

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C(s^t), \frac{M(s^t)}{P_t}, l(s^t)) \quad (1)$$

subject to total time constraint:

$$l(s^t) + h(s^t) = 1 \quad (2)$$

and budget constraint:

$$\begin{aligned} \sum_{s^{t+1}} [P^b(s^{t+1} | s^t) B_H(s^{t+1}) + e(s^t) P^{b*}(s^{t+1} | s^t) B_H^*(s^{t+1})] + M(s^t) \leq \\ B(s^t) + e(s^t) B^*(s^t) + M(s^{t-1}) + N(s^t) + \\ + \Pi(s^t) + W(s^t) h(s^t) - P(s^t) C(s^t) - P_t \tau(s^t), \end{aligned} \quad (3)$$

where $C(s^t)$ is the home country household's consumption, $l(s^t)$ is leisure, the rest of the household's time $h(s^t)$ is labor supplied to firms. Household has to make its decision on consumption, labor, internationally traded home assets $B(s^{t+1})$ and foreign assets $B^*(s^t)$ that are available at prices in the home currency $P^b(s^{t+1} | s^t)$ and $e(s^t) P^{b*}(s^{t+1} | s^t)$, where $e(s^t)$ is exchange rate. It also decides on its money holdings of domestic currency $M(s^t)$. The domestic household's income consists of firm's profits $\Pi(s^t)$, income from bonds holdings $B(s^t) + e(s^t) B^*(s^t)$ and labor income $W(s^t) h(s^t)$. The household pays lump sum tax $\tau(s^t)$ denominated in composite good and it receives transfers $N(s^t)$ from monetary authority.

Intermediate goods firms Intermediate firms are renting household's labor $h(s^t)$ for the price of W_t to produce intermediate goods X_t according to the production function that is subject to technology shocks. Intermediate firms maximize their profits:

$$\pi_t^I = P_{X_t} X_t - W_t h_t, \quad (4)$$

firms superscripts H and F will be used.

subject to the total domestic good constraint $X_t = X_{Ht} + X_{Ft}$, where X_{Ht} is the amount of domestic intermediate good used for production of domestic final good and P_{Xt} is the domestic intermediate good price denominated in domestic currency.

Final good firms Final good firms are maximizing their profits according to:

$$\pi^F = P_t Y_t - P_{Xt} X_{Ht} - e_t P_{Xt}^* X_{Ht}^*. \quad (5)$$

The domestic final good Y_t is produced using home and foreign intermediate goods:

$$Y_t = [s^{1-\rho}(X_{Ht})^\rho + (1-s)^{1-\rho}(X_{Ht}^*)^\rho]^{\frac{1}{\rho}}, \quad (6)$$

where s is the weight of the home intermediate good in the domestic final good basket.

Government In each period, the domestic government consumes the domestic final good. The domestic government consumption is financed by lump-sum taxation:

$$P_t G_t = P_t \tau_t, \quad (7)$$

where G_t follow growth process that is subject to stationary AR(1) shock process.

Monetary authority The monetary authority policy choice is the proxy to various exchange rate arrangements simulation. The domestic monetary authority is setting the domestic money supply M_t and interest rate R_t in order to follow the prescribed goals by Taylor rule in the form:

$$R_t = k_y \hat{Y}_t + k_p \hat{P}_t,$$

where \hat{Y}_t, \hat{P}_t are deviations from targeted output and price. During the first stage, two different Taylor rules are present in the model because the national monetary authority is free to chose its target. In the second stage, the exchange rate peg is implemented by identifying the exchange rate as a function of state variables. Then the accessing monetary authority has to set such value of money growth that satisfy the prescribed exchange rate target. During the common currency period, both national monetary authorities are using the same Taylor rule that is mixture of independent Taylor rules.

Shocks and Rigidities To simulate real economies behavior various shocks and rigidities are introduced into the two country framework. Shocks will affect intermediate good production, household's money demand and government expenditures. All exogenous shocks follow autoregressive process:

$$\log(X_t) = \rho_X \log(X_{t-1}) + (1 - \rho_X) \log(X) + \epsilon_{Xt},$$

where $|\rho_X| < 1$, $\epsilon_X \sim N(0, \sigma_X)$ and for X shock specific index is substituted.

The intermediate production function is defined as:

$$X_t = A_t h_t,$$

where A_t introduces stationary exogenous technological shock to technology. This shock to technology is source of country specific supply shock. Shocks to money demand, with aforementioned structure will be introduced through the shock to weight of real money holdings in the household's utility function.

In this model, nominal rigidities are driven by staggered nominal wage contracts that are used to set nominal wages. Nominal wage contracts are set by à la Calvo mechanism.

General Equilibrium As in Dellas (2003b) and Dellas (2003a) I close the two open economy framework description with equilibrium definition.

Definition 1. An equilibrium of this economy is a sequence of prices

$$\{\bar{P}_t\}_{t=0}^{\infty} = \{W_t, P_t, P_{Xt}, P_t^b, R_t, e_t, W_t^*, P_t^*, P_{Xt}^*, P_t^{b*}, R_t^*\}_{t=0}^{\infty}$$

and sequence of quantities

$$\{\bar{Q}_t^H\}_{t=0}^{\infty} = \{C_t, l_t, B_{H,t+1}, B_{H,t+1}^*, M_{t+1}, C_t^*, l_t^*, B_{F,t+1}, B_{F,t+1}^*, M_{t+1}^*\}_{t=0}^{\infty}$$

and

$$\{\bar{Q}_t^F\}_{t=0}^{\infty} = \{h_t, Y_t, X_t, X_{Ht}, X_{Ht}^*, h_t^*, Y_t^*, X_t^*, X_{Ft}, X_{Ft}^*\}_{t=0}^{\infty}$$

such that:

1. given a sequence of prices $\{\bar{P}_t\}_{t=0}^{\infty}$ and sequence of shocks, $\{\bar{Q}_t^H\}_{t=0}^{\infty}$ is the solution to the representative household's problem
2. given a sequence of prices $\{\bar{P}_t\}_{t=0}^{\infty}$ and sequence of shocks, $\{\bar{Q}_t^F\}_{t=0}^{\infty}$ is the solution to the representative firm's problem

3. given a sequence of quantities $\{\bar{Q}_t^H, \bar{Q}_t^F\}_{t=0}^\infty$ clears the goods, money and capital markets.

$$\begin{aligned}
X_t &= X_{Ht} + X_{Ft}, \\
X_t^* &= X_{Ht}^* + X_{Ft}^*, \\
Y_t &= C_t + G_t, \\
Y_t^* &= C_t^* + G_t^*, \\
B_{H,t+1} &= -B_{F,t+1}^*, \\
B_{H,t+1}^* &= -B_{F,t+1}.
\end{aligned} \tag{8}$$

4. Nominal wages are set using labor contracts, such that nominal wage clears the labor market.
5. Monetary policy is conducted according to the prescribed procedure.

Research methodology There will be three different models representing the three different international monetary arrangements associated with the stages of currency union accession. I assume that the monetary authorities are following a sort of Taylor rule because the Taylor rule explains observed interest rate paths fairly enough.

As was mentioned above, there are two independent monetary policies in the first unionization stage. In the first model, these independent monetary policies will be modelled by different parameter choices for the Taylor rule. In the second model, the EMU representing economy will follow the same rule as in the first model, but the accessing country must find and set such domestic money growth that will keep the exchange rate fixed. In the model of currency union monetary authorities use identical monetary policy rules. These rules are a proportional mixture of the independent rules, that were used to simulate the period of independent monetary authorities.

The complete solution of the models requires a lot of econometric effort to estimate the models' parameters, because a lack of empirical studies on macroeconomic parameters for Central European transition countries is present. Particular effort should be devoted to estimating the elasticity of substitution between foreign and domestic goods, because this parameter is crucial for model performance in matching the qualitative properties of business cycles. The structure of government expenditure shocks will be estimated from government consumption series filtered for deterministic trend and coefficients of the Taylor rule will be estimated from series of output gaps, inflation and interest rates. The supply shock structure will be recovered from output and employment series.

