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Working Paper

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Economics working paper / Christian-Albrechts-Universität Kiel, Department of Economics, No. 2008,01

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January 7, 2008

Abstract

Several empirical studies are concerned with measuring the effect of currency and current account crises on economic growth. Using different empirical models this paper serves two aspects. It provides an explicit assessment of country specific factors influencing the costs of crises in terms of economic growth and controls via a treatment type model for possible sample selection governing the occurrence of crises in order to estimate the impact on economic growth correctly. The applied empirical models allow for rich intertemporal dependencies via serially correlated errors and capture latent country specific heterogeneity via random coefficients. For accurate estimation of the treatment type model a simulated maximum likelihood approach employing efficient importance sampling is used. The results reveal significant costs in terms of economic growth for both crises. Costs for reversals are linked to country specific variables, while costs for currency crises are not. Furthermore, shocks explaining current account reversals and growth show strong significant positive correlation.

JEL classification: F32, C15, C23, C33, O10

Keywords: Currency crises; Current account reversals; Treatment Model; Discrete dependent variable; Efficient Importance Sampling; Panel Data

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1 Introduction

Macroeconomic crises often trigger adjustment processes characterized by painful deteriorations of economic growth. Well known examples are the lessons from the Mexican crisis in 1994 and the crises in Argentina in the 1990ies. The occurrence of macroeconomic crises involve often currency crises connected to large depreciations of exchange rates preceded in case of pegged exchange rates by a depletion of international reserves. Such turbulences causing abrupt changes in the terms of trade and other prices can induce demand driven boom-bust cycles linked to the observation of induced current account reversals. Links between these two crises phenomena, also incorporated in several theoretical models concerned with inflation stabilization, see Calvo and Vegh (1999) for an overview, have been analyzed by Milesi-Ferretti and Razin (2000). The empirical literature nevertheless often captures crises episodes either via concentrating on large exchange rate and reserve level fluctuations, see e.g. Kaminsky and Reinhart, or via focusing on reversing current account balances, see e.g. Edwards (2004). Ignoring the relationship between both crises phenomena several articles analyze the relationship of these specific crises indicators on economic growth. Using the econometric methodology of Arellano and Bond (1991), Edwards (2001) highlights the negative impact of current account reversals on growth via controlling for indirect effects stemming from investment and the role large current account deficits play in financial crises episodes. Using a panel of six East Asian countries Moreno (1999) analyzes the large output contractions observed in the aftermath of crises episodes. Gupta et al. (2003) provide mixed evidence concerning whether currency crises have contractionary or expansionary effects on growth. Their analysis also establishes some stylized facts for currency crises. Currency crises on average cause an output contraction and revert growth to previous levels by the second year after the crises, but a considerable degree of heterogeneity is present. Currency crises occurring in the 1990ies do not have caused larger output contraction when compared to crises episodes in the 1970ies and 1980ies. Furthermore, larger emerging countries experience more contractionary crises than smaller ones. The idea of heterogeneity in the influence of crises depending on country specifics is also put forward by Edwards (2004) who finds that current account reversals are less severe for more open economies.

As stated above, Milesi-Ferretti and Razin (2000) analyze the empirical regularities of both crises phenomena. They observe that currency crises are often followed by reversal episodes. This observation poses two questions. First, are external currency crises inevitably followed by sharp reductions in current account deficits, and second, what is the effect of currency crises and reversals in current account balances on economic performance. Milesi-Ferretti and Razin (2000) answer these two questions using probit regressions for each type of crises measure and assess the impact of both events on economic growth by a "before-after" analysis regressing growth before and after the crises event on the binary indicators. Their main finding is that although currency crises are often followed by reversal episodes, both events exhibit distinct properties and show different influence on economic growth with reversal showing no systematic impact on growth, while currency crises cause a growth reduction. Also Komarek and Melecky (2005) provide a joint analysis of both crises. In their study they find in contrast to Milesi-Ferretti (2000) a systematic slowdown of economic growth given the occurrence of a current account reversal but no impact of currency crises on growth. Most costs of are involved for a country, when both crises occur simultaneously.

Given this empirical evidence on the influence of crises from models ignoring links incorporated by several theoretical models between the two crises indicators and economic growth, this paper fills some gaps in explaining crises and assessment of their influence on economic growth. The above cited literature either ignores the completely the links between currency crises and current account reversals, or does not account for intertemporal dependency between both crises. Furthermore, the estimated effect on economic growth is not controlled for possible sample selection. Shocks hitting economic growth may also affect the occurrence probability of crises. Ignoring this correlation would lead to biased estimates of the effect of crises on economic growth. Therefore, a joint model is needed to assess the effects correctly. Next to possibly sample selection, intertemporal links are incorporated via explicit consideration of sources of serial dependence. The proposed model framework addresses three sources of serial dependence for currency crises and current account reversals. First, serial dependence is considered via lagged crises, since the experience of past crises may affect the future occurrence probability of crises. Secondly, transitory shocks affecting the growth process and the occurrence of crises are incorporated via serial correlated errors. Thirdly, latent country specific factor possible stemming from unobserved variables may exhibit a persistent effect on crises and economic growth. This latent heterogeneity provides a source for serial dependence and possibly alters the interaction of crises and economic growth. This latent heterogeneity is captured via random coefficients within the growth equation and provides a country specific growth dynamic. Also within the equations explaining the occurrence of crises random coefficients are considered, which capture different institutional settings and economic conditions within the countries. The notion that controlling for serial dependence is essential in binary models is discussed at full length by Hyslop (1999). Falcetti and Tudela (2006) also discuss these issues and document the presence of heterogeneity and serial dependence in the context of explaining currency crises.

A further advantage of a joint modeling of economic growth, current account reversals, and currency crises with several sources of serial dependence is its capability to trace the effect of crises on economic growth over time. A shock causing the occurrence of a currency crises may simultaneously effect the growth process and the occurrence of a current account reversal. Also the next periods probability of a reversal may be altered thus rising the probability of a current account reversal in the next period thus causing further damage to economic growth. The incorporation of several sources for serial dependence allows thus a better approximation of cumulative output losses generated by the occurrence of crises.

Estimation is performed via maximum likelihood. As the likelihood function of the trivariate treatment type model given these features involves high dimensional integrals, estimation is performed using simulation techniques. To obtain accurate estimates an Efficient Importance Sampler following Liesenfeld and Richard (2007) is employed. The developed sampler incorporates the considered model features of serially correlated errors and country specific latent heterogeneity. It therefore enlarges the range of available Efficient Importance Sampler for multiperiod discrete choice models documented in the literature. The Efficient Importance Sampler is assessed within a simulation study and provides a huge (10 to 100fold) reduction of numerical simulation errors compared to the baseline GHK-sampler documented in Geweke and Keane (2001). It therefore allows to evaluate 50 dimensional integrals with the required numerical precision.

The findings of this paper can be summarized as follows. Both types of crises are associated with a growth slowdown, which is linked for reversals to country size and trade openness. While neglecting endogeneity causes a upward bias for the estimated effect of current account reversals on economic growth, no significant sample selection bias is found for a currency crises. Furthermore, the results document the presence of unobserved heterogeneity and state dependence, which has to be taken into consideration to assess the determinants and costs of crises correctly.

The paper is organized as follows. Section 2 describes the employed data, introduces the applied definitions of the analyzed crises and reviews shortly the related theoretical literature. Section 3 presents the empirical models and the applied estimation methodology. The empirical results are given in Section 4. Section 5 concludes.

2 Data Description, Crises Definition and Theoretical Background

To investigate the relationship between the two crises phenomena and the circumstances which allow a country to hinder a spreading of crises on the real economy, the following data set is used. Data is taken from the Global Development Finance database of the World Bank, the World Development Indicators (also World Bank), the International Financial Statistics and the Balance of Payments database, both International Monetary Fund. Not all variables of interest are available for all periods from 1975 to 1997, which is the time period used to construct the currency crises indicator, thus resulting in an unbalanced panel, where 67 countries are included for analysis.[1]

[1] These are: Argentina, Bangladesh, Belize, Bolivia, Botswana, Brazil, Burundi, Cameroon, Chile, China, Colombia, Costa Rica, Cyprus, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Ethiopia, Fiji, Ghana, Grenada, Guatemala, Guinea-Bissau, Guyana, Haiti, Honduras, Hungary, India, Indonesia, Jamaica, Jordan, Kenya, Korea, Lao Peoples D.R., Madagascar, Malawi, Malaysia, Mali, Malta, Mauritius, Mexico, Morocco, Mozambique, Nepal, Nicaragua, Nigeria, Pakistan, Panama, Paraguay, Peru, Philippines, Romania, Sierra Leone, South Africa, Sri Lanka, Swaziland, Syrian Arab Republic, Thailand, Trinidad & Tobago, Tunisia, Turkey, Uganda, Uruguay, Venezuela, Zambia, Zimbabwe.

The definition of a current account reversal follows Milesi-Ferretti and Razin (1998). A reversal episode in period t is given when the current account balance in t is indeed a deficit and the average current account deficit in the periods t to $t+2$ compared to the average current balance over periods $t-3$ to $t-1$ is reduced by at least 3%. A further restriction is that for a current account reversal the deficit level after the reversal does not exceed 10%. Since the use of moving averages allows to the same reduction to show up twice in the reversal indicator, the two periods following a reversal are excluded from bearing a further reversal. Moreover, the maximum deficit after a reversal is not allowed to exceed the minimum deficit before the reversal in order to classify the period as a reversal. The episodes of currency crises are taken from Glick and Hutchinson (2005). They define a currency crises upon a monthly index of currency pressure, defined as a weighted average of real exchange rate changes and monthly reserve losses taken from the International Financial Statistics database.[2] A currency crises occurs, when changes in the pressure index exceed 5% and are larger than the country specific mean plus two times the country specific standard deviation. Dependence between the two crises indicators can be assessed via a χ^2-test of independence, see Table (1). While no significant contemporaneous dependence is found, lagged currency crises and present current account reversals show strong dependency, see also Milesi-Ferretti and Razin (2000). This finding should be incorporated, when modeling the occurrence of crises and the effect of both crises on economic growth.

As explaining variables for growth and both types of crises, the following set is included as suggested by different theories. The lagged growth rate, the ratio of international reserves to broad money, investment proxied by gross fixed capital formation relative to GDP, current account deficits, trade openness, life expectancy at birth, GDP per capita in 1984 in 1000 US$, US real interest rates, and the OECD growth rates. Summary statistics are given in Table (2). The global variables, US real interest rates and OECD growth rates, capture the state of international financial markets and the state of the world business cylce affecting a countries access to international capital. The important role of the international borrowing constraint has been emphasized by Atkeson and Rios-Rull (1996). A theoretical link between investment, growth and current account balance is formalized in the balance-of-payments stages hypothesis in the work of Fischer and Franklin (1974). Life expectancy serves as a proxy of productivity thus enhancing growth, while higher GDP per capita reflects a higher level of development, where higher developed countries are expected to grow at lower rates. The ratio of international reserves to broad money (M2) functions as indicator of financial instutional development. On the one hand, a developed financial sector provides intermediary services, which should cause higher growth, on the other hand it should lower the risk of the considered crises.