These three models representing different international monetary arrangements will be log-linearized around the deterministic steady state as in Collard and Dellas (2002). Then the numerical methods will be employed to solve linearized dynamic systems.

After the models are solved, impulse responses will be calculated. The values of responses will reveal information on asymmetry and extent of output responses to shock under examined monetary regimes. These models will be used to predict standard deviations of the input and output series. The characteristics of macroeconomic volatility will be used to compare the macroeconomic stability under the above described monetary regimes.

In further research, I will introduce tradable and non-tradable goods into the model to incorporate the Harrod-Balassa-Samuelson effect in the models. Because the Harrod-Balassa-Samuelson effect originates from different productiveness in tradable and non-tradable goods sector additional technology shock processes for non-tradable good production sectors are constructed. The country differences in productivity of the non-tradable good sector will drive the deviations from purchasing power parity in the model. Due to additional good introduction, the household will have to make additional decisions on domestic non-tradable good consumption. The non-tradable goods producers will face the profit maximization problems. For exchange rate analysis, the consumption based price index will be derived. This price index represents the minimum expenditure to purchase a unit of composite good that consist of the foreign and domestic tradable good and domestic non-tradable good.

To solve the advanced version of the model additional parameter estimations will be needed. Size of the tradable and non-tradable goods sector will be estimated according to standard classifications of goods, this means that goods like construction and services will be considered as non-tradable goods.

As in the first part of my research each of the examined monetary regime will be modelled by individual model. After I solve the models the analysis of the macroeconomic series properties will be conducted. By comparing the stability characteristics (in terms of volatility) of the independent monetary regime and common currency regime with the fixed exchange rate regime, I will identify the costs of the second stage of monetary unionization.

The performance of the all models will be evaluated by testing the results for robustness. Specifically, result robustness with respect to changes in elasticity parameters and contract length will be examined to evaluate the models' fit.

2.4 Data

The data needed for the model's calibration should be available from international statistical databases. The works and papers mentioned above usually use data provided by global organizations that focus their research on European economies. I expect the European Central Bank is capable of providing all the required data for my research because it supports the research on the EU and EMU enlargement. The other useful data bases are International Monetary Statistics and Source OECD provided by IMF and OECD and accessible for CERGE-EI researchers in CERGE-EI library.

3 Stochastic DEA

This proposal section presents the motivation for my research in the productivity analysis field and contains my contribution to the theoretical development of the Stochastic Data Envelopment Analysis (SDEA) models. This motivation demonstrates the research possibilities on the production efficiency research by two recent papers (Afonso, Schuknecht and Tanzi 2003, Osiewalski, Koop and Steel 1997) and more specific motivation is part of the work presented in appendix section.

Data Envelopment Analysis (DEA) offers an interesting alternative to parametric approach to estimating the production function and production function frontier. The knowledge of the production frontiers is useful in search for the most efficient allocation of inputs and outputs. DEA search for the production possibility frontier is based on properties that are imposed on the production possibility set. Using the knowledge of production possibility frontier we can easily construct an estimate of production function.

Afonso et al. (2003) uses the DEA methodology (although they do not mention it explicitly in the paper, but they refer to non-parametric framework) to find the frontier of public sector efficiency. The authors examine the performance and the efficiency of the public sectors of 23 industrialized OECD countries. Afonso et al. (2003) used public sector performance indexes (consists of socio-economic indicators like health, education, public infrastructure, GDP per capita and GDP growth) as public sector output and the public sector expenditures (as fraction of GDP) were used as inputs for public sector production function. Afonso et al. (2003) conclude that the small governments tend to show higher efficiency score in use of public expenditures and they calculated that EU countries are using 27% more public spending than the "most efficient" countries (US, Japan and Luxembourg) with similar public sector performance indicators.

Estimating the productivity gap between transition countries and developed countries was the impulse for the paper by Osiewalski et al. (1997). The authors applied the production frontier idea in a macroeconomic context to search for “world production frontier”. The examined 22 countries are producers of output (measured as GDP) given inputs (e.g. capital and labor, measured as capital stock per worker and total employment). Authors improved the methodology proposed in their previous works to break down output growth into technical, efficiency and input changes. The examination growth patterns for period of 1980-1990 shows the low efficiency scores for Poland. Thus Osiewalski et al. (1997) explain recent years Poland’s fast growth by possibility of increasing output through efficiency change alone.

In the Appendix section, I present my theoretical contribution to Stochastic Data Envelopment Analysis, that makes DEA models capable of handling errors in data. The ability to handle errors makes analysis results robust. The usefulness of SDEA methodology will be demonstrated by application in productivity research in agricultural sector and for this purpose I developed tool for solving SDEA models.

4 Dissertation Committee

I propose following structure of my dissertation committee:

Chair: Michal Kejak

Members: Byeongju Jeong
Jose de J. Noguera

5 Research Time Plan

Month	Year	Activity
December	2003	SDEA paper final version
January	2004	Initiate macroeconomic stability research
March	2004	First model solution and data collection
June	2004	First macroeconomic paper draft
September	2004	First paper and model development
December	2004	Second model solution and data collection
April	2005	Second macroeconomic paper draft
June	2005	Second paper and model development
August	2005	Final versions of macroeconomic papers
September	2005	Dissertation defence

6 Mobility

The researchers who contributed to the development of the two country framework used for my macroeconomic research are currently employed at the Department of Economics at the Faculty of Social Sciences of the University of Bern, Switzerland. The staff of the Department of Economics is focusing their research on the EU integration effects, therefore I find it useful to meet them and consult my research results. Also, the research consultations should help me keep up to date with the newest research devoted to monetary unionization in Europe.

For the productivity analysis part of my work, I would like to consult with researchers employed at the Warwick Business School, The University of Warwick in the United Kingdom. Research at Warwick is devoted to specific DEA applications in private and public sector organizations. Researchers at Warwick are well known for their focus on DEA methodology of productivity research. As their web page informs, a number of MSc/MBA projects on DEA are undertaken each year as a part of this research approach whilst a number of PhD projects are currently under progress.

A Stochastic DEA paper

Title: Stochastic DEA models:
Creation, Orientation, Linearization and Solution

Abstract

In this paper I will construct chance constrained problems for DEA analysis. The goal is to construct oriented DEA models that account for noise in the analyzed data. The noise in the form of single factor symmetric error is incorporated into the model and I create the corresponding stochastic programming problem. The stochastic models are transformed into deterministic equivalents and then linearized. The linearized form allows me to construct a solver that is capable of solving this problem by interior point methods for linear programming problems and utilize their advantages in comparison with simplex methods solvers.

A.1 Introduction

Data envelopment analysis (DEA) involves an alternative principle for extracting information about a population of observations, so called decision making units (DMUs), that are described by the same quantitative characteristics. Each DMU is assumed to have used the same set of inputs to produce the same set of outputs, but it uses them in various amounts.

DEA and Stochastic Frontier Analysis (SFA) models have been developed for the purpose of production frontier search. DEA involves an alternative approach to SFA for information extraction from the population observations of decision processes. DEA approach is considered as a nonparametric approach to estimating the production frontier, because the DEA approach does not require specification of the production function form relating inputs to outputs. DMUs are directly compared against a peer or combination of peers. In contrast to parametric approaches for information extraction, objective of the DEA is to calculate a linear (piecewise linear) frontier determined by set of Pareto-efficient DMUs. This frontier is used to calculate the relative (among the elements of DMU set) measure of technical efficiency.

The measurement of input and output values is subject of errors and noise. Also, the analyzed production sector may face different shocks. The noise in data usually leads to mistakes in production frontier specification and efficiency scores. The dilemma of model choice depends on the trade off between the minimal specification that favors DEA and handling of stochastic error in measuring DMU efficiency that favors SFA. To compete with SFA in error handling, the stochastic data envelopment analysis (SDEA) approach

was developed by considering the value of inputs and outputs as random variables in SDEA approach.

Present SDEA approaches lead to chance constrained optimization problems that consume extensive amount of computational time for the optimal solution search even for the simple stochastic models. I continue the chance constrained programming tradition in which random disturbances are incorporated in inputs and outputs on the assumption that the probabilistic distribution of disturbances is known. My contribution consist of creation of input and oriented stochastic models and by simplification of error structure I derived the linearized model forms. The linearization allows me to construct a solver that is capable of solving large size models using significantly reduced amount of computational time in comparison with solving chance constrained optimization problems.

The following section reviews the literature on DEA and SDEA. In the third section usual notation is introduced. The fourth section defines production possibility set properties that will be used to construct stochastic model in the fifth section. Then the model's error structure is presented and incorporated in the model, the derivation of linearized model is described. This is followed by introduction of efficiency measure that is used to construct the oriented models that are linearized. The last section proposes numerical methods that can be used to solve such models and introduces my solver that can be used to solve these models when applying these models for specific analysis.

A.2 Literature review

As the introduction to the Charnes, Cooper, Lewin and Seiford (1994) explain, the story of data envelopment analysis begins with Edwardo Rhodes's dissertation, which was the basis for the later published paper by Charnes, Cooper and Rhodes (1978). In his dissertation, E. Rhodes analyzes the educational program for disadvantaged students in the USA. He compared the performance of students from school that were participating and not participating in the program. The performance was recorded in terms of inputs and outputs, e.g.: "Increased self-esteem" (measured by psychology tests) as output and the time spent by mother reading with child as input. The following work on efficiency evaluation of multiple inputs and outputs technology led to the paper by Charnes et al. (1978), where the CCR model for DEA was formulated.

The presented CCR model is capable of handling only the technology with constant returns to scale. This fact is reflected in the shape of production frontier when the frontier is formed by a single ray. The DMU is evaluated

as efficient if it is an element of production possibility frontier. To handle the variable returns to scale the CCR model was extended by Banker, Charnes and Cooper (1984). Since the BCC model's frontier is a piecewise linear set, Banker et al. (1984) defined weak efficiency (weak efficient DMU has nonzero slacks) and efficiency (efficient DMU has zero slacks). Further, only the efficient DMUs are elements of the estimated production possibility set frontier in framework of BCC model.

Since 1978, over 1000 articles, books and dissertation have been published¹⁰ and DEA theory and applications have rapidly extended. As many applications suggest, DEA can be a powerful tool when used wisely. Two capabilities that make DEA powerful tool are capability of handling multiple inputs and outputs models and that these inputs and outputs can have different measurement units. For example, input could be in units of lives saved or it could be in units of dollars without requiring an a priori tradeoff between the two. This property allows expansion of DEA methodology into very different production sectors. To examine the efficiency of hospitals or health care centers is the very popular application of DEA, e.g. a recent study by Halme and Korhonen (1999) examines the dental care units or the study by Byrnes and Valdmanis (1989) where 123 US hospitals were covered. Other applications of DEA methodology are covering industries like air transportation (Land, Lovell and Thore 1993), fishing (Walden and Kirkley 2000) and banking (Ševčovič, Halická and Brunovský 2001).

The study by Byrnes and Valdmanis (1989) joined the expanding interest in health care applications of DEA that occurred in the beginning of 1980's. Many earlier studies of cost efficiency calculated only the technical-efficiency of DMUs and this study also examined the decomposition of overall efficiency into its component parts. This means that Byrnes and Valdmanis (1989) can figure out how efficiently hospitals are using each of the inputs or outputs in comparison to other competitors from the DMUs set. Their approach shows how many different types of information can be gathered using the DEA model. They also mentioned how the managers can utilize these different information types.

The expanding number of papers devoted to DEA helped to identify the limitations of the DEA approach. An analyst should keep these limitations in mind when choosing whether or not to use DEA. DEA is good at estimating "relative" efficiency of a DMU but it converges very slowly to "absolute" efficiency. In other words, it can tell you how well DMU is doing compared to other DMU but not compared to a "theoretical maximum." This is the result of the analyst's limitation in knowledge of the true production function.

¹⁰According to Emrouznejad (1995-2001) homepage.

Since DEA is an extreme point technique, noise (even symmetrical noise with zero mean) such as measurement error can cause significant problems, because the frontier is sensitive to these errors.

Therefore theoretical attempts to incorporate these errors were done. The SDEA works are based on the theoretical paper by Land et al. (1993), where the authors used their new models to examine the efficiency of the same schooling program for disabled scholars as in Charnes et al. (1978). In the Land et al. (1993), the authors have offered the prospect of stochastic data envelopment analysis and constructed their own model (LLT model). They imported stochastic component to DEA and created chance constrained problems by introducing the variability to outputs that is conditional on inputs. This simply means that only outputs were taken as normally distributed random variables. After the stochastic optimization problems were created, Land et al. (1993) transformed these problems to their deterministic equivalents, which allowed them to determine the efficient DMUs.

Olesen and Petersen (1995) presented different approach to incorporate the stochastic component into DEA. Olesen and Petersen (1995) assumed that inefficiency of DMU can be decomposed into true inefficiency and disturbance term. The approaches of Land et al. (1993) and Olesen and Petersen (1995) to SDEA are compared by Olesen (2002) and weaknesses of both approaches are identified. LLT model is criticized because it does not account for all correlations that can occur in disturbances. Olesen (2002) critique the OP-model proposed by Olesen and Petersen (1995) because the OP-model ignores the fact that a convex combination of, e.g., two i.d. random input output vectors from two DMUs has a lower variance than the random vectors themselves, except for the case where the input output vectors are perfectly correlated. After Olesen (2002) stressed the weaknesses of both the models, he proposed a model that combines attractive features of the LLT and OP models. Forward remedy from the OP model is to take the union of confidence regions for any linear combination of the stochastic vectors themselves, and not using a piecewise linear enveloping of the confidence regions and this idea is implemented in the combined chance constraint model proposed in this paper.

The theoretical paper by Huang and Li (n.d.) sketches stochastic models with the possibility of variations in inputs and outputs. Huang and Li (n.d.) define efficiency measure of a DMU via joint probabilistic comparisons of inputs and outputs with other DMUs and can be characterized by solving a chance constrained programming problem. By utilizing the theory of chance constrained programming, deterministic equivalents are obtained for both situations of multivariate symmetric random disturbances and a single random factor in the production relationships. The linear deterministic

equivalent and its dual form are obtained via the programming theory under the assumption of the single random factor. An analysis of stochastic variable returns to scale is developed using the idea of stochastic supporting hyperplanes. The relationships of the presented SDEA models with some conventional DEA models are also discussed.

The following paper shows that there still exist research directions in which the future developments on DEA and SDEA can be driven. Gstach (1998) addresses the issue that the outcome of a production process might not only deviate from a theoretical maximum due to inefficiency, but also due to non-controllable errors. As usually, this raises the issue of reliability of DEA in noisy environments. The author proposes to assume an i.i.d. data generating process with a bounded noise component. This assumption makes the approach that mixes the parametric and non-parametric approach to production frontier estimation feasible. Gstach (1998) propose to use DEA to estimate a pseudo frontier (nonparametric shape estimation) and then apply a maximum likelihood-technique to the DEA-estimated efficiencies to estimate the scalar value by which this pseudo-frontier must be shifted downward to get the true production frontier (location estimation).

At the end of this review I present paper that is devoted to DEA models computational problems. The major problems associated with solution of DEA models are the analysis of large set of DMUs and that the solutions with zero elements. The analysis of large data set leads to large size optimization problems that can be costly to solve. The solutions with zero elements cause problems when these solutions are interpreted as inputs and outputs shadow prices. Gonzales-Lima, Tapia and Thrall (1996) present the primal-dual interior-points computational methods as the methods that significantly improve the reliability of solution in comparison to simplex methods. The interior-points methods maximize the product of the positive components among solutions, this means that the number of zero components of the optimal solution is minimized. Due to this solution's property it is easier to interpret the DEA models results.