The next paragraph provides some theoretical mechanisms for explaining the links and occurrence of both crises. The idea that both types of crises are closely interrelated is rooted in several theoretical

[2] The weights are inversely chosen to the variance of each component, see Kaminsky and Reinhart (1999) for details.

models established in the literature. These models, see e.g. Calvo and Vegh (1999), deal with the matter of inflation stabilization. Macroeconomic stabilization programs aiming at disinflation are assumed to cause an output contraction either at the start of the program, when a money based stabilization is implemented, or, when an exchange rate based stabilization is chosen, a later recession is likely to occur at the end of the program, see Hoffmaister and Vegh (1996) for a discussion of the "recession-now-versus-recession-later" hypothesis. The choice of the nominal anchor is, besides a choice for the timing of recession, a choice between cumulative losses involved in these crises. Various models, see Calvo and Vegh (1999) for an overview, show that stabilization programs may cause in the presence of inflation inertia or lack of credibility a currency crisis, as a formerly fixed exchange rate breaks down, thus leading furthermore to a reversing current account balance. As illustrated by the seminal model of Krugman (1979) with a fixed exchange rate mechanism, a lower interest rate on international reserves would result in faster depletion of reserves, thus enhancing the losses in reserves causing possibly a currency crises. A run on international reserves may also cause a shortening in domestic credit, as the domestic aggregate money supply decreases, see for a short discussion Flood, Garber and Kramer (1996). As argued by Milesi-Ferretti and Razin (2000) a shortening of external financing via rising world interest rates may cause a current account reversal in order to remain solvent. Decreases in domestic credit may cause a shortening in investment, especially in less developed countries (LDC), as these do not necessarily have full access to international financing. Thus a shock altering domestic credit growth and/or access to international capital markets caused by capital market liberalization as analyzed by Glick and Hutchinson (2005) may lead to alterations in a country's exposure to both types of crises. Other shocks, e.g. a temporarily income shock caused by an uprise of international prices for commodities can also influence the exposure to crises. Such an income shock, which can be temporarily or permanent, may cause a reduction in current account deficits, see Kraay and Ventura (1997) for a more complete discussion. Alterations in export prices also effect the terms of trade, which can lead according to Tornell and Lane (1998) to ambiguous effects on current account balance.

This set of different theories provides the background for the empirical models used to assess the effect of crises on growth in the next section.

3 Model Description and Estimation

This section presents the applied panel frameworks used for the analysis. Also the employed estimation methodology is introduced. Starting point is a panel model, where the effect of both crises on economic growth is considered. Two forms of heterogeneity are taken into account. The costs of crises are linked to observable specifics of a country, and the model accounts for latent country specific heterogeneity stemming from unobservable factors. Several models incorporating these two forms of heterogeneity at different degrees are considered. Afterwards, a trivariate treatment type model is analyzed in order to capture the possible endogeneity of the event of crisis.

3.1 Panel Model

As a starting point a panel model for economic growth gr_{it} in country i at time t ignoring possible endogeneity of both crises is considered. It takes the form

$$gr_{it} = X_{it}\beta_i + \gamma_{1i}(\,_1y_{it}) + \gamma_{2i}(\,_2y_{it}) + e_{it}, \quad i = 1, \ldots, n; \quad t = D(i), \ldots, T(i), \tag{1}$$

where $D(i)$ denotes the first period available for country i and $T(i)$ the last, X_{it} are (weak) exogenous regressors discussed in the literature on growth and $_1y_{it}$ and $_2y_{it}$ indicate the occurrence of a currency and reversal crisis respectively. $\gamma_{1i}(\,_1y_{it})$ and $\gamma_{2i}(\,_2y_{it})$ are functions of the crisis events taking the form[3]

$$\gamma_{ji}(\,_jy_{it}) = (\delta_j + Z_{ji}\zeta_j)y_{it}, \quad j = \{1, 2\}, \tag{2}$$

where the parameters δ_j, $j = \{1, 2\}$ measure the costs associated with the occurrence of both types of crises and the parameters ζ_j, $j = \{1, 2\}$ capture the influence of country specifics on costs. This setup allows to test several hypothesis, namely whether currency crises exhibit systematic influence on growth, and whether larger and more open economies suffer more from crises than smaller ones.

To control for country specific heterogeneity within the growth dynamics and the control variables, a random coefficient approach as suggested by Swamy (1971), Swamy and Arora (1972), and Swamy et al. (1988a, 1988b, 1989) is estimated. This random coefficient specification assumes a multivariate distribution for the parameters, which are assumed to bear unobserved country specific heterogeneity. Hence, the random coefficients are specified as[4]

$$\beta_i \overset{\text{iid}}{\sim} \mathcal{N}(b, \Omega), \tag{3}$$

thus allowing for correlation between the random coefficients via the covariance matrix Ω. Note that if X_{it} incorporates country specific time invariant regressors besides the constant no random coefficient can be assigned to these. Also the crises indicators cannot be linked to a random coefficient as not all countries experience both crises. The modeling of unobserved heterogeneity via random coefficients provides a parsimonious, yet flexible structure. Specification of a fixed effects would in contrast increase the number of parameters rapidly.

Errors are assumed to follow a moving average process of order one in order to capture via serial correlation unobserved persistence, hence

$$e_{it} = \varphi v_{it-1} + v_{it}, \quad v_{it} \overset{\text{iid}}{\sim} \mathcal{N}(0, \sigma^2). \tag{4}$$

[3] Also a specification incorporating lagged crises indicators has been estimated.

[4] Note that an interaction term between both types of crises measuring an additional effect was not significant in any specification. Note that random coefficients imply a heteroscedastic variance for the dependent variable gr_{it} given as $\Sigma + X_i^{\text{ran}'}\Omega X_i^{\text{ran}}$.

A maximum likelihood estimation is performed. Denoting the vector of all model parameters as θ, the corresponding log likelihood estimator is given as

$$\hat{\theta}_{ML} = \arg\max_{\theta} \ell(gr;\theta) = \sum_{i=1}^{n} \ln \left(\int_{\mathbb{R}^k} (2\pi)^{-\frac{t_i}{2}} \det(\Sigma_i)^{-.5} \exp\left(-\frac{1}{2} e_i \prime \Sigma_i^{-1} e_i\right) f(\beta_i) d\beta_i \right), \tag{5}$$

with t_i denotes the number of observed periods for individual i, k the number of assigned random parameters, $e_i = gr_i - X_i\beta_i - \gamma_{1i}(\cdot) - \gamma_{2i}(\cdot)$ and Σ_i given as the covariance matrix of an MA(1) process of dimension t_i. The integral within the log likelihood can be computed analytically.

The analysis of treatment measured via discrete variables in the above considered framework possibly ignores the endogeneity of both types of crises. Several frameworks suitable to cope with endogeneity and the induced bias in the parameter estimation have been suggested by Maddala (1983). Furthermore, the macroeconomic character of the data asks for cautious specification of serial correlation within the probit equations explaining the occurrence of both crises. Thus high dimensional integration methods as documented in Geweke and Keane (2001) have to be used. The next section therefore presents a model framework dealing with the matter of endogeneity and gives the used estimation methodology.

3.2 Treatment Model

To capture the influence both types of crises exhibit on economic growth of a country, a trivariate treatment type model is used allowing for possibly endogeneity of both crises in order to prevent biased estimation. The seminal papers of Heckman (1978) and Heckman (1990) have suggested several model types coping with the endogeneity of one dummy variable. This approach given below extends the setting under consideration of random coefficients to two possible endogenous indicator variables. The growth equation given in Equation (1) is linked to two equations explaining the occurrence of both crises, which constitute a bivariate probit model given as

$$_1y_{it} = \begin{cases} 1, & \text{if } _1y_{it}^* \geq 0 \\ 0, & \text{if } _1y_{it}^* < 0 \end{cases}, \qquad _2y_{it} = \begin{cases} 1, & \text{if } _2y_{it}^* \geq 0 \\ 0, & \text{if } _2y_{it}^* < 0 \end{cases}, \tag{6}$$

$$_1y_{it}^* = X_{it}^{(1)}\beta_{1i} + \delta_{11}\ _1y_{it-1} + \delta_{12}\ _2y_{it-1} + \ _1e_{it}, \tag{7}$$

$$_2y_{it}^* = X_{it}^{(2)}\beta_{2i} + \delta_{21}\ _1y_{it-1} + \delta_{22}\ _2y_{it-1} + \ _2e_{it}. \tag{8}$$

Equations (8) and (9) link the latent variables for currency crises and current account reversals to explanatory factors discussed in the literature. Via inclusion of the lagged binary variables, the model is able to deal with state dependence. Furthermore, as suggested by Falcetti and Tudela (2006), serial correlation is modeled within the error terms, thus capturing correlation of shocks over time. Allowing for serially correlated errors hinders an improper treatment of the conditional relationship between future and past crises called spurious state dependence, see Hyslop (1999). Hence the errors are given as a bivariate autoregressive process of order one, modeled as

$$\begin{pmatrix} {}_1e_{it} \\ {}_2e_{it} \end{pmatrix} = \begin{pmatrix} \varphi_1 & 0 \\ 0 & \varphi_2 \end{pmatrix} \begin{pmatrix} {}_1e_{it-1} \\ {}_2e_{it-1} \end{pmatrix} + \begin{pmatrix} {}_1u_{it} \\ {}_2u_{it} \end{pmatrix}. \tag{9}$$

With respect to the error structure of the three equations, a trivariate normal distribution is assumed given as

$$\begin{pmatrix} e_{it} \\ {}_1u_{it} \\ {}_2u_{it} \end{pmatrix} \sim \mathcal{N}(0, \Sigma), \quad \Sigma = \begin{pmatrix} \sigma^2 & \psi_1 & \psi_2 \\ \psi_1 & 1 & \rho \\ \psi_2 & \rho & 1 \end{pmatrix}. \tag{10}$$

This quite general error structure allows to incorporate forms of serial correlation of shocks between the different equation, allowing for rich intertemporal dependencies. Furthermore, again heterogeneity stemming from differences with regard to the institutional background of countries are taken into consideration via random coefficients assigned to several variables with

$$\beta_{1i} \overset{\text{iid}}{\sim} \mathcal{N}(b_1, W_1) \quad \text{and} \quad \beta_{2i} \overset{\text{iid}}{\sim} \mathcal{N}(b_2, W_2). \tag{11}$$

Given this model setup one can state the selection bias occurring when endogeneity of the crises dummies is ignored as follows. Assume for simplicity the random coefficients as given and the absence of any serial correlation structure within the errors. The conditional expectation given the explaining variables and the occurrence of both crises can be expressed as

$$\begin{aligned} E[gr_{it} |\ {}_1y_{it} = 1,\ {}_2y_{it} = 1, X_{it}] &= X_{it}\beta_i + \gamma_1(\ {}_1y_{it}) + \gamma_2(\ {}_2y_{it}) \qquad (12) \\ &\quad + \begin{pmatrix} \psi_1 & \psi_2 \end{pmatrix} \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix}^{-1} E\left[\begin{pmatrix} {}_1u_{it} \\ {}_2u_{it} \end{pmatrix} |\ {}_1y^*_{it} > 0,\ {}_2y^*_{it} > 0 \right], \end{aligned}$$

where the conditional expectation of the errors of the probit equation conditional on the event of crises has the form

$$E\left[\begin{pmatrix} {}_1u_{it} \\ {}_2u_{it} \end{pmatrix} |\ {}_1y^*_{it} > 0,\ {}_2y^*_{it} > 0 \right] = \begin{pmatrix} \frac{\phi(h)\left[1-\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]+\rho\phi(k)\left[1-\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]}{\Pr(\ {}_1u_{it}>h,\ {}_2u_{it}>k)} \\ \frac{\rho\phi(h)\left[1-\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]+\phi(k)\left[1-\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]}{\Pr(\ {}_1u_{it}>h,\ {}_2u_{it}>k)} \end{pmatrix}, \tag{13}$$

where

$$h = -(X^{(1)}_{it}\beta_{1i} + \delta_{11}\ {}_1y_{it-1} + \delta_{12}\ {}_2y_{it-1}), \qquad k = -(X^{(2)}_{it}\beta_{2i} + \delta_{21}\ {}_1y_{it-1} + \delta_{22}\ {}_2y_{it-1}) \tag{14}$$

and $\Pr(\ {}_1u_{it} > h,\ {}_2u_{it} > k))$ is the joint probability derived from the bivariate normal distribution.[5] The expectation in Equation (13) is a bivariate extension of the well known Mills's ratio. Inclusion

[5]For a derivation of these moments of the truncated bivariate normal distribution, see Rosenbaum (1961) and Regier and Hamdan (1971).

of Mill's ratio as a further regressor within a two step estimation procedure would also be possible but less efficient than a simultaneous estimation of all parameters. Thus ignoring sample selection induces a bias depending on the covariance parameters of the trivariate normal distribution.