A.2.1 Notation

In this section, I introduce notation and definitions that will be used to construct the DEA models in the next section. The notation in this paper coincides with the notation used in papers by Li (1998) and Huang and Li (n.d.). The task is to analyze the set of DMU_j where $1 \leq j \leq n$. Each of the DMUs is described by the vector $\tilde{x}_j \in \mathbb{R}_+^m$, $\tilde{x}_j = (\tilde{x}_{1j}, \dots, \tilde{x}_{mj})^T$ of m input amounts that are used to produce s outputs in amounts described by vector $\tilde{y}_j \in \mathbb{R}_+^s$, $\tilde{y}_j = (\tilde{y}_{1j}, \dots, \tilde{y}_{sj})^T$. These vectors will constitute matrices of inputs

and outputs, therefore the following matrix notation will be used:

matrix of inputs	$\tilde{X} = (\tilde{x}_1, \dots, \tilde{x}_n)$
i^{th} row of 'input' matrix \tilde{X}	$i\tilde{x} = (\tilde{x}_{i1}, \dots, \tilde{x}_{in})^T, i = 1, \dots, m$
matrix of expected inputs	$\bar{X} = (\bar{x}_1, \dots, \bar{x}_n)$
i^{th} row of expected 'input' matrix \bar{X}	$i\bar{x} = (\bar{x}_{i1}, \dots, \bar{x}_{in})^T, i = 1, \dots, m$
matrix of outputs	$\tilde{Y} = (\tilde{y}_1, \dots, \tilde{y}_n)$
r^{th} row of 'output' matrix \tilde{Y}	$r\tilde{y} = (\tilde{y}_{r1}, \dots, \tilde{y}_{rn})^T, r = 1, \dots, s$
matrix of expected outputs	$\bar{Y} = (\bar{y}_1, \dots, \bar{y}_n)$
r^{th} row of expected 'output' matrix \bar{Y}	$r\bar{y} = (\bar{y}_{r1}, \dots, \bar{y}_{rn})^T, r = 1, \dots, s$

A.2.2 Production possibility set

In the stochastic, framework the DMUs are characterized by distributions moments. The production possibility set is defined in terms of means. In further model development, the second moments will be used in the transformation from the chance constrained problem to its deterministic equivalent.

The true production possibility set can be constructed using the true production function. In nonparametric DEA methodology, this function is not known, therefore the general production possibility set is defined and the set of properties that the production possibility set should fulfill is postulated.

Definition 1. General stochastic production possibility set $T \subset \mathbb{R}_+^{m+s}$ is defined as follows: $T = \{(\tilde{x}, \tilde{y}) \mid \text{using inputs } \tilde{x} \text{ outputs } \tilde{y} \text{ can be produced}\}$

When constructing the stochastic production possibility set T using the $DMU_j, j = 1, \dots, n$, T should have these properties:

Property 1. Convexity: If $(\tilde{x}_j, \tilde{y}_j) \in T, j = 1, \dots, n$ and $\lambda \in \mathbb{R}_+^n, \sum_{j=1}^n \lambda_j = 1 \Rightarrow (\tilde{X}\lambda, \tilde{Y}\lambda) \in T$.

Property 2. Inefficiency property: If $(\bar{x}, \bar{y}) \in T$ and $x \geq \bar{x}$, then $(x, \bar{y}) \in T$. If $(\bar{x}, \bar{y}) \in T$ and $y \leq \bar{y}$ then $(\bar{x}, y) \in T$.

Property 3. Minimum extrapolation: T is the intersection of all sets satisfying convexity and inefficiency property and subject to that each of the observed vectors $(\tilde{x}_j, \tilde{y}_j) \in T, j = 1, \dots, n$.

Set $T_o = \{(\tilde{x}, \tilde{y}) \mid \tilde{x} \geq \tilde{X}\lambda, \tilde{y} \leq \tilde{Y}\lambda, \lambda \geq 0\}$ satisfies the aforementioned properties. T_o is the stochastic generalization of the production possibility set of constant returns to scale production function as it was used by Charnes et al. (1978) in derivation of the CCR model. Similarly, set $T_1 = \{(\tilde{x}, \tilde{y}) \mid \tilde{x} \geq \tilde{X}\lambda, \tilde{y} \leq \tilde{Y}\lambda, e^T\lambda = 1, \lambda \geq 0\}$ also satisfies the properties postulated for the stochastic production set. Set T_1 is the production possibility set

appropriate for production technology with no returns to scale. Further, set T_1 and its modifications will be used to derive models with variable returns to scale.

Generally, I can define the parameterized production possibility set T_φ that covers case of T_1 and T_0 as $T_\varphi = \{(\tilde{x}, \tilde{y}) \mid \tilde{x} \geq \tilde{X}\lambda, \tilde{y} \leq \tilde{Y}\lambda, \varphi(e^T\lambda) = \varphi, \lambda \geq 0\}$.

Next, I introduce the concept of effectiveness. The element of the production possibility set is called the efficient point of production set if there does not exist another production point that produces more of output without consuming more input, or consumes less of input without producing less output. This leads to the following efficiency domination definition among the DMUs:

Definition 2. DMU_j is not dominated in the sense of efficiency if $\nexists (x^*, y^*) \in T$ such that $x^* \leq x_j$ or $y^* \geq y_j$ with at least one strict inequality for input or output components.

In the deterministic environment, the efficient DMU_j are elements of the production possibility set frontier and there is no possibility of violating of the production possibility set properties.

In the stochastic framework, the properties violations are allowed with the probability $\alpha, 0 \leq \alpha \leq 1$. The term $1 - \alpha$ in the chance constrained programming problem can be interpreted as the modeler's confidence level, therefore α is interpreted as the modeler's risk that equals probability measure of the extent to which specified conditions are violated. I introduce two similar types of stochastic models. In the first model type the efficiency dominance is violated with probability α . The second model type allows for violations of constraints specifying the production possibility set with probability α . First, I consider case where Pareto efficiency can be violated due to errors and therefore I define stochastic efficiency of point as follows:

Definition 3. Stochastic efficiency of point in set T_φ : $(\tilde{x}^*, \tilde{y}^*) \in T_\varphi$ is called α -stochastically efficient point associated with $T_\varphi \Leftrightarrow$ if the analyst is confident that $(\tilde{x}^*, \tilde{y}^*)$ is Pareto-efficient with probability $1 - \alpha$ in the set T_φ .

This definition means that point $(\tilde{x}^*, \tilde{y}^*)$, considered as efficient by modeler, is dominated (in the sense of efficiency dominance) by any other point in T_φ with a probability less or equal to α . Next, I define the efficiency of DMU_j :

Definition 4. Stochastic efficiency of DMU_j : DMU_j is α -stochastically efficient in set $T_\varphi \Leftrightarrow (\tilde{x}_j, \tilde{y}_j)$ is point associated with DMU_j and $(\tilde{x}_j, \tilde{y}_j) \in T_\varphi$ is α -stochastically efficient production point associated with T_φ .

These definitions and aforementioned properties of the set T_φ straightforwardly imply that for efficient DMU_j and for any λ such that $\varphi(e^T\lambda) = \varphi, \lambda \geq 0$ I can state, that with at least one strict inequality in input–output constraints following expression holds:

$$Prob(\tilde{X}\lambda \leq \tilde{x}_j, \tilde{Y}\lambda \geq \tilde{y}_j) \leq \alpha.$$

The second case considered in this paper is the case where production possibility set constraints are violated in efficiency definition. In this approach modeler’s risk relates to risk that some DMUs are not in the production possibility set due to measurement errors. For these models I define efficiency dominance as follows:

Definition 5. DMU_j is not dominated in the sense of efficiency if $\nexists(x^*, y^*) \in T$ such that $Prob(x_i^* \leq x_{ij}) \geq 1 - \alpha$ or $Prob(y_r^* \geq y_{rj}) \geq 1 - \alpha$ with at least one strict inequality for input or output components.

To demonstrate difference in stochastic and deterministic approach I compare deterministic and stochastic models from the view of the shape of efficient points set. Figure (1) shows the deterministic frontier and compares it to the true production possibility frontier. We observe two inefficient DMUs, namely DMU #4 and DMU #5. The solid piecewise linear line is the unknown true production possibility frontier and the dashed line is DEA estimate of it. In Figure (2) the same DMUs are pictured and the stochastic production possibility frontier is pictured as the grey shaded area. We observe, that the DMU #4 became an efficient unit, because now it is part of the frontier.

A.2.3 Stochastic model

In this chapter, I derive almost 100% confidence chance constrained problem that will be basis for further theoretical development of SDEA model. In the following section I will made assumptions about the error structure in the model and the model will be transformed to its deterministic equivalent.

From the set properties follows that $\{\tilde{X}\lambda \leq \tilde{x}_j, \tilde{Y}\lambda \geq \tilde{y}_j\} \subset \{e^T(\tilde{X}\lambda - \tilde{x}_j) + e^T(\tilde{y}_j - \tilde{Y}\lambda) < 0\}$ ¹¹ and using probability properties I derive following inequality: $Prob(\tilde{X}\lambda \leq \tilde{x}_j, \tilde{Y}\lambda \geq \tilde{y}_j) \leq Prob(e^T(\tilde{X}\lambda - \tilde{x}_j) + e^T(\tilde{y}_j - \tilde{Y}\lambda) < 0)$. Therefore for λ such that $\varphi(e^T\lambda) = \varphi, \lambda \geq 0$ the condition $Prob(e^T(\tilde{X}\lambda - \tilde{x}_j) + e^T(\tilde{y}_j - \tilde{Y}\lambda) < 0) \leq \alpha$ is a sufficient condition for DMU_j to be α -stochastically efficient.

¹¹The inequality type change is due to the additional restriction that $\{\tilde{X}\lambda \leq \tilde{x}_j, \tilde{Y}\lambda \geq \tilde{y}_j\}$ holds with at least one strict inequality.

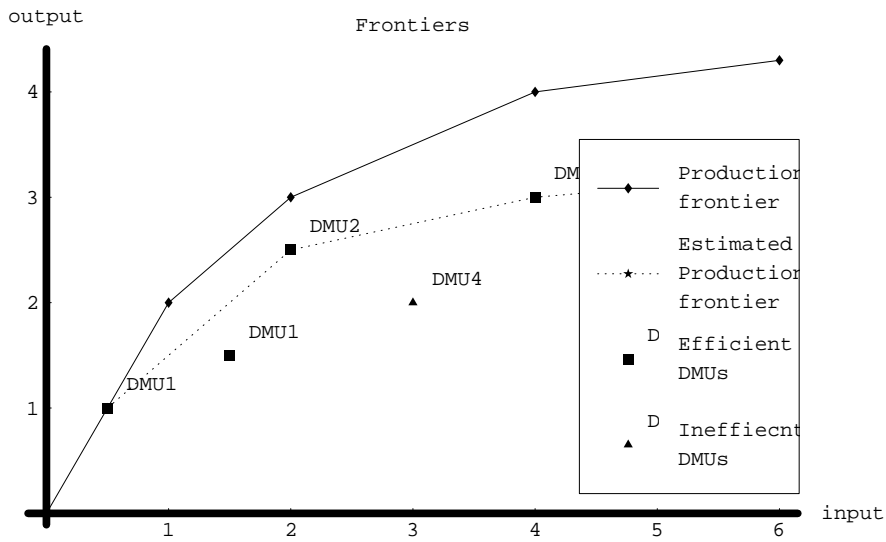


Figure 1: DEA production possibility frontier

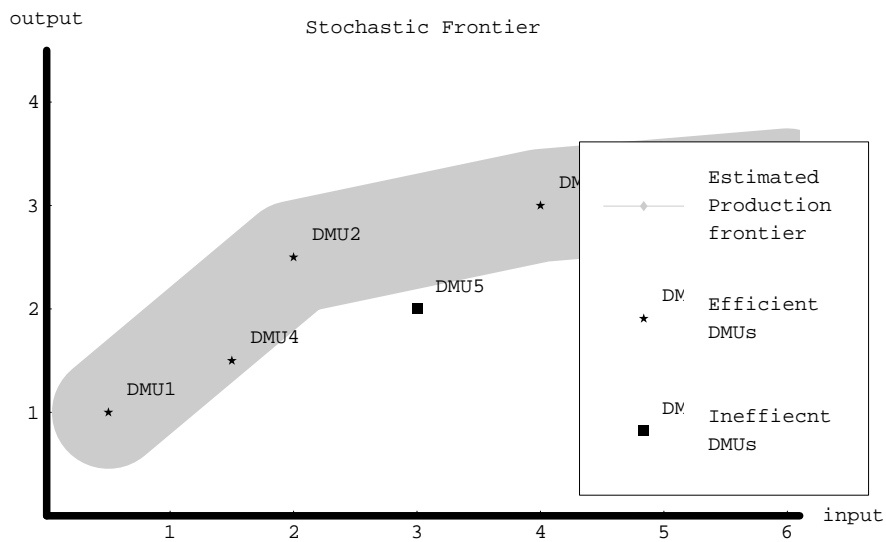


Figure 2: Stochastic production possibility frontier

Using this fact, Cooper, Huang, Lelas, Li and Olesen (1998) constructed the following almost 100% confidence chance constrained problem (in matrix notation):

$$\begin{aligned} \max_{\lambda} \quad & \text{Prob}(e^T(\tilde{X}\lambda - \tilde{x}_j) + e^T(\tilde{y}_j - \tilde{Y}\lambda) < 0) - \alpha & (9) \\ \text{s.t.} \quad & \\ & \text{Prob}({}_i\tilde{x}\lambda < \tilde{x}_{ij}) \geq 1 - \epsilon, & i = 1, \dots, m; \\ & \text{Prob}({}_r\tilde{y}\lambda > \tilde{y}_{rj}) \geq 1 - \epsilon, & r = 1, \dots, s; \\ & \varphi(e^T\lambda) = \varphi, \\ & \lambda \geq 0, \end{aligned}$$

where ϵ is non-Archimedean infinitesimal quantity.¹² Theorem (3) by Cooper et al. (1998) implies that if the maximum value of the chance functional $\text{Prob}(e^T(\tilde{X}\lambda - \tilde{x}_j) + e^T(\tilde{y}_j - \tilde{Y}\lambda) < 0)$ exceeds α , then DMU_j is not α -stochastically efficient.

A.2.4 Symmetric shock model

In this section, I introduce single symmetric error structure that allows us to transform model from chance constrained problem to the linear programming problem. In the single factor symmetric model, errors in all variables are driven by single symmetric shock ε . I consider, as in Li (1998), m inputs and s outputs structure of n DMUs in the following form:

$$\begin{aligned} \tilde{x}_{ij} &= \bar{x}_{ij} + a_{ij}\varepsilon \\ \tilde{y}_{ij} &= \bar{y}_{ij} + b_{ij}\varepsilon, \end{aligned}$$

where ε follows normal distribution with $E(\varepsilon) = 0, \text{Var}(\varepsilon) = \sigma_\varepsilon^2$. The following vector notation is introduced to simplify the description of the shock effects to DMU:

$$\begin{aligned} a_j &= (a_{1j}, \dots, a_{mj})^T, & b_j &= (b_{1j}, \dots, b_{sj})^T, & j &= 1, \dots, n; \\ {}_i a &= (a_{i1}, \dots, a_{in}), & {}_r b &= (b_{r1}, \dots, b_{rn}), & i &= 1, \dots, m, r = 1, \dots, s; \end{aligned}$$

and by consolidation of these vectors I construct matrices:

$$A = (a_1, a_2, \dots, a_n), \quad B = (b_1, \dots, b_n).$$

Using properties of normal distribution and inverse of cumulative distribution function $\Phi(\alpha)$, by rewriting of constraints and objective function in the

¹²This means that ϵ is less than any positive real number. According to Charnes et al. (1994): "Computational Aspects of DEA", I will select $\epsilon < \min_{j=1, \dots, n} 1 / \sum_{i=1}^m x_{ij}$ in the calculations of these models.