The model shall be investigated via a (simulated) maximum likelihood estimation. The properties of the simulation based estimator have been analyzed by Gourieroux and Monfort (1996).The likelihood contribution of country i conditional on the random parameter of the growth equation can be stated as

$$L_{i|\beta_i} = f(gr_{i\cdot}|\beta_i) \left[\iint \left(\int \cdots \int f_{\epsilon_{i\cdot}|gr_{i\cdot}}(\epsilon_{iD(i)}, \ldots, \epsilon_{iT(i)}) d\epsilon_{iD(i)} \cdots d\epsilon_{iT(i)} \right) f(\beta_{1i}, \beta_{2i}) d\beta_{1i} d\beta_{2i} \right], \quad (15)$$

where $\epsilon_{i,t} = (\ _1e_{it},\ _2e_{it})$ and $f_{\epsilon_{i\cdot}|gr_{i\cdot}}$ denotes the conditional distribution of the latent errors given growth $gr_{i\cdot}$. The log likelihood is hence obtained as

$$\ell(gr; \theta) = \sum_{i=1}^{N} \log \left(\int L_{i|\beta_i} f(\beta_i) d\beta_i \right). \quad (16)$$

As the likelihood contains integrals with up to fifty dimensions in the present application, an Efficient Importance Sampler based on the GHK procedure of Geweke et al. (1994), Hajivassiliou (1990), and Keane (1993, 1994) is used adapting the Sampler of Liesenfeld and Richard (2007) developed in the context of the multiperiod multinomial probit model. The sampler is constructed in order to allow accurate computation of the involved integrals and therefore reduces the simulation error affecting parameter estimates to conventional levels. The incorporation of random coefficients within an Efficient Importance Sampler in the context of a treatment type model is new in the literature.[6] The sampler uses importance densities based on gaussian kernels and builds upon the Cholesky decomposition employed in the GHK-sampler, which is described in detail in Geweke and Keane (2001) in the context of the multinomial multiperiod probit model. The necessity to improve the GHK-procedure arises also, as documented in Geweke et al. (1997), from the serious bias in parameter estimates, especially, when high correlation is prevailing. Improvement of integration accuracy is achieved via the use of simple Least-Square optimizations, which transfer information concerning sampling moments in the likelihood structure ignored within the standard GHK procedure towards the sequentially employed importance sampling densities. The derivation of sampling moments, a full description of the integrating constants, the structure of the algorithm, and further technical details are given in Appendix B. The appropriateness of the employed Efficient Importance Sampler is illustrated by a Monte Carlo Simulation in Appendix C.

The next section gives the empirical results of the different models and discusses the determinants and costs of both types of crises.

[6]Note that the implemented sampler is also suited to cover the multinomial multiperiod probit model with unobserved heterogeneity.

4 Empirical Results

Within this section the estimation results for the different models are presented. The first subsection gives the results for the univariate model, while the second is concerned with the bivariate treatment model, where possible endogeneity of crises is controlled. The estimates are obtained as described above by (simulated) maximum likelihood estimation and are based upon 500 draws. The MC errors are calculated using 20 different sets of common random numbers for estimation.

4.1 Panel Model

The estimates of the panel model described in Equations 1 to 4 are given in Table 3. In order to test the hypotheses on the heterogeneous influence of both crises, three specifications allowing for various degree of heterogeneity are considered. Specification I considers no heterogeneity for crises and no heterogeneity among the explaining variables of economic growth. The estimates reveal significant costs for both types of crises. The occurrence of a current account reversal reduces economic growth initially by 1.0541 percentage points, while a currency crises leads to a contraction of output by 1.244 percentage points. The results are controlled for several typical macroeconomic variables considered as determinants of growth within the empirical literature. The financial development of a country is captured by the ratio of reserves to broad money. A low value proxies a more developed financial and banking sector of a country. The estimates indicate no significant influence of this variable. Also higher investment is significantly correlated with higher economic growth. Country specifics are captured by the variables life expectation and GDP per capita. Life expectation serves as a proxy for productivity and human capital. On the one hand higher GDP per capita also signals productivity, which can be expected to generate growth, on the other it proxies more generally the stage of development of a country, where classical theory suggests that less developed countries grow faster. Both variables have expected signs. Higher life expectancy enhances growth positively, while higher GDP per capita is related to lower growth, but only the effect of GDP per capita on growth is estimated significant. Trade openness and lagged ratio of current account balance to GDP are included to control for the degree of international integration of an economy. Current account deficits and trade openness reflect access to international financial and world goods markets, what possibly enhances higher growth. Both variables have positive sign, although both are not significantly estimated at conventional levels. Also the global variables U.S. real interest rates and OECD growth rate show significant influence on economic growth. While higher U.S. real interest rates have negative influence on growth, OECD growth rates enhance growth. The positive influence of OECD growth on growth of the analyzed sample of merely developing and emerging markets can be explained via a higher demand for commodities, which constitute a large fraction of exports for these countries. The negative influence of US real interest rates may be based upon a rationing of international capital available for more risky investment in these countries.

Specifications II and III extend Specification I in order to test for heterogeneity within the influences of both types of crises. Specification II considers the interaction between both crises and a country's size measured by GDP per capita in 1984, as well as a country's trade openness. With respect to the interaction of country specific with the influence of reversals, the findings suggest that larger countries suffer more from the occurrence of reversals and more openness can hinder a damaging effect. Both estimates are highly significant at the 1% level. The interaction between country specifics and the costs involved in currency crises is less clear. Again estimated coefficients point towards higher costs for larger economies and lower costs for more open economies, but neither coefficient is estimated significant. Although the three parameters capturing the effect of currency crises on economic growth are according to an LR test jointly significant, a test for joint significance of the two interaction terms of trade openness, and country size with currency crises confirms the finding of both interactions being insignificant. Thus the results so far confirm the results presented by Edwards (2004) that the influence current account reversals exhibit on economic growth depends on the country specific characteristic of trade openness. Also the idea of Gupta et al. (2003) that larger countries experience more severe losses in output growth is confirmed, but only for reversals, while no systematic heterogenous influence is present for currency crises.

The next Specification III considers random coefficients within the explanatory variables of economic growth. This accounts for possible heterogeneity within the growth dynamics of a country. The results document a considerable degree of heterogeneity captured by the random coefficients with significant standard deviations for lagged economic growth, the level of reserves, and the US real interest rates. Specifying heterogeneity in this way allows for a country specific growth path characterized by specific dynamics and unconditional growth. The importance of country specific dynamics of growth, which is likely present due to institutional differences, has been emphasized by Lee et al. (1998). Two alternative specifications of the matrix Ω have been considered. The above results refer to a diagonal specification, thus independent random coefficients. Results based on a fully specified covariance matrix (not reported here) revealed similar results. The documented costs of both types of crises as in Specification II are also present, when heterogeneity is incorporated within the growth equation. Model fitness for all three specifications is also assessed via adjusted coefficients of determination (adj. R^2). Calculation in case of random coefficients is based on expected β_i's, see Appendix E for details. The figures are given in the last row of Table (3) and show an increase from 0.208 to 0.348 in model fitness, when heterogeneity in costs and country specific growth dynamic are considered.

Summarizing, the results presented so far document heterogeneity for the influence of reversals, but possibly lack the control for endogeneity of both types of crises. Thus the next section presents the results for a bivariate treatment model.

4.2 Treatment Model

The estimation results concerning the Bivariate Treatment model incorporating serial correlation and heterogeneity in the sense of Specification III of the previous section are given in Table (5).[7] With respect to the determinants of both types of crises, an analysis based on a Bivariate Probit model provides similar results, which are given in Table (4).

Considered determinants of both crises are lagged current account deficits, money reserves ratio, investment, life expectation, lagged economic growth, trade openness, lagged crises indicators, and the global variables, US real interest rates and OECD growth rates. The estimates suggest that higher current account deficits significantly raise the probability of a current account reversal, while showing no significant influence on the occurrence probability of a currency crises. This finding is consistent with the analysis of current account sustainability, which has been triggered since the Mexican crises in 1994, see Milesi-Ferretti and Razin (1996), and Ansari (2004). Global portfolio investment, as argued by Calvo (1998), may be more sensitive to shocks given already high deficits. Therefore, even smaller shocks are sufficient to render capital flows, thus enhancing current account reversals.

A lower ratio of international reserves to broad money increases significantly the probability of both types of crises. This finding can be linked to theoretical issues. In typical models of balance of payment crises as in Flood and Garber (1984) and Obstfeld (1994), the crises occurs when the stock of reserves is depleted. Hence, the higher the reserves are, the later if at all, the crisis will occur. As mentioned above this variable captures also the stage of development of the financial institutions, where a lower money to reserves ratio captures less development. The results suggest that this channel seems less important in the context of crises or is dominated by the role of international reserves.

Life expectancy as a proxy of productivity is estimated significantly for both types of crises. Higher productivity may increase the export capabilities of a country. Its negative effect on the occurrence of currency crises might capture the stabilizing effect of a developed institutional background, which is also reflected in higher life expectancy. Although not significant, trade openness has a stabilizing effect on the occurrence of both types of crises, as a higher degree of trade openness allows a country to smooth domestic shocks. Investment, while also having no significant influence on the occurrence of currency crises, positively affects the probability of a current account reversal. Higher investment as argued by Blanchard (2006) strengthens a countries ability to pay of current account deficits via raising exports. GDP growth, while not significant for both types of crises, exhibits negative influence on the probability of both crises. Higher growth can be a signal of a sound macroeconomic environment, which decreases the probability of financial crises.

[7] Thereby some insignificant random coefficients have not been considered further.

The global variables, US real interest rates and OECD growth rates, which capture the influence of the international business cycle on the occurrence of crises in the analyzed set of (mostly) developing countries, effect the probability of experiencing a reversal positive and are both significant at conventional levels. Such an influence is in line with the theoretical strand of literature, which argues that a shortening of external finance capabilities enhanced by a rise in safe interest rates and higher growth rates in more developed countries signaling investment opportunities, leads either to capital outflow or a less inflow of capital, or both. In the context of current account reversals higher OECD growth rates may reflect higher exports of commodities, which is often a substantial fraction of export revenues for the analyzed countries. This channel has been emphasized by Obstfeld and Rogoff (2000), i.e. a current account reversal occurs to ensure the solvency of a country in face of shortened external finance. For currency crises only the global variable US real interest rate shows significant influence on the probability of a currency crises. One could argue along Hoffmaister and Vegh (1996) that countries vulnerable to currency crises often have a high degree of dollarization, which is an often observed phenomenon in high inflation periods. Hence a higher US interest rate possibly accelerates the money outflow and thus rises the probability of a currency crises.

The lagged binary indicators of both crises are included to capture possible state dependence. Both have significant influence on the probability of a current account reversal. As argued by Falcetti and Tudela (2006) state dependence occurs, when a past crisis has a structural effect on the economic constraints and behavior involved in crises. The positive effect of lagged currency crises, which is typically connected to a devaluation of currency, seems to influence the trade and financial capabilities of a country, thus rising the probability of a current account reversal. Note that allowing the error structure to capture serial correlation hinders to assign state dependence spuriously to past crises. Current account reversals show significant negative influence on future reversals. For currency crises no influence is found of lagged current account reversals. This confirms the theoretical suggestion of Calvo and Mendoza (1996) that a currency crisis raises the probability of a balance of payments crisis. Past currency crises influence the probability of a crisis today negatively. One could argue that there is a kind of learning effect of economic agents (e.g. government) which renders the probability of a currency crash, but basically this results could reflect the depletion of international reserve hindering a renewed run on international assets.

Besides controlling for state dependence via inclusion of the lagged binary indicators, the model incorporates two other forms of serial dependence. Transitory serial dependence is incorporated via autocorrelated errors in order not to assign state dependence spuriously to lagged crises indicators. Persistent country specific heterogeneity stemming from unobserved factors is incorporated via random parameters. The correlation parameters for the two probit equations are all not estimated significantly. Thus implying that unobserved shocks are neither serially correlated nor correlated between equations. Country specific heterogeneity incorporated via random coefficients is assigned to both constants in order to incorporate a random effect, to the current account deficit for reversals, and to the level of reserves for currency crisis respectively. Only the lagged current account deficit exhibits heterogenous influence on the occurrence of current account reversals. This might reflect the observation that some countries provide investment opportunities, which are viewed as solid, thus causing no higher risk of a current account reversal.