almost 100% confidence chance constrained problem (9), the following non-stochastic equivalent is derived:

$$\begin{aligned}
\min_{\lambda} \quad & e^T(\bar{X}\lambda - \bar{x}_j) + e^T(\bar{y}_j - \bar{Y}\lambda) + \\
& + |e^T(A\lambda - a_j) + e^T(\bar{b}_j - \bar{B}\lambda)| \sigma_{\epsilon} \Phi^{-1}(\alpha) \\
s.t. \quad & \\
& {}_i\bar{x}\lambda \leq \bar{x}_{ij} + |{}_i a\lambda - a_{ij}| \sigma_{\epsilon} \Phi^{-1}(\epsilon), \quad i = 1, \dots, m, \\
& {}_r\bar{y}_{rj} \leq {}_r\bar{y}\lambda + |{}_r b_{rj} - {}_r b\lambda| \sigma_{\epsilon} \Phi^{-1}(\epsilon), \quad r = 1, \dots, s, \\
& \varphi(e^T\lambda) = \varphi, \\
& \lambda \geq 0.
\end{aligned} \tag{10}$$

To linearize constraints I remove the absolute value terms from constraints in problem (10). The trick is to decompose the absolute value term in each constraint into the difference of two positive numbers and I add cumulative term $\epsilon(\sum_{r=1}^s(q_{1r} + q_{2r}) + \sum_{i=1}^m(h_{1i} + h_{2i}))$ into the objective function. This trick does not affect the optimal solutions of problem (10). Therefore, problem (10) is equivalent to the following problem with linear constraints:

$$\begin{aligned}
\min_{\lambda, q_{kr}, h_{ki}} \quad & e^T(\bar{X}\lambda - \bar{x}_j) + e^T(\bar{y}_j - \bar{Y}\lambda) + \\
& + |e^T(A\lambda - a_j) + e^T(\bar{b}_j - \bar{B}\lambda)| \sigma_{\epsilon} \Phi^{-1}(\alpha) + \\
& + \epsilon(\sum_{r=1}^s(q_{1r} + q_{2r}) + \sum_{i=1}^m(h_{1i} + h_{2i})) \\
s.t. \quad & \\
& {}_i\bar{x}\lambda \leq \bar{x}_{ij} + (h_{1i} + h_{2i})\sigma_{\epsilon} \Phi^{-1}(\epsilon), \\
& {}_i a\lambda - a_{ij} = h_{1i} - h_{2i}, \quad i = 1, \dots, m, \\
& {}_r\bar{y}_{rj} \leq {}_r\bar{y}\lambda + (q_{1r} + q_{2r})\sigma_{\epsilon} \Phi^{-1}(\epsilon), \\
& {}_r b_{rj} - {}_r b\lambda = q_{1r} - q_{2r}, \quad r = 1, \dots, s, \\
& \varphi(e^T\lambda) = \varphi, \\
& \lambda \geq 0, q_{kr} \geq 0, h_{ki} \geq 0, \quad k = 1, 2.
\end{aligned} \tag{11}$$

In the next step I remove the absolute value from the objective function. The inverse of cumulative distribution function $\Phi(\alpha)$ takes positive or negative values, to account for this factor define δ such that:

$$\delta = \begin{cases} -1 & \text{if } \alpha < 0.5 \\ 1 & \text{if } \alpha > 0.5. \end{cases}$$

The absolute value term in the objective function is the sum of the absolute value terms in constraints; therefore, the decomposition that was used in constraints is just substituted in the objective function. Thus as in Li (1998), the absolute value terms are eliminated from objective function and

the following problem with linear objective function is obtained:

$$\begin{aligned}
\min_{\lambda, q_{kr}, h_{ki}} \quad & e^T(\bar{X}\lambda - \bar{x}_j) + e^T(\bar{y}_j - \bar{Y}\lambda) + \\
& + \delta(e^T(A\lambda - a_j) + e^T(b_j - \bar{B}\lambda))\sigma_\varepsilon\Phi^{-1}(\alpha) + \\
& + \epsilon(\sum_{r=1}^s(q_{1r} + q_{2r}) + \sum_{i=1}^m(h_{1i} + h_{2i})) \\
s.t. \quad & \\
& {}_i\bar{x}\lambda \leq \bar{x}_{ij} + (h_{1i} + h_{2i})\sigma_\varepsilon\Phi^{-1}(\epsilon), \\
& {}_i a\lambda - a_{ij} = h_{1i} - h_{2i}, \\
& {}_r\bar{y}_j \leq {}_r\bar{y}\lambda + (q_{1r} + q_{2r})\sigma_\varepsilon\Phi^{-1}(\epsilon), \\
& {}_r b_j - {}_r b\lambda = q_{1r} - q_{2r}, \\
& \varphi(e^T\lambda) = \varphi, \\
& \lambda \geq 0, q_{kr} \geq 0, h_{ki} \geq 0,
\end{aligned} \tag{12}$$

Problem (12) is known as the envelopment formulation of the DEA model, because in each problem the part of envelopment adjacent to the analyzed DMU_j is set up. Define e as the vector of ones and I can write the dual problem (13) to primal problem (12), which is a modification of the problem created by Li (1998) is as follows:

$$\begin{aligned}
\min_{\mu, \nu, \eta, \omega, \mu_j} \quad & \mu^T \bar{y}_j - \nu^T \bar{x}_j - \eta^T b_j - \omega^T a_j - \varphi \mu_j \\
s.t. \quad & \\
& \mu^T \bar{y}_l - \nu^T \bar{x}_l - \eta^T b_l - \omega^T a_l - \varphi \mu_j \geq 0, \\
& -\sigma_\varepsilon\Phi^{-1}(\varepsilon)\mu + \eta \geq -\sigma_\varepsilon(\Phi^{-1}(\varepsilon) + \varepsilon)e - \delta\sigma_\varepsilon\Phi^{-1}(\alpha)e, \\
& -\sigma_\varepsilon\Phi^{-1}(\varepsilon)\mu - \eta \geq -\sigma_\varepsilon(\Phi^{-1}(\varepsilon) + \varepsilon)e + \delta\sigma_\varepsilon\Phi^{-1}(\alpha)e, \\
& -\sigma_\varepsilon\Phi^{-1}(\varepsilon)\nu + \omega \geq -\sigma_\varepsilon(\Phi^{-1}(\varepsilon) + \varepsilon)e - \delta\sigma_\varepsilon\Phi^{-1}(\alpha)e \\
& -\sigma_\varepsilon\Phi^{-1}(\varepsilon)\nu + \omega \geq -\sigma_\varepsilon(\Phi^{-1}(\varepsilon) + \varepsilon)e + \delta\sigma_\varepsilon\Phi^{-1}(\alpha)e, \\
& \mu \geq e, \\
& \nu \geq e, \\
& \eta, \omega, \mu_j \text{ unconstrained.}
\end{aligned} \tag{13}$$

A.3 Measuring efficiency

The solution of problems (12) and (13) consist of the data envelopment defining hyperplane that defines estimated production frontier for DMU_j . The important part of solution is projected point $(\hat{x}_j, \hat{y}_j) = (\bar{X}\lambda, \bar{Y}\lambda)$ such that belongs to the data envelopment defining hyperplane. Specific, the hyperplane is obtained from solution of multipliers problem (13) and the projected point is from solution of envelopment problem (12) for specific j . In this section, the projected point and envelopment defining hyperplane will be utilized to create the inefficiency measure for the DMU_j .

For the purpose of a simple inefficiency measure, I can use the distance measure of a discrepancy between expected and projected point, that is

$(\hat{x}_j, \hat{y}_j) - (\bar{x}_j, \bar{y}_j)$. This discrepancy expresses the difference between the efficient frontier represented by projected point (\hat{x}_j, \hat{y}_j) and the present position of DMU_j . Starting from (\bar{x}_j, \bar{y}_j) I can follow different paths to the envelopment surface, represented by defining hyperplane for DMU_j , therefore different projected points and inefficiency measures can be created. In the following derivation of efficiency measure directions of lowering inputs and increasing in outputs will be used.

First, for inputs of DMU_j I denote $\bar{x}_j - \bar{X}\lambda = e_j$ and following the path $-e_j$ we can lower inputs and move towards the production possibility frontier. When inputs lowering path is used in construction of the efficiency measure the input oriented DEA model is created. Similarly, I create a DEA output oriented model, for outputs I get the projection path $s_j = \bar{Y}\lambda - \bar{y}_j$. The path s_j projects DMU_j on to production possibility frontier in outputs maximizing direction.

Next, to determine the maximal scale effects in lowering inputs or increasing outputs, the projection paths s_j, e_j are decomposed to a proportional increase (decrease) and residual as follows: $s_j = \rho\bar{y}_j + \delta_s^j$, $e_j = \gamma\bar{x}_j + \delta_e^j$,¹³ where proportional increase of outputs ρ and proportional decrease of inputs γ are defined as follows:

$$\begin{aligned}\rho &= \min_{r=1, \dots, s} \frac{\hat{y}_{rj} - \bar{y}_{rj}}{\bar{y}_{rj}} \geq 0, \\ \gamma &= \min_{i=1, \dots, m} \frac{\bar{x}_{ij} - \hat{x}_{ij}}{\bar{x}_{ij}} \geq 0.\end{aligned}\tag{14}$$

Next, I will use the notation of Ali and Seiford (1993) to define new variables for proportional part of projection. The new variable for output oriented model are defined as $\phi = 1 + \rho$ and for input oriented model $\theta = 1 - \gamma$. To identify the maximal output scale effect, I will search for maximal ϕ , and for input reduction I will search for minimal θ .

For the identification of scale effects, I construct two stage models. In first stage of model the maximal ϕ or minimal θ will be identified. The second stage of modelling utilizes the identified scale effect to optimize for envelope distance. Thus, in the first stage I replace \bar{x}_j with $\theta\bar{x}_j$ and I search for minimal θ . The solution to the first stage for DMU_j is denoted as $\hat{\theta}_j$. The $\hat{\theta}_j$ is used in the second stage where I search for envelopment. Similarly, for the input oriented model I replace \bar{y}_j by $\rho\bar{y}_j$ and search for maximal input scaling by $\hat{\rho}_j$. These two stage models are summarized in the Table (1).

¹³Note that at least one component of each δ is zero, because of projection on to the

Output oriented model

First stage	Second stage
$\max_{\lambda, \phi}$ s.t. $Prob({}_i\tilde{x}\lambda < \tilde{x}_{ij}) \geq 1 - \epsilon$ $Prob({}_r\tilde{y}\lambda > \phi\tilde{y}_{rj}) \geq 1 - \epsilon$ $\varphi(e^T\lambda) = \varphi$ $\lambda \geq 0$	$\max_{\lambda} Prob(e^T(\tilde{X}\lambda - \tilde{x}_j) + e^T(\hat{\phi}_j\tilde{y}_j - \tilde{Y}\lambda)) - \alpha$ s.t. $Prob({}_i\tilde{x}\lambda < \tilde{x}_{ij}) \geq 1 - \epsilon$ $Prob({}_r\tilde{y}\lambda > \hat{\phi}_j\tilde{y}_{rj}) \geq 1 - \epsilon$ $\varphi(e^T\lambda) = \varphi$ $\lambda \geq 0$ $i = 1, \dots, m; r = 1, \dots, s.$

Input oriented model

First stage	Second stage
$\min_{\lambda, \theta}$ s.t. $Prob({}_i\tilde{x}\lambda < \theta_j\tilde{x}_{ij}) \geq 1 - \epsilon$ $Prob({}_r\tilde{y}\lambda > \tilde{y}_{rj}) \geq 1 - \epsilon$ $\varphi(e^T\lambda) = \varphi$ $\lambda \geq 0$	$\max_{\lambda} Prob(e^T(\tilde{X}\lambda - \hat{\theta}_j\tilde{x}_j) + e^T(\tilde{y}_j - \tilde{Y}\lambda)) - \alpha$ s.t. $Prob({}_i\tilde{x}\lambda < \hat{\theta}_j\tilde{x}_{ij}) \geq 1 - \epsilon$ $Prob({}_r\tilde{y}\lambda > \tilde{y}_{rj}) \geq 1 - \epsilon$ $\varphi(e^T\lambda) = \varphi$ $\lambda \geq 0$ $i = 1, \dots, m; r = 1, \dots, s.$

Table 1: Two stage oriented almost 100% confidence chance constrained models

A.4 Oriented models

Two stage oriented models described in Table (1) can be collapsed to one stage model. In both stages the objective function optimization is subject to the same constraints, the only one difference is the objective function. To merge these stages in one optimization problem, the non-Archimedean ϵ is used as weight for second stage objective function. The presence of non-Archimedean ϵ in the objective function allows such proportional movement towards the frontier that it drive out the slacks optimization. In following sections almost 100% confidence chance constrained oriented models will be defined and their linearization will be presented.

Output oriented model In this section, I linearize almost 100% confidence chance constrained output oriented problem. I use the one stage model, derived from two stage optimization process that was presented in

production possibility frontier.

Table (1). The one stage model is stated as follows:

$$\begin{aligned}
\max_{\lambda, \phi} \quad & \phi + \epsilon(\text{Prob}(e^T(\tilde{X}\lambda - \tilde{x}_j) + e^T(\phi\tilde{y}_j - \tilde{Y}\lambda)) - \alpha) & (15) \\
\text{s.t.} \quad & \text{Prob}({}_i\tilde{x}\lambda < \tilde{x}_{ij}) \geq 1 - \epsilon, & i = 1, \dots, m; \\
& \text{Prob}({}_r\tilde{y}\lambda > \phi\tilde{y}_{rj}) \geq 1 - \epsilon, & r = 1, \dots, s; \\
& \varphi(e^T\lambda) = \varphi \\
& \lambda \geq 0;
\end{aligned}$$

I apply the same linearization procedure as was applied to problem (9) and described in the previous section. The following model is derived:

$$\begin{aligned}
\max_{\lambda, q_{kr}, h_{ki}, \phi} \quad & \phi - \epsilon[e^T(\bar{X}\lambda - \bar{x}_j) + e^T(\phi\bar{y}_j - \bar{Y}\lambda) + \\
& + \delta(e^T(A\lambda - a_j) + e^T(\phi\bar{b}_j - \bar{B}\lambda))\sigma_\epsilon\Phi^{-1}(\alpha)] + \\
& + \epsilon(\sum_{r=1}^s(q_{1r} + q_{2r}) + \sum_{i=1}^m(h_{1i} + h_{2i})) \\
\text{s.t.} \quad & {}_i\bar{x}\lambda \leq \bar{x}_{ij} + (h_{1i} + h_{2i})\sigma_\epsilon\Phi^{-1}(\epsilon), \\
& {}_i a\lambda - a_{ij} = h_{1i} - h_{2i}, & i = 1, \dots, m, \quad (16) \\
& \phi\bar{y}_{rj} \leq {}_r\bar{y}\lambda + (q_{1r} + q_{2r})\sigma_\epsilon\Phi^{-1}(\epsilon), \\
& \phi b_{rj} - {}_r b\lambda = q_{1r} - q_{2r}, & r = 1, \dots, s, \\
& \varphi(e^T\lambda) = \varphi, \\
& \lambda \geq 0, q_{kr} \geq 0, h_{ki} \geq 0, & k = 1, 2,
\end{aligned}$$

Input oriented model Similarly, as in the previous section, the almost 100% confidence chance constrained input oriented problem will be derived. I use one stage model, that condenses two stage optimization process that was presented in Table (1). The one stage model is stated as follows:

$$\begin{aligned}
\min_{\lambda, \theta} \quad & \theta - \epsilon(\text{Prob}(e^T(\tilde{X}\lambda - \theta\tilde{x}_j) + e^T(\tilde{y}_j - \tilde{Y}\lambda)) - \alpha) & (17) \\
\text{s.t.} \quad & \text{Prob}({}_i\tilde{x}\lambda < \theta\tilde{x}_{ij}) \geq 1 - \epsilon, & i = 1, \dots, m; \\
& \text{Prob}({}_r\tilde{y}\lambda > \tilde{y}_{rj}) \geq 1 - \epsilon, & r = 1, \dots, s; \\
& \varphi(e^T\lambda) = \varphi \\
& \lambda \geq 0;
\end{aligned}$$