The estimated effect of both types of crises on economic growth are given in the last column of Table (5). Taking the endogeneity of both types of crises into account alters the estimated costs of both types of crises. In order to test for significance of the covariance parameters governing the sample selection mechanism, univariate asymptotic t-tests are accompanied by LR-tests assessing the joint significance. Therefore the log likelihood value of the bivariate treatment model is compared to the sum of log likelihood values obtained from an estimation of a bivariate probit model and the estimated growth model. The estimated growth model is readily contained within the specification of the bivariate treatment model and allows to judge the determinants of both types of crises phenomena. Table (6) gives the log likelihood values for specifications allowing different degrees of serial correlation and heterogeneity. They are estimated jointly and separately, thus ignoring sample selection, in order to check for robustness. The first lines give the log likelihood value in case, when no serial correlation and no heterogeneity is considered, while the next specification incorporates serial correlation. The third specification considers heterogeneity but no serial correlation, and finally, the last one considers heterogeneity and serial correlation. The corresponding LR test statistics indicate significance of all treatment specifications at the 1% level. The results suggest that only current account reversals are subject to a sample selection mechanism. The unobservable shocks of growth an reversals are positively correlated, such that neglecting this correlation leads to upward biased estimates.

The severity of both crises shall be assessed via computation of cumulative output losses involved in the occurrence of each type of crisis over time. The analyzed model framework providing a rich structure of intertemporal dependence seems well suited to capture the influence of crises over time. Cumulated output loss is conceptualized as

$$E\left[\sum_{t=0}^{t^*} gr_t |\text{ shock in } t=0, X^{\text{shock}}\right] - E\left[\sum_{t=0}^{t^*} gr_t |\text{ no shock in } t=0, X^{\text{no shock}}\right].$$

The conditioning on two different sets of explaining variables is necessary in order to capture the reaction of the weak exogenous regressors on the shock as e.g. the ratio of reserves to broad money responds to the occurrence of crises.

The two profiles of regressors capturing the behavior of regressors in case of a shock are constructed as follows. In order to mimic the reaction of explaining variables in case of a shock in a representative manner, all crises episodes are monitored and the average for the variables is computed in the period of occurrence and the following periods. In case of no shock, the average is computed over the periods before the first crisis is observed. For the strict exogenous regressors capturing the state of global business cycle and world financial markets, two different scenarios are considered in order to capture a prosperous and a frail state of the world economy. Scenario I is characterized with high OECD growth rates and high US real interest rates, where high interest and growth rates are measure as the 75% quantile of the rates observed over the period 1975 to 2004. Scenario II corresponds to a more fragile state of the world economy with low growth and interest rates set as the 25% quantiles of observed interest and growth rates. The expectations stating the cumulative output losses are calculated via simulation, see Appendix D for details.

The results are given in Table (7) and can be summarized as follows. Currency crises are less costly and cause only significant costs in the period of occurrence. Furthermore, the costs are higher when the world economy is in a favorable state. This reflects the opportunity costs of growth. i.e. growth would have been high in absence of a currency crises. The costs in involved in a reversal are higher and are also significant in the period following the reversal episode. Profiles of growth given the occurrence of a crisis under the different considered global states are plotted in Figure (1). The estimated costs as delivered by the treatment model suggest a larger discrepancy than the cumulated output losses given in the bottom row of Table (7). This illustrates the raise in the occurrence probability of a reversal conditional on a currency crises occurred in the previous period. Thus neglecting the interdependence of both types of crises causes an underestimation of involved costs. The result presented here are therefore at odds to those of Komarek and Melecky (2005) who report no direct effect of currency crises on economic growth and support the view of Milesi-Ferretti and Razin (1998) who report that currency crises are less distortive with respect to output performance than current account reversals. Both studies do not control for the possible endogeneity of both types of crises.

Also the allowed heterogeneity within the growth equations confirms the findings of the previous panel specification. The estimates characterize the present heterogeneity as a random effect, heterogeneous growth dynamics, and heterogeneity within the influence of investment. Overall the numerical MC errors are sufficiently small in to order to guarantee valid inference.

The two specifications presented here are consistent with the stylized facts discussed in the empirical literature on determinants of currency crises and current account reversals and their influence on economic growth. The estimation takes explicitly the endogeneity of both types of crises into account and documents higher costs for reversals when sample selection is taken into account.

5 Conclusion and Outlook

Within this paper the effect of macroeconomic crises such as currency crises and current account reversals on economic growth is analyzed. This paper contributes an analysis allowing an explicit modeling of heterogeneity within the impact of crises. Also the possible endogeneity is controlled via a Treatment framework. Sources of serial dependence are incorporated within the model and estimation is performed based on Simulated Maximum Likelihood. For accurate calculation of the involved integrals, an Efficient Importance Sampling approach is developed and its performance is assessed. The results suggest an huge increase in integration accuracy, which allows to perform the required estimation properly. Using explaining variables discussed in the empirical literature on currency crises and current account reversals, two model specifications one allowing to control for possible endogeneity are used to capture the influence of both crises. The estimation results can be summarized as follows. Firstly, both types of crises have negative effects on economic growth in the period of occurrence. Secondly ,while the effect of a reversal crisis is significantly depending on a country's size and openness, the effect of a currency crisis is not. Thirdly, significant heterogeneity prevails within the growth equation connected with the steady state level and growth dynamics captured via random coefficients. Fourthly, the estimation results of the Trivariate Treatment type model controlling for possible endogeneity suggest differences in the estimated costs of reversal crises on economic growth. Reversal are causing large reduction in growth than currency crises. Accounting for endogeneity results in higher estimated costs as unobserved shocks are correlated for both equations explaining growth and the occurrence of current account reversals. Finally, currency crises serve as leading indicators of current account reversals.

An interesting expansion of analysis could be to assess the influence of both forms of crises via a nonparametric setting leaving the functional form unspecified. Nevertheless, this is beyond the scope of this paper and left for future research.

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Appendix

A – Integration of the Likelihood for the Linear Panel Model with Random Coefficients

The integral within the likelihood

$$\int_{R^k} (2\pi)^{-t_i/2} \det(\Sigma_i)^{-1/2} \exp\{-\frac{1}{2} e_i \Sigma_i^{-1} e_i\} f(\beta_i) d\beta_i$$

with k denoting the number of random coefficients has the following solution. Since $e_i = gr_i - \overline{X}_i' \overline{\beta} - X_i \beta_i$ denote $v_i = gr_i - \overline{X}_i' \overline{\beta}$. Then the integral expression can be rearranged as

$$\begin{aligned} & (2\pi)^{-t_i/2} \det(\Sigma_i)^{-1/2} \int_{R^k} \exp\{-\frac{1}{2} \left((v_i - X_i\beta_i)'\Sigma_i^{-1}(v_i - X_i\beta_i) + (\beta_i - b)'\Omega^{-1}(\beta_i - b)\right)\} d\beta_i \\ = \; & (2\pi)^{-t_i/2-k/2} \det(\Omega)^{-1/2} \det(\Sigma_i)^{-1/2} \Xi_i \int_{R^k} \exp\{-\frac{1}{2} \left((\beta_i - \hat{\beta}_i)'\Psi_i(\beta_i - \hat{\beta}_i) + (\beta_i - b)'\Omega^{-1}(\beta_i - b)\right)\} d\beta_i, \end{aligned}$$

where

$$\hat{\beta}_i = (X_i'\Sigma_i^{-1}X_i)^{-1} X_i'\Sigma_i^{-1} v_i, \quad \Psi_i = (X_i'\Sigma_i^{-1}X_i), \quad \Xi_i = \exp\{\frac{1}{2} \left(v_i'\Sigma_i^{-1}X_i\Psi^{-1}X_i'\Sigma_i^{-1}v_i - v_i'\Sigma_i^{-1}v_i\right)\}.$$

The above given quadratic forms in β_i can simplified towards

$$(2\pi)^{-t_i/2-k/2} \det(\Omega)^{-1/2} \det(\Sigma_i)^{-1/2} \Xi_i \int_{R^k} \exp\{-\frac{1}{2} \left((\beta_i - \tilde{\beta})'(\Psi_i^{-1} + \Omega)^{-1}(\beta_i - \tilde{\beta}) + (\hat{\beta} - b)'(\Psi_i^{-1} + \Omega)^{-1}(\hat{\beta} - b)\right)\} d\beta_i,$$

where $\tilde{\beta} = (\Psi_i^{-1} + \Omega)^{-1}(X_i'\Sigma_i^{-1}v_i + \Omega^{-1}b)$. Thus the solution is

$$(2\pi)^{-t_i/2} \det(\Psi_i^{-1} + \Omega)^{1/2} \det(\Omega)^{-1/2} \det(\Sigma_i)^{-1/2} \exp\{-\frac{1}{2} \left((\hat{\beta} - b)'(\Psi_i^{-1} + \Omega)^{-1}(\hat{\beta} - b)\right)\} \Xi_i.$$

Summing up over all individuals provides the likelihood of the model.

B – Estimation of Bivariate Treatment Model with Serial Correlation and Random Coefficients via an Efficient Importance Sampler

In order to obtain accurate estimates of the integral quantities involved within the likelihood, an efficient importance sampler based on the GHK-simulator of Geweke (1991), Börsch-Supan and Hajivassiliou (1993), and Geweke, Keane, and Runkle (1997) is employed. The Efficient Importance Sampler (EIS) for the Bivariate Treatment Model with serially correlated errors and random effects is based on Liesenfeld and Richard (2007) who establish an EIS sampler for the multiperiod multinomial probit model with serial correlation within the error terms. In contrast to the multinomial probit model the lower bound for integration is not for all time periods given as $-\infty$. This asks for another handling of the integrating constant of the considered importance densities and for several refinements of the Efficient Importance sampler in order to obtain an efficiency gain. The covariance structure of the model with serial correlation provides a setup in which not necessarily the nearest neighboring observation provides the most information about the sampling moments of the efficient sampler. Therefore, the integrating constant is ordered in such a way that each part containing only information from another time period is redirected to this very period. Importance Sampling based on the GHK procedure relies on proposal densities "which ignore critical information relative to the underlying correlation structure of the model under consideration, leading to potentially significant efficiency losses" (Liesenfeld and Richard (2007), p. 2). Efficiency improvements are achieved by simple Least-Squares approximations.

The likelihood for country i takes via combining Equations (17) and (18) the form

$$L_i = \int_{R^{k_0+k_1+k_2}} \int_{R^{2t_i}} f_{\epsilon_{i\cdot}|e_{i\cdot},\underline{\beta}_i}(\epsilon_{iD(i)}, \ldots, \epsilon_{iT(i)}) d\epsilon_{i\cdot} f(e_{i\cdot}|\underline{\beta}_i) f(\underline{\beta}_i) d\underline{\beta}_i, \tag{17}$$

where $\epsilon_{i,t} = (\ {}_1e_{it},\ {}_2e_{it})$ and $f_{\epsilon_{i\cdot}|gr_{i\cdot}}$ denotes the conditional distribution of the latent errors given growth $gr_{i\cdot}$ and random coefficients of all equations, which have to be integrated out afterwards. The integral of dimension $2t_i$ approximates the probability of the observed crises indicators conditional on $gr_{i\cdot}$ and the involved random coefficients within the probit equations, i.e.

$$\begin{aligned} \kappa^{(m)} &= \Pr{}^{(m)}_{gr_{i\cdot}}(a^{(1)}_{it} \le \epsilon^{(1)}_{it} \le b^{(1)}_{it}, a^{(2)}_{it} \le \epsilon^{(2)}_{it} \le b^{(2)}_{it} : t = D(i), \ldots, T(i)) \\ &\approx \int \cdots \int f_{\epsilon_{i\cdot}|gr_{i\cdot}}(\epsilon_{iD(i)}, \ldots, \epsilon_{iT(i)}) d\epsilon_{iD(i)} \cdots d\epsilon_{iT(i)}. \end{aligned}$$