I constructed the following linear deterministic equivalent of the chance constrained model:

$$\begin{aligned}
\min_{\lambda, q_{kr}, h_{ki}, \theta} \quad & \theta + \epsilon [e^T(\bar{X}\lambda - \theta\bar{x}_j) + e^T(\bar{y}_j - \bar{Y}\lambda) + \\
& + \delta(e^T(A\lambda - \theta a_j) + e^T(\bar{b}_j - \bar{B}\lambda))\sigma_\epsilon\Phi^{-1}(\alpha)] + \\
& + \epsilon(\sum_{r=1}^s(q_{1r} + q_{2r}) + \sum_{i=1}^m(h_{1i} + h_{2i})) \\
s.t. \quad & {}_i\bar{x}\lambda \leq \theta\bar{x}_{ij} + (h_{1i} + h_{2i})\sigma_\epsilon\Phi^{-1}(\epsilon), \\
& {}_i a\lambda - \theta a_{ij} = h_{1i} - h_{2i}, \quad i = 1, \dots, m, \quad (18) \\
& \bar{y}_j\lambda \leq {}_r\bar{y} + (q_{1r} + q_{2r})\sigma_\epsilon\Phi^{-1}(\epsilon), \\
& {}_r b_j - {}_r b\lambda = q_{1r} - q_{2r}, \quad r = 1, \dots, s, \\
& \varphi(e^T\lambda) = \varphi, \\
& \lambda \geq 0, q_{kr} \geq 0, h_{ki} \geq 0, \quad k = 1, 2,
\end{aligned}$$

A.5 Future research

All above derived models are appropriate to use in case of the constant returns to scale production function. Therefore, my future theoretical goal is to introduce the variable returns to scale into the SDEA models. I will follow the methodology used for development of deterministic models to develop almost 100% chance constrained DEA models with variable returns to scale to increase the range of practical applicability.

For purpose of applied research in productivity analysis, the solver capable of solving will be constructed. The solver will use primal-dual interior point method algorithm for constructed models solution. The planned application of SDEA methodology will compare the productivity analysis results obtained by parametric methods to results obtained by SDEA.

References

- Afonso, Antonio, Ludger Schuknecht, and Vito Tanzi**, "Public sector efficiency: An International Comparison," *ECB Working Paper*, July 2003, 242.
- Ali, Agha Iqbal and Lawrence M. Seiford**, *The measurement of productive efficiency: Techniques and Applications*, New York: Oxford University Press,
- Ballasa, Bela**, "The purchasing power parity doctrine: A reappraisal," *Journal of Political Economy*, December 1964, 72, 584–596.
- Banker, R. D., Abraham Charnes, and William W. Cooper**, "Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis," *Management Science*, 1984, 30, 1078–192.

- Bayoumi, Tamim and Barry Eichengreen**, “Ever closer to heaven? An optimum-currency-area index for European countries,” *European Economic Review*, 1997, 41, 761–770.
- Byrnes, Patricia and Vivian Valdmanis**, *Cost Analysis Applications Of Economics and Operation Research*, Berlin: Springer Verlag, 1989.
- Charnes, Abraham, William W. Cooper, and E. Rhodes**, “Measuring the efficiency of decision making units,” *European Journal of Operational Research*, 1978, 2, 429–444.
- , — , **Arie Y. Lewin, and Lawrence M. Seiford**, *Data Envelopment Analysis: Theory, Methodology and Applications*, Kluwer Academic Publishers, 1994.
- Collard, Fabrice and Harris Dellas**, “Exchange rate systems and macroeconomic stability,” *Journal of Monetary Economics*, 2002, 49, 571–599.
- Cooper, William W., Zhimin Huang, Vedran Lelas, Susan X. Li, and Ole B. Olesen**, “Chance Constrained Programming Formulations for Stochastic Characterizations of Efficiency and Dominance in DEA,” *Journal of Productivity Analysis*, 1998, 9, 53–79.
- Dellas, Haris**, “Monetary Policy in Open Economies,” August 2003.
- , “Monetary Policy in Open Economies under Imperfect Information,” *Hong Kong Institute for Monetary Research Working Papers*, April 2003, 7.
- Emrouznejad, Ali**, “Ali Emrouznejad’s DEA HomePage,” web page 1995–2001. Warwick Business School, Coventry CV4 7AL, UK.
- Fidrmuc, Jarko and Iikka Korhonen**, “Similarity of supply and demand shocks between the euro area and CEECs,” *BOFIT Discussion Papers*, 2001, 14.
- Frankel, Jeffrey A. and Andrew K. Rose**, “The Endogeneity of the Optimum Currency Area Criteria,” *NBER Working Paper Series*, August 1996, 5700.
- Gonzales-Lima, Maria D., Richard A. Tapia, and Robert M. Thrall**, “On the construction of strong complementarity slackness solutions for DEA linear programming problems using a primal–dual interior–point method,” *Annals of Operations Research*, 1996, 66, 139–162.

- Gstach, Dieter**, “Another approach to data envelopment analysis in noisy environments: DEA+,” *Journal of Productivity Analysis*, 1998, *9*, 161–176.
- Halme, Merja and Pekka Korhonen**, “Restricting Weights In Value Efficiency Analysis,” October 1999.
- Huang, Zhimin and Susan X. Li**, “Chance Constrained Programming And Stochastic Dea Models.” School of Business, Adelphi University, Garden City, New York.
- Land, K.C., C.A.K Lovell, and S. Thore**, “Chance-constrained Data Envelopment Analysis,” *Managerial and Decision Economics*, 1993, *14*, 541–554.
- Lane, Philip R.**, “The new open economy macroeconomics: survey,” *Journal of International Economics*, 2001, *54*, 235–266.
- Li, Susan X.**, “Stochastic models and variable returns to scales in data envelopment analysis,” *European Journal of Operational Research*, 1998, *104*, 532–548.
- McKinnon, Ronald I.**, “Optimum Currency Area,” *The American Economic Review*, September 1963, *53* (4), 717–725.
- Mundell, Robert A.**, “A Theory of Optimum Currency Area,” *The American Economic Review*, September 1961, *51* (4), 657–665.
- Obsfeld, Muarice and Kenneth Rogoff**, “Exchange rate dynamics redux,” *Journal of Political Economy*, 1995, *103*, 624–660.
- and — , *Foundation of International Macroeconomics*, Cambridge, Massachusetts: The MIT Press, 1996.
- Olesen, O. B.**, “Comparing and Combining Two Approaches for Chance Constrained DEA,” Technical Report, The University of Southern Denmark December 2002.
- Olesen, O.B. and N.C. Petersen**, “Chance constrained efficiency evaluation,” *Management Science*, 1995, *41*, 442–457.
- Osiewalski, Jacek, Gary Koop, and Mark F.J. Steel**, “A Stochastic Frontier Analysis Of Output Level And Growth In Poland And Western Economies,” *Tilburg University Discussion Paper Series*, 1997, *85*.

- Rose, Andrew K.**, “One Money, One Market: Estimating The Effect of Common Currencies On Trade,” *NBER Working Paper Series*, December 1999, 7432.
- **and Charles Engel**, “Currency Unions and International Integration,” *NBER Working Paper Series*, September 2000, 7872.
- Samuelson, Paul A.**, “Theoretical notes on trade problems,” *Review of Economic and Statistics*, May 1964, 46, 145–154.
- Ševčovič, Daniel, Margaréta Halická, and Pavol Brunovský**, “DEA analysis for a large structured bank branch network,” *Central European Journal of Operations Research*, 2001, 9 (4), 329–343.
- Walden, John B. and James E. Kirkley**, “Measuring Technical Efficiency and Capacity in Fisheries by Data Envelopment Analysis Using the General Algebraic Modelling System (GAMS): A Workbook,” report, National Marine Fisheries Service, Woods Hole, Massachusetts October 2000.