This probability corresponds to a high dimensional integral over a multivariate normal distribution. Since the joint distribution of all errors for country i has a normal distribution with moments

$$\mu = \left(O_{3(T(i)-D(i)+1)\times 1} \right) \quad \text{and} \quad \Omega = \begin{pmatrix} \Sigma_{11} & \Sigma_{12} & \Sigma_{13} \\ \Sigma_{21} & \Sigma_{22} & \Sigma_{23} \\ \Sigma_{31} & \Sigma_{32} & \Sigma_{33} \end{pmatrix},$$

where Σ_{11} denote the covariance structure of a MA(1) process, and Σ_{22} and Σ_{33} give the covariance matrix of an AR(1) process, each of dimension $T(i) - D(i) + 1$. The matrices Σ_{12}, Σ_{23}, and Σ_{23} are given as

$$\Sigma_{12} = \Sigma'_{21} = \begin{pmatrix} \psi_1(1+\varphi\varphi_1) & \psi_1(1+\varphi\varphi_1)\varphi_1 & \psi_1(1+\varphi\varphi_1)\varphi_1^2 & \ldots & \psi_1(1+\varphi\varphi_1)\varphi_1^{T(i)-D(i)} \\ \psi_1\varphi & \psi_1(1+\varphi\varphi_1) & \psi_1(1+\varphi\varphi_1)\varphi_1 & \ldots & \psi_1(1+\varphi\varphi_1)\varphi_1^{T(i)-D(i)-1} \\ 0 & \ddots & & \ldots & \vdots \\ \vdots & & & \psi_1(1+\varphi\varphi_1) & \psi_1(1+\varphi\varphi_1)\varphi_1 \\ 0 & \ldots & 0 & \psi_1\varphi & \psi_1(1+\varphi\varphi_1) \end{pmatrix},$$

$$\Sigma_{13} = \Sigma'_{31} = \begin{pmatrix} \psi_2(1+\varphi\varphi_2) & \psi_2(1+\varphi\varphi_2)\varphi_2 & \psi_2(1+\varphi\varphi_2)\varphi_2^2 & \ldots & \psi_2(1+\varphi\varphi_2)\varphi_2^{T(i)-D(i)} \\ \psi_2\varphi & \psi_2(1+\varphi\varphi_2) & \psi_2(1+\varphi\varphi_2)\varphi_2 & \ldots & \psi_2(1+\varphi\varphi_2)\varphi_2^{T(i)-D(i)-1} \\ 0 & \ddots & & \ldots & \vdots \\ \vdots & & & \psi_2(1+\varphi\varphi_2) & \psi_2(1+\varphi\varphi_2)\varphi_2 \\ 0 & \ldots & 0 & \psi_2\varphi & \psi_2(1+\varphi\varphi_2) \end{pmatrix},$$

and

$$\Sigma_{23} = \Sigma'_{32} = \frac{\rho}{1-\varphi_1\varphi_2} \begin{pmatrix} 1 & \varphi_1 & \varphi_1^2 & \ldots & \varphi_1^{T(i)-D(i)} \\ \varphi_2 & 1 & \varphi_1 & \ldots & \varphi_1^{T(i)-D(i)-1} \\ \varphi_2^2 & \ddots & 1 & \ldots & \vdots \\ \vdots & & & 1 & \varphi_1 \\ \varphi_2^{T(i)-D(i)} & \varphi_2^{T(i)-D(i)-1} & \ldots & \varphi_2 & 1 \end{pmatrix}.$$

Hence the conditional distribution of the errors within the probit equations has moments given as

$$\mu_c = \begin{pmatrix} \Sigma_{21} \\ \Sigma_{32} \end{pmatrix} \Sigma_{11}^{-1} \hat{e}^{(0)}_{i\cdot} \quad \text{and} \quad \Omega_c = \begin{pmatrix} \Sigma_{22} & \Sigma_{23} \\ \Sigma_{32} & \sigma_{33} \end{pmatrix} - \begin{pmatrix} \Sigma_{21} \\ \Sigma_{32} \end{pmatrix} \Sigma_{11}^{-1} \begin{pmatrix} \Sigma_{12} & \Sigma_{23} \end{pmatrix},$$

where $\hat{e}_{i.}^{(0)}$ is the realized residual of the growth equation given as $gr_i - X_i\beta - X_i^{\text{ran}}\beta_i - \gamma_1(\cdot) - \gamma_2(\cdot)$.

Given these preliminaries, the integration problem can be rephrased employing the Cholesky factorization of the covariance matrix. The considered integral gives the likelihood contribution of the ith panel member. For ease of notation indices referring to individual i are dropped. It is given as

$$L = \int_{R^{k_0+k_1+k_2}} \int_{R^{2t_i}} \prod_{t=1}^{2t_i} D_t \phi(x_t) d\underline{x} f(gr|\underline{\alpha}) f(\underline{\alpha}) d\underline{\alpha}$$

where $k - 0$, k_1 and k_2 denote the number of random coefficients in the growth and probit Equations 1 and 2 respectively, $\phi()$ denotes the density of a standard normal distribution, $f(gr)$ denotes the distribution of observed growth rates conditional on the random coefficients, $f(\underline{\alpha})$ denotes the joint unconditional distribution of the random effects, and the range of integration is given as

$$D_t = I\left[\left(\frac{-\mu_t - H_t\underline{\alpha} - L_{t,1:t-1}\underline{x}_{t-1}}{L_{t,t}}, \infty\right)^{y_{it}} \left(-\infty, \frac{-\mu_t - H_t\underline{\alpha} - L_{t,1:t-1}\underline{x}_{t-1}}{L_{t,t}}\right)^{1-y_{it}}\right],$$

where L refers to the Cholesky decomposition of the Ω^c,

$$\mu_t = X_t^{1,2}\beta^{1,2} - \begin{pmatrix} \Sigma_{12} \\ \Sigma_{32} \end{pmatrix} \Sigma_{11}^{-1}(gr_t - X_0\beta^0)$$

and

$$H_t = \begin{cases} (-\begin{pmatrix} \Sigma_{21} \\ \Sigma_{32} \end{pmatrix} \Sigma_{11}^{-1} X_{0r}^{\text{ran}} \quad X_{1r}^{\text{ran}} \quad 0) & \text{if } t \text{ is odd;} \\ (-\begin{pmatrix} \Sigma_{21} \\ \Sigma_{32} \end{pmatrix} \Sigma_{11}^{-1} X_{0r}^{\text{ran}} \quad 0 \quad X_{2r}^{\text{ran}}), & \text{if } t \text{ is even.} \end{cases}$$

Denote $\underline{\eta}_t = (\underline{\alpha}, \underline{x}_t)$ The importance sampling densities are introduced as follows

$$\int_{R^{2t_i+k_0+k_1+k_2}} \frac{D_{2t_i}\phi(x_{2t_i})}{k_{2t_i}(\underline{\eta}_{2t_i})} \prod_{t=2}^{2t_i-1} \frac{\chi_{t+1}(\underline{\eta}_t)D_t\phi(x_{t-1})}{k_t(\underline{\eta}_{t-1})} \frac{\chi_2(\underline{\eta}_1)D_1\phi(x_1)}{\frac{k_1(\underline{\eta}_1)}{\chi_1(\underline{\alpha})}}$$
$$\frac{f(gr|\underline{\alpha})f(\underline{\alpha})}{m_0(\underline{\alpha})} \prod_{t=2}^{2t_i} m_t(x_i|\underline{x}_{i-1}, \underline{\alpha}) m_1(x_1|\underline{\alpha}) m_0(\underline{\alpha}) d\underline{x} d\underline{\alpha},$$

where $m_t(x_t|\underline{\eta}_{t-1})$ denotes the conditional density of x_t given $\underline{\eta}_{t-1}$ derived out of $k_t(\underline{x}_t)/\chi_t(\underline{\eta}_t)$. The task is to find the moments of $m_t(\cdot)$ and forms of the integrating constants $\chi_t(\cdot)$ and kernels $k_t(\cdot)$ such that the closest possible fitting of the importance density is obtained. With respect to the importance density of the random effects the density is chosen in order to match the integrating constant left from the integration of the errors best. Note that parts of the integrating constants for the errors do only depend on the random effects and are hence directly incorporated in $m_0(\cdot)$. The following paragraph will explicitly state the forms of all integrating constants and the conditional moments of the importance density.

In general the following form for $k_t(\cdot)$ shall be considered

$$k_t(\underline{\eta}_t) = \frac{1}{\sqrt{2\pi}} D_t \exp\left\{-\frac{1}{2}\left[\underline{\eta}_t{}' P_t \underline{\eta}_t - 2\underline{\eta}_t{}' q_t + r_t\right]\right\}. \tag{18}$$

The forms of P_t, q_t and r_t and the corresponding values of $\chi_t(\cdot)$ have to be considered for each period recursively. Furthermore, define for notational convenience

$$\begin{aligned}
a_{t-1} &= \frac{\frac{-\mu_t}{L_{t,t}} - \mu^c_{1t}}{\sigma^c_t}, \\
h_{t-1} &= \frac{\frac{-H_t}{L_{t,t}} - \mu^c_{2t}}{\sigma^c_t}, \\
b_{t-1} &= \frac{\frac{-L_{t,1:t-1}}{L_{t,t}} - \mu^c_{3t}}{\sigma^c_t}, \\
\delta_t &= 1 - 2y_t, \\
\omega_t(\underline{\eta}_t) = \omega_t &= (a_t + h_t\underline{\alpha} + b_t\underline{x}_t),
\end{aligned}$$

where μ^c_{1t}, μ^c_{2t} and μ^c_{3t} are parts of the conditional mean μ^c_t and σ^c_t denotes the conditional moments of the conditional sampling densities for x_t. Note that given this notation the integrating constant takes the general form

$$\chi_t(\underline{\eta}_{t-1}) = \sigma^c_t \Phi(\delta_t \omega_{t-1}) \exp -\frac{1}{2}[\underline{\eta}_{t-1}\prime P^*_{t-1}\underline{\eta}_{t-1} - 2\underline{\eta}_{t-1}\prime q^*_{t-1} + r^*_{t-1}].$$

The specific evolution of the integrating constants and the conditional moments are obtained via a backward recursion.

Period $2t_i$: $k_{2t_i}(\cdot)$ is chosen such that a close match to $D_{2t_i}\phi(x_{2t_i})$ is achieved. In this case perfect fit can be achieved by setting

$$\begin{aligned}
P_{2t_i} &= e_{2t_i} e_{2t_i}\prime, \quad e_{2t_i} = (0, 0, \ldots, 0, 1)\prime \in R^{2t_i+k_0+k_1+k_2}, \\
q_{2t_i} &= (0, \ldots, 0)' \in R^{2t_i+k_1+k_2}, \\
r_{2t_i} &= 0.
\end{aligned}$$

This choice results in $\mu^c_{2t_i} = 0$, where $\mu_{1,2t_i} = 0$, $\mu_{2,2t_i} = (00)$, $\mu_{3,2t_i} = (0 \ldots 0) \in R^{2t_i - 1}$, and $\sigma^c_{2t_i} = 1$ and provides the corresponding integrating constant given as

$$\chi_{2t_i}(\underline{\eta}_{2t_i-1}, \underline{\alpha}) = \Phi\left(\delta_{2t_i} w_{2t_i-1}\right).$$

Note that in period $2t_i$ no part of the integrating constant can be isolated to depend solemnly on the random effects. This will be different in the following periods.

Period $2t_i - 1$: $k_{2t_i-1}(\cdot)$ is chosen to match $\chi_{2t_i}(\underline{\eta}_{2t_i-1}) D_{2t_i-1}\phi(x_{2t_i-1})$. Key part is to set the kernel $k_{2t_i-1}(\underline{\eta}_{2t_i-1})$ equal to

$$k_{2t_i-1}(\underline{\eta}_{2t_i-1}) = \frac{1}{\sqrt{2\pi}} D_{2t_i-1} \exp\left\{-\frac{1}{2}\left[x^2_{2t_i-1} + \hat{\alpha}_{2t_i-1}\omega^2_{2t_i-1} - 2\hat{\beta}_{2t_i-1}\omega_{2t_i-1}\right]\right\},$$

where $\hat{\alpha}_{2t_i-1}$ and $\hat{\beta}_{2t_i-1}$ are obtained from the regression

$$\log\left(\Phi(\delta_{2t_i}\omega_{2t_i-1})\right) = \tilde{c}_0 + \tilde{c}_1\omega_{2t_i-1} + \tilde{c}_2\omega^2_{2t_i-1},$$

with $\tilde{c}_1 = \hat{\beta}_{2t_i-1}$ and $\tilde{c}_2 = -\frac{1}{2}\hat{\alpha}_{2t_i-1}$. This choice for $k_{2t_i-1}(\underline{\eta}_{2t_i-1})$ can be represented in the form given in Equation (18) by setting

$$
\begin{aligned}
P_{2t_i-1} &= e_{2t_i-1}e'_{2t_i-1} + \hat{\alpha}_{2t_i-1}\begin{pmatrix} h'_{2t_i-1} \\ b'_{2t_i-1} \end{pmatrix}\begin{pmatrix} h_{2t_i-1} & b_{2t_i-1} \end{pmatrix}, \quad e_{2t_i-1} = (0,\ldots,0,1)\prime, \\
q_{2t_i-1} &= \left[(\hat{\beta}_{2t_i-1} - \hat{\alpha}_{2t_i-1}a_t)\begin{pmatrix} h'_{2t_i-1} \\ b'_{2t_i-1} \end{pmatrix}\right] \\
r_{2t_i-1} &= \hat{\alpha}_{2t_i-1}(a_{2t_i-1})^2 - 2\hat{\beta}_{2t_i-1}(a_{2t_i-1}).
\end{aligned}
$$

Given this form for $k_{2t_i-1}(\underline{\eta}_{2t_i-1})$ the integrating constant is obtained via

$$
\begin{aligned}
\chi_{2t_i-1}(\underline{\eta}_{2t_i-2}) &= \int D_{2t_i-1}k_{2t_i-1}(\underline{\eta}_{2t_i-1})dx_{2t_i-1} \\
&= \Phi\left(\delta_{2t_i-1}\omega_{2t_i-2}\right) \\
&\quad \exp\left\{-\frac{1}{2}\left[\underline{\eta}'_{2t_i-2}P^*_{2t_i-2}\underline{\eta}_{2t_i-2} - 2\underline{\eta}_{2t_i-2}\prime q^*_{2t_i-2} + r^*_{2t_i-2}\right]\right\}
\end{aligned} \tag{19}
$$

with

$$
\begin{aligned}
P^*_{2t_i-2} &= P^I_{2t_i-1} - \frac{P^{III}_{2t_i-1}\prime P^{III}_{2t_i-1}}{P^{II}_{2t_i-1}}, \\
q^*_{2t_i-2} &= q^I_{2t_i-1} - \frac{q^{II}_{2t_i-1}P^{III}_{2t_i-1}}{P^{II}_{2t_i-1}}, \\
r^*_{2t_i-2} &= r_{2t_i-1} - \left(\frac{q^{II}_{2t_i-1}}{\sqrt{P^{II}_{2t_i-1}}}\right)^2 + \log(P^{II}_{2t_i-1}),
\end{aligned}
$$

Superscript I, II, III refer to partitions of the matrices P_t and q_t given as

$$
P_t = \begin{pmatrix} P^I_t & P^{III}_t\prime \\ P^{III}_t & P^{II}_t \end{pmatrix}, \quad q_t = \begin{pmatrix} q^I_t \\ q^{II}_t \end{pmatrix}.
$$

Within the integration performed in Equation (19), the conditional moments used for sampling of x_{2t_i-1} are identified as

$$
\mu^c_{2t_i-1} = \frac{q^{II}_{2t_i-1} - P^{III}_{2t_i-1}\underline{\eta}_{2t_i-2}}{P^{II}_{2t_i-1}} \quad \text{and} \quad \sigma^c_{2t_i-1} = \frac{1}{\sqrt{P^{II}_{2t_i-1}}},
$$

where

$$
\begin{aligned}
\mu^c_{2t_i-1} &= \frac{q^{II}_{2t_i-1} - P^{III}_{2t_i-1}\underline{\eta}_{2t_i-2}}{P^{II}_{2t_i-1}} \\
&= \frac{q^{II}_{\mu,2t_i-1} - P^{III}_{\alpha,2t_i-1}\underline{\alpha} - P^{III}_{x,2t_i-1}\underline{x}_{2t_i-2}}{P^{II}_{2t_i-1}} \\
&= \mu_{1,2t_i-1} + \mu_{\alpha,2t_i-1}\underline{\alpha} + \mu_{x,2t_i-1}\underline{x}_{2t_i-2}.
\end{aligned}
$$

Period $t : 2 \to 2t_i - 2$: Given the results from period $2t_i - 1$ for the following periods a recursive relationship for the integrating constant and conditional moments can be established. The kernel $k_t(\underline{\eta}_t)$ is given as

$$
k_t(\underline{\eta}_t) = \frac{1}{\sqrt{2\pi}}D_t \exp\left\{-\frac{1}{2}\left[\underline{\eta}'_t P_t \underline{\eta}_t - 2q'_t\underline{\eta}_t + r_t\right]\right\},
$$

where

$$\begin{aligned}
P_t &= e_t e_t' + \hat{\alpha}_t \begin{pmatrix} h_t' \\ b_t \end{pmatrix} \begin{pmatrix} h_t & b_t \end{pmatrix} + P_t^*, \\
q_t &= q_t^* + (\hat{\beta}_t - \hat{\alpha}_t a_t) \begin{pmatrix} h_t' \\ b_t' \end{pmatrix}, \\
r_t &= r_t^* - 2\hat{\beta}_t(a_t) + \hat{\alpha}_t(a_t)^2.
\end{aligned}$$

The corresponding conditional moments are given as

$$\mu_t^c = \frac{q_t^{II} - P_t^{III}\prime \underline{\eta}_{t-1}}{P_t^{II}} \quad \text{and} \quad \sigma_t^c = \frac{1}{\sqrt{P_t^{II}}},$$

where

$$\begin{aligned}
\mu_t^c &= \frac{q_t^{II} - P_t^{III} \underline{\eta}_t}{P_t^{II}} \\
&= \frac{q_{\mu,t}^{II} - P_{\alpha,t}^{III} \underline{\alpha} - P_{x,t}^{III} \underline{x}_t}{P_t^{II}} \\
&= \mu_{1,t} + \mu_{\alpha,t}\underline{\alpha} + \mu_{x,t}\underline{x}_t,
\end{aligned}$$

and the integrating constant takes the form

$$\begin{aligned}
\chi_t(\underline{\eta}_{t-1}) &= \sigma_t^c \Phi\left(\delta_t \omega_{t-1}\right) \\
&\quad \exp\left\{-\frac{1}{2}\left[\underline{\eta}_{t-1}' P_{t-1}^* \underline{\eta}_{t-1} - 2\underline{\eta}_{t-1}\prime q_{t-1}^* + r_{t-1}^*\right]\right\}
\end{aligned}$$

and

$$\begin{aligned}
P_{t-1}^* &= P_t^I - \frac{P_t^{III}\prime P_t^{III}}{P_t^{II}}, \\
q_{t-1}^* &= q_t^I - \frac{q_t^{II} p_t^{III}}{p_t^{II}}, \\
r_{t-1}^* &= r_t - \left(\frac{q_t^{II}}{\sqrt{p_t^{II}}}\right)^2 + \log(p_t^{II}).
\end{aligned}$$

Period 1: For the first period the kernel $k_1(\cdot)$ takes the form

$$k_1(\underline{\eta}_1) = \frac{1}{\sqrt{2\pi}} D_1 \exp\{-\frac{1}{2}[\underline{\eta}_1 P_1 \underline{\eta}_1 - 2q_1\underline{\eta}_1 + r_1]\},$$

where

$$\begin{aligned}
P_1 &= e_1 e_1' + \hat{\alpha}_1 \begin{pmatrix} h_1' \\ b_1 \end{pmatrix} \begin{pmatrix} h_1 & b_1 \end{pmatrix} + P_1^*, \\
q_1 &= q_1^* + (\hat{\beta}_1 - \hat{\alpha}_1 a_1) \begin{pmatrix} h_1' \\ b_1 \end{pmatrix}, \\
r_1 &= r_1^* - 2\hat{\beta}_1(a_1) + \hat{\alpha}_1(a_1)^2.
\end{aligned}$$

Hence, the integrating constant takes the form

$$\chi_1(\underline{\alpha}) = \Phi\left(\delta_1(a_0 - h_0\underline{\alpha})\right) \exp\left\{-\frac{1}{2}\left(\underline{\alpha}' P_0^* \underline{\alpha} - 2\underline{\alpha} q_0^* + r_0^*\right)\right\},$$

where

$$
\begin{aligned}
P_0^* &= P_1^I - \frac{P_1^{III}{\prime} P_1^{III}}{P_1^{II}}, \\
q_0^* &= q_1^I - \frac{q_1^{II} P_1^{III}}{P_1^{II}}, \\
r_0^* &= r_1 - \left(\frac{q_1^{II}}{\sqrt{P_1^{II}}} \right)^2 + \log(P_1^{II}).
\end{aligned}
$$

and the conditional moments are given as

$$
\mu_1^c = \frac{q_1^{II} - P_1^{II} \underline{\alpha}}{P_1^{II}}, \quad \text{and} \quad \sigma_1^c = \frac{1}{\sqrt{P_1^{II}}}.
$$

Sampling of the random coefficients: Since the integrating constant in period 1 is a quadratic form of $\underline{\alpha}$, the kernel is given as

$$
k_0(\underline{\alpha}) = \exp\{-\frac{1}{2} \left[\underline{\alpha}' P_0 \underline{\alpha} - 2 q_0 \underline{\alpha} + r_0\right]\},
$$

where

$$
\begin{aligned}
P_0 &= \Upsilon + P_0^* + \hat{\alpha}_0 (h_0' h_0), \\
q_0 &= q_0^* + (\hat{\beta}_0 - \hat{\alpha}_o a_0) h_0 + q_\alpha, \\
r_0 &= \hat{\alpha}_0 a_0^2 - 2 \hat{\beta}_0 a_0 + r_0^* + r_\alpha.
\end{aligned}
$$

Note that via Υ, q_α, and r_α the distributions $f(gr|\underline{\alpha}) f(\underline{\alpha})$ are taken into account. The derivation is following the principles laid down in Appendix A. These parameters are given as

$$
\begin{aligned}
\Upsilon &= \Psi + \Omega^{-1}, \\
q_\alpha &= \Psi \underline{\hat{\alpha}}, \\
r_\alpha &= \underline{\hat{\alpha}}' \Psi \underline{\hat{\alpha}} - gr' \Sigma_{11}^{-1} X_{0r} \Psi^{-1} X_{or}' \Sigma_{11}^{-1} gr + gr' \Sigma_{11}^{-1} gr.
\end{aligned}
$$

Thereby

$$
\Psi = \begin{pmatrix} X_{0r}' \Sigma_{11}^{-1} X_{0r} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \quad \text{and} \quad \underline{\hat{\alpha}} = \begin{pmatrix} (X_{0r}' \Sigma_{11}^{-1} X_{0r})^{-1} X_{0r}' \Sigma_{11}^{-1} v_i \\ 0 \\ 0 \end{pmatrix}
$$

The moments are given as

$$
\begin{aligned}
\Sigma_{\underline{\alpha}} &= P_0^{-1}, \\
\mu_{\underline{\alpha}} &= P_0^{-1} q_0,
\end{aligned}
$$

and the integrating constant is given as

$$
\chi_0 = (2\pi)^{-t_i/2} \exp\{\frac{1}{2}[q_0' P_0 q_0 - r_0]\} \det(P_0^{-1})^{.5} \det(\Omega)^{-.5} \det(\Sigma_{11})^{-.5}
$$

Given the EIS regression coefficients the estimate of the integral providing the likelihood contribution is obtained via collecting all integrating constants. It takes therefore the form

$$\hat{p} = \frac{1}{S}\sum_{s=1}^{S}\prod_{t=2}^{2t_i}\left(\frac{D_t^{(s)}\phi(x_t^{(s)})\chi_t(\underline{x}_{t-1}^{(s)},\underline{\alpha}^{(s)})}{k_t(\underline{x}_t^{(s)},\underline{\alpha}^{(s)})}\right)\frac{D_1\phi(x_1^{(s)})\chi_1(x_1^{(s)},\underline{\alpha}^{(s)})}{k_1(x_1^{(s)},\underline{\alpha}^{(s)})}\frac{f(\underline{\alpha}^{(s)})}{m_0(\underline{\alpha}^{(s)})}.$$

After discarding the terms included in the nominator and denominator, this expression can be restated as

$$\hat{p} = \frac{1}{S}\sum_{s=1}^{S}\left[\prod_{t=2}^{2t_i}\frac{\Phi(\delta_{t+1}\tilde{\omega}_t^{(s)})}{\exp\{-\frac{1}{2}(\tilde{\alpha}_t[\tilde{\omega}_t^{(s)}]^2-2\hat{\beta}_t\tilde{\omega}_t^{(s)})\}}\right]\frac{\Phi(\delta_1(a_0+h_0\underline{\alpha}^{(s)}))}{\exp\{-.5(\hat{\alpha}_0(a_0+h_0\underline{\alpha}^{(s)})^2)-2\hat{\beta}_0(a_0+h_0\underline{\alpha}^{(s)})\}}\chi_0.$$

C – Monte Carlo Studies for Assessment of Efficient Importance Sampling Accuracy

Three Monte Carlo studies shall be performed to highlight the increase in numerical accuracy achieved by the efficient importance sampler. These experiments are performed for the Bivariate Probit Model with serially correlated errors and random coefficients. This model exhibits the same features for integrational purposes, but is slightly more handy to deal with.

For reference, the results for the Efficient Importance Sampler are compared to the results obtained using the GHK-sampler. Data sets stemming from the bivariate probit model are generated, whereas a constant and two regressor are considered within in both equations. One of the regressors and the constants are assigned to bear a random coefficient. Several parameter constellations are analyzed, with varying degree of serial correlation. The results are based on three different scenarios for the structural parameters $\theta = (\underline{\beta}_1, \underline{\beta}_2, \rho, \psi_1, \psi_2, \underline{\alpha}_1, \underline{\alpha}_2)$. These are

- set I: $\underline{\beta}_1 = (-.8, .1, -.3)$, $\underline{\beta}_2 = (.3, -.2, .3)$, $\rho = -.2$, $\psi_1 = -.2$, $\psi_2 = .3$, $\underline{\alpha}_1 = (.4, .5)$, $\underline{\alpha}_2 = (.5, .8)$.
- set II: $\underline{\beta}_1 = (-.8, .1, -.3)$, $\underline{\beta}_2 = (.3, -.2, .3)$, $\rho = .2$, $\psi_1 = .8$, $\psi_2 = .3$, $\underline{\alpha}_1 = (.8, .5)$, $\underline{\alpha}_2 = (1, .2)$.
- set III: $\underline{\beta}_1 = (-.8, .1, -.3)$, $\underline{\beta}_2 = (.3, -.2, .3)$, $\rho = .6$, $\psi_1 = -.5$, $\psi_2 = .5$, $\underline{\alpha}_1 = (.2, .1)$, $\underline{\alpha}_2 = (.5, .8)$.

Experiment I

The experiment has the following setup. A data set consisting out of one individual and different number of time periods $T = (5, 10, 20, 50)$ is generated. Then the corresponding integral providing the log likelihood is evaluated for 1000 different sets of common random numbers. The integral is evaluated via GHK and GHK-EIS. The results for the simulated (negative) log likelihood are given in Table 1 below. Integral evaluation is based in 500 draws. The results indicate a 100fold reduction in the MC standard error across all considered scenarios. The obtained reduction rises as the number of time periods increases, while the observed MC error are larger, when the underlying serial correlation and correlation across equations is higher. For $T = 5$ the reduction is 5-10fold while for $T = 50$ the reduction is up to 100fold. The differences between the two samplers can be explained on basis of the bias, which the GHK-simulator displays for high dimensional integrals.

Experiment II

Experiment II checks whether the samplers deliver accurate Hessian matrices in order to have a correct assessment of the sample uncertainty, which is essential for testing, see Geweke et al. (1997). Hence, data sets for the different parameter constellations were generated. Each data set is estimated with the same set of common random numbers and a period length of $T = 20$. Estimation is based on 50 draws for integration. Table 2 gives the results for the MC study. The columns report the true parameter value of the data generating process (DGP), the average parameter estimate, the standard deviation of parameter estimates, the root mean squared error, the mean absolute error, and the average standard error calculated via inversion of the Hessian matrix (first for GHK sampler, then for GHK-EIS sampler; from left to right). The results show for all three parameter scenarios that with respect to the mean parameters both samplers deliver average asymptotic standard errors, which are similar to the empirical standard deviations of the estimates. In general deviations between asymptotic and empirical standard deviations are smaller for the GHK-EIS procedure.

For the correlation and variance parameters, the performance of the GHK-EIS procedure is superior compared to the GHK procedure. Mean absolute deviations are smaller for correlation and variance parameters. Also the mean asymptotic standard errors are in general closer to their empirical counterparts for correlation and variance parameters and all three parameter scenarios.

Experiment III

Experiment III checks the transmission of the numerical inaccuracy involved in the integration on parameter estimates for one data set. Therefore a data set under different parameter constellations is generated and repeated estimation is performed using different set of common random numbers (CRN) for integration. Table 3 shows hence for different parameter constellations the true values of the data generating process, the average estimates, and the involved MC errors for the different parameters and the bias. Estimation is based on 50 draws used for each integration. Performance measures are calculated with respect to pseudo true values, which are obtained via estimation based on $S = 500$ draws. The results suggest 10 to 100fold reduction in the numerical standard errors, which indicates a sharp increase in the accuracy of estimation for one data set and the involved testing.

D – Calculation of Expected Output Losses

The simulation of the involved expectations is done in two main steps.

1. Simulate the errors such that the assumed shock (currency crisis are current account reversal) takes place, i.e.

$$e,\ {}_1e,\ {}_2e|\ {}_jy_0 = 1, X \sim \mathcal{N}()$$

2. Given the errors, iterate over the periods $t = 0, 1, \ldots, t^*$, in the following way

   (a) Given the simulated trajectories errors, calculate trajectories for ${}_1y_t^*$, ${}_2y_t^*$ and ${}_1y_t$, ${}_2y_t$ correspondingly.

   (b) Calculate trajectories for gr_t given ${}_1y_t$, ${}_2y_t$. Proceed with period $t + 1$.

E – Calculation of adjusted R^2

Adjusted coefficients of determination are based on expected random coefficients β_i. These are calculated via numerical integration as

$$E[\beta_i|\text{data}_i,\theta] = \frac{\int \beta_i L(\theta;\text{data}_i)d\beta_i}{\int L(\theta;\text{data}_i)d\beta_i}.$$

This integrational problem is solved using the GHK-EIS procedure. The denominator is readily calculated within the estimation procedure, while the nominator requires a further run of the algorithm. In case of the treatment model the adjusted R^2 is calculated for the growth equation including the expected Mills' ratios for each period, which is only possible, when no serial correlation is considered within the errors (no serial correlation is estimated significantly). Hence the derived adjusted R^2 is only a proxy for model fitness. The considered cases for the Mill's ratio are

1. ${}_1y_{it} = 1,\ {}_2y_{it} = 1$:

$$\begin{pmatrix} \frac{\phi(h)\left[1-\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]+\rho\phi(k)\left[1-\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]}{\Pr({}_1u_{it}>h,\ {}_2u_{it}>k)} \\ \frac{\rho\phi(h)\left[1-\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]+\phi(k)\left[1-\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]}{\Pr({}_1u_{it}>h,\ {}_2u_{it}>k)} \end{pmatrix}.$$

2. ${}_1y_{it} = 0,\ {}_2y_{it} = 1$:

$$\begin{pmatrix} \frac{-\phi(h)\left[1-\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]-\rho\phi(k)\left[\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]}{\Pr({}_1u_{it}>h,\ {}_2u_{it}<k)} \\ \frac{-\rho\phi(h)\left[1-\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]+\phi(k)\left[\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]}{\Pr({}_1u_{it}>h,\ {}_2u_{it}<k)} \end{pmatrix}.$$

3. ${}_1y_{it} = 1,\ {}_2y_{it} = 0$:

$$\begin{pmatrix} \frac{\phi(h)\left[\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]-\rho\phi(k)\left[1-\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]}{\Pr({}_1u_{it}<h,\ {}_2u_{it}>k)} \\ \frac{\rho\phi(h)\left[\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]-\phi(k)\left[1-\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]}{\Pr({}_1u_{it}<h,\ {}_2u_{it}>k)} \end{pmatrix}.$$

4. ${}_0y_{it} = 0,\ {}_2y_{it} = 0$:

$$\begin{pmatrix} \frac{\phi(h)\left[-\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]+\rho\phi(k)\left[-\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]}{\Pr({}_1u_{it}<h,\ {}_2u_{it}<k)} \\ \frac{\rho\phi(h)\left[-\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]+\phi(k)\left[-\Phi\left(\frac{k-\rho h}{\sqrt{1-\rho^2}}\right)\right]}{\Pr({}_1u_{it}<h,\ {}_2u_{it}<k)} \end{pmatrix}.$$

Tables

Table 1: Joint Occurrence of Currency Crises and Current Account Reversals

↓ currency crises, → reversals											
t, t				$t-1$,t				t,$t-1$			
	0	1	$\sum cr$		0	1	$\sum cr$		0	1	$\sum cr$
0	972	59	1031	0	924	51	975	0	911	58	975
1	122	8	130	1	106	13	119	1	119	6	119
$\sum rev$	1094	67	1161	$\sum rev$	1030	64	1094	$\sum rev$	1030	64	1094
$\chi^2 = 0.0395(0.8425)$				$\chi^2 = 6.2424(0.0125)$				$\chi^2 = 0.2825(0.5951)$			

Notes: The χ^2 test statistics follow a χ^2 distribution with one degree of freedom; p-values are given in parenthesis; cr and rev refer to currency crises and current account reversals respectively.

Table 2: List of Variables and Summary Statistics

variable	frequency	data source	mean	sd
current account balance as % of GDP	annual	WDI	-4.2610	6.2851
GDP growth	annual	WDI	3.5739	4.9729
gross fixed investment as % of GDP	annual	WDI	22.3613	7.7402
trade openness	annual	WDI	65.8738	41.4010
annual OECD growth rates	annual	OECD	2.6922	1.3492
US real interest rates	annual	WDI	5.0311	2.4573
life expectancy at birth in total years in 1997	–	WDI	62.6982	11.1418
GDP per capita in 1984 (1000$)	–	WDI	1.6572	1.6297
money (M2) reserves ratio	annual	WDI	5.0392	52.6280
# observations		1161		
time period		1975-1997 (unbalanced)		

Table 3: Panel Model of Growth - Maximum Likelihood Estimation

	I	*II*	*III*
con	-0.2371 (1.0675)	-0.2851 (1.0625)	0.0271 (1.0613)
growth $t-1$	0.5092^{**} (0.0667)	0.4826^{**} (0.0678)	0.2254^{**} (0.0931)
reserves	0.0014 (0.0028)	0.0013 (0.0027)	-0.0207^{*} (0.0114)
investment $t-1$	0.0503^{**} (0.0223)	0.0558^{**} (0.0268)	0.0273 (0.0338)
current account	0.0372 (0.0268)	0.0424 (0.0294)	0.2800 (0.3872)
trade openness	0.0520 (0.0367)	0.0379 (0.0443)	0.1000^{*} (0.0602)
σ_{con}	–	–	0.0010 (0.7192)
σ_{growth}	–	–	0.2175^{**} (0.0418)
σ_{reserves}	–	–	0.0331^{**} (0.0153)
$\sigma_{\text{investment}}$	–	–	0.0089 (0.0288)
$\sigma_{\text{current account}}$	–	–	0.0803 (0.4403)
$\sigma_{\text{trade openness}}$	–	–	0.0028 (0.0608)
US real interest rate	-0.1591^{*} (0.0889)	-0.1744^{**} (0.0838)	-0.2897^{**} (0.1016)
OECD growth rate	0.3011^{**} (0.1174)	0.3154^{**} (0.1129)	0.3531^{**} (0.1098)
$\sigma_{\text{US real int. rate}}$	–	–	0.1353^{**} (0.0584)
$\sigma_{\text{OECD growth}}$	–	–	0.0256 (0.1462)
life expectation	0.2054 (0.1706)	0.2092 (0.1699)	0.4698^{**} (0.2384)
GDP p.c. in 1000$ in 1984	-0.2180^{**} (0.1072)	-0.1303 (0.1156)	-0.3026^{*} (0.1628)
γ_1 – reversal	-1.0541^{*} (0.6152)	-1.6132 (1.2620)	-2.0651^{**} (1.0365)
GDP p.c. $\times$ reversal	–	-1.0328^{**} (0.3684)	-1.2558^{**} (0.3402)
trade $\times$ reversal	–	0.3634^{**} (0.1685)	0.4619^{**} (0.1484)
γ_2 – currency crisis	-1.2444^{**} (0.4438)	-0.5584 (1.0077)	-0.4538 (0.9790)
GDP p.c. $\times$ currency cr.	–	-0.4029 (0.2742)	-0.3095 (0.2480)
trade $\times$ currency cr.	–	0.0007 (0.1312)	-0.0037 (0.1160)
ρ	-0.2652^{**} (0.0761)	-0.2352^{**} (0.0727)	0.0327 (0.1089)
σ	4.3358 (0.0973)	4.3107 (0.0975)	4.0466 (0.1015)
log likelihood	-3159.5	-3152.7	-3131.9
adj. R^2	0.208	0.216	0.348

Notes: Asymptotic standard errors are given in parentheses; ** denotes significance at the one sided 1% level; * denotes significance at the one sided 5% level.

Table 4: Bivariate Probit

	reversal	MC	crises	MC
constant	-6.3079^{**} (0.9873)	0.0103	-0.9169^{*} (0.4767)	0.0020
reserves	0.0134^{**} (0.0059)	0.0000	0.0074^{*} (0.0043)	0.0000
investment	0.0176 (0.0137)	0.0001	0.0039 (0.0092)	0.0000
life expectation	0.3171^{**} (0.1210)	0.0007	-0.1089^{*} (0.0647)	0.0001
current account deficit	-0.1264^{**} (0.0278)	0.0005	−0.0054 (0.0097)	0.0000
trade	−0.0223 (0.0263)	0.0001	−0.0216 (0.0165)	0.0001
growth	−0.0277 (0.0177)	0.0000	−0.0131 (0.0118)	0.0000
US real interest rates	0.1673^{**} (0.0553)	0.0002	0.0594^{*} (0.0346)	0.0002
OECD growth rates	0.2078^{**} (0.0677)	0.0006	0.0558 (0.0445)	0.0001
lagged currency crises	0.3690^{*} (0.2179)	0.0006	-4.8182^{**} (1.0004)	0.0043
lagged reversal	-1.3232^{**} (0.5791)	0.0079	−0.2231 (0.2393)	0.0011
σ_{con}	0.0002 (1.0417)	0.0027	0.0285 (0.4404)	0.0056
$\sigma_{\text{cad}}/\sigma_{\text{res}}$	0.0606^{**} (0.0177)	0.0004	0.0001 (0.0055)	0.0000
φ_1/φ_2	−0.1276 (0.1714)	0.0030	0.1169 (0.2532)	0.0009
ρ	−0.0467 (0.1258)	0.0012		
log likelihood	-557.2507	0.0571		
Pseudo R^2	0.119			

Notes: Asymptotic standard errors are given in parentheses; ** denotes significance at the one sided 1% level; * denotes significance at the one sided 5% level. Estimates are based on $S = 500$. MC errors are obtained via 20 independent replications.

Table 5: Bivariate Treatment

	reversal	MC	crises	MC	growth	MC
constant	−6.4498** (0.8570)	0.0376	−0.9321** (0.4109)	0.0043	0.4414 (1.0338)	0.1279
reserves	0.0104** (0.0048)	0.0013	0.0077** (0.0038)	0.0005	−0.0593** (0.0168)	0.0122
investment	0.0204* (0.0112)	0.0003	0.0037 (0.0088)	0.0001	0.0418 (0.0283)	0.0047
life expectation	0.3457** (0.1060)	0.0047	−0.1072* (0.0578)	0.0005	0.5082** (0.2006)	0.0047
current account deficit	−0.1258** (0.0224)	0.0011	−0.0056 (0.0091)	0.0001	0.0179 (0.0285)	0.0024
trade	−0.0237 (0.0217)	0.0004	−0.0218 (0.0145)	0.0002	0.0834 (0.0544)	0.0030
growth	−0.0259 (0.0179)	0.0015	−0.0127 (0.0108)	0.0002	0.1651** (0.0765)	0.0001
lagged currency crises	0.3907** (0.1759)	0.0013	−3.8014** (1.0026)	0.3991	–	–
lagged reversal	−1.2302** (0.4393)	0.0013	−0.2348 (0.2472)	0.0067	–	–
US real interest rates	0.1560** (0.0499)	0.0005	0.0608* (0.0333)	0.0003	−0.2507** (0.0865)	0.0007
OECD growth rates	0.2258** (0.0619)	0.0026	0.0561 (0.0433)	0.0002	0.4133** (0.1067)	0.0025
GDP per capita	–	–	–	–	−0.2933* (0.1528)	0.0052
currency crises	–	–	–	–	−0.3423 (1.9160)	0.0329
currency × GDP	–	–	–	–	−0.3642 (0.2363)	0.0089
currency crises × trade	–	–	–	–	0.0469 (0.1104)	0.0018
reversal	–	–	–	–	−6.2109** (2.2533)	0.0069
reversal × GDP	–	–	–	–	−1.2038** (0.3428)	0.0045
reversal × trade	–	–	–	–	0.4857** (0.1739)	0.0064
σ_{con}	0.0001 (1.0632)	0.0002	0.0338 (0.1933)	0.0151	0.7973* (0.3952)	0.2364
$\sigma_{\text{cad}}/\sigma_{\text{growth}}$	0.0658** (0.0133)	0.0006	–	–	0.2303** (0.0537)	0.0015
σ_{res}	–	–	0.0031 (0.0130)	0.0010	0.0350** (0.0166)	0.0055
$\sigma_{\text{investment}}$	–	–	–	–	0.0135 (0.0204)	0.0084
$\sigma_{\text{US real int.}}$	–	–	–	–	0.0212 (0.1323)	0.0174
$\varphi_1/\varphi_2/\varphi_0$	−0.0213 (0.1145)	0.0156	0.1445 (0.1659)	0.0009	0.0942 (0.0784)	0.0032
$\psi_1/\psi_2/\rho$	0.5835** (0.1507)	0.0060	0.0783 (0.1127)	0.0028	−0.0664 (0.1075)	0.0113
log likelihood/ adj. R^2 / σ	-3677.6	0.0571	0.367		4.1135 (0.1419)	0.0044

Notes: Asymptotic standard errors are given in parentheses; ** denotes significance at the one sided 1% level; * denotes significance at the one sided 5% level. Estimates are based on $S = 500$. MC errors are obtained via 20 independent replications.

Table 6: Model Specification Tests

	log likelihood		MC
pooled		-3716.0	0.0173
separate	-566.0+(-3157.4)	-3723.4	0.0189
LR-statistic		14.8***	
serial + no het.		-3711.2	0.0451
separate	-565.7+(-3152.7)	-3718.4	0.0233
LR-statistic		14.3***	
no serial + het.		-3678.1	0.0678
separate	-557.4+(-3132.6)	-3690.0	0.0435
LR-statistic		23.8***	
serial + het.		-3677.9	0.0660
separate	-557.4+(-3131.9)	-3689.3	0.0583
LR-statistic		22.8***	

Notes: *** denotes significance at the one sided 1% level; ** denotes significance at the one sided 5% level; * denotes significance at the one sided 10% level. Estimates are based on $S = 500$. MC errors are obtained via 20 independent replications.

Table 7: (Cumulated) Output Losses

	currency crises I		currency crises II		reversal crises I		reversal crises II	
	Loss	95% CI	Loss	95% CI	Loss	95% CI	Loss	95%CI
$t = 0$	-2.1508	$[-3.3038 ; -1.0111]$	-3.5212	$[-4.7283 ; -2.2701]$	-3.8455	$[-5.0670 ; -2.7496]$	-5.1339	$[-6.3165 ; -3.8486]$
$t = 1$	-0.3627	$[-1.0134 ; 0.2892]$	-0.1893	$[-0.9909 ; 0.5974]$	-0.9314	$[-1.5952 ; -0.3026]$	-0.8638	$[-1.6961 ; -0.0352]$
$t = 2$	0.0014	$[-0.6766 ; 0.6672]$	-0.0392	$[-0.8980 ; 0.8327]$	-0.4304	$[-1.1368 ; 0.2170]$	-0.5849	$[-1.4189 ; 0.2559]$
$t = 3$	0.2186	$[-0.4223 ; 0.8945]$	0.4977	$[-0.3907 ; 1.3161]$	-0.0282	$[-0.6520 ; 0.5797]$	0.2396	$[-0.5032 ; 1.0009]$
$\sum$	-2.2935	$[-4.1768 ; -0.3679]$	-3.2520	$[-5.3650 ; -0.9758]$	-5.2354	$[-7.2941 ; -3.3646]$	-6.3430	$[-8.6931 ; -4.0541]$

Notes: Scenario I corresponds to high OECD growth rates and high US real interest rates; Scenario II corresponds to low OECD growth rates and low US real interest rates; the last row gives the cumulated output losses over 4 periods.

Table 8: Monte Carlo Experiment 1 - Accuracy of Efficient Importance Sampler

	I		*II*		*III*	
	GHK	GHK-EIS	GHK	GHK-EIS	GHK	GHK-EIS
T=5						
MC-Mean	1.4186	1.4191	3.9786	3.9787	3.1516	3.1495
MC-Std	0.0380	0.0034	0.0398	0.0089	0.0638	0.0045
MC-coeff. of var.	0.0268	0.0024	0.0100	0.0022	0.0203	0.0014
T=10						
MC-Mean	15.1189	15.0735	5.3296	5.3221	3.8515	3.8486
MC-Std	0.2916	0.0036	0.1642	0.0128	0.0903	0.0085
MC-coeff. of var.	0.0193	0.0002	0.0308	0.0024	0.0235	0.0022
T=20						
MC-Mean	15.2034	15.2006	7.9509	7.8700	14.4205	14.3873
MC-Std	0.1100	0.0035	0.3676	0.0173	0.2780	0.0105
MC-coeff. of var.	0.0072	0.0002	0.0462	0.0022	0.0193	0.0007
T=50						
MC-Mean	30.4523	30.4057	44.2886	42.8124	38.9467	37.7662
MC-Std	0.2973	0.0058	1.3572	0.0249	1.3117	0.0128
MC-coeff. of var.	0.0098	0.0002	0.0306	0.0006	0.0337	0.0003

Note: MC-estimation of log-likelihood contribution for simulated data using the different parameter sets *I*-*III*. The mean standard deviation and the coefficient of variation are obtained from 1000 independent replications of the MC estimation. The estimates are based upon a simulation sample size of $S = 500$.

Table 9: Monte Carlo Experiment 2 - Accuracy of Efficient Importance Sampler

DGP			GHK					GHK-EIS			
T=20	$\bar{\hat{\theta}}$	sd	RMSE	MAE	$\overline{ASD}$	$\bar{\hat{\theta}}$	sd	RMSE	MAE	$\overline{ASD}$	
β_{11}	-0.8	-0.7869	0.1559	0.1226	0.1525	0.3347	-0.8438	0.1489	0.1294	0.1516	0.1541
β_{12}	0.1	0.1368	0.1543	0.1336	0.1548	0.2290	0.1318	0.1612	0.1340	0.1603	0.1681
β_{13}	-0.3	-0.2793	0.2134	0.1659	0.2091	0.2366	-0.2885	0.1836	0.1420	0.1793	0.2037
β_{21}	0.3	0.2542	0.2307	0.2001	0.2294	0.2579	0.2724	0.2208	0.1648	0.2169	0.1660
β_{22}	-0.2	-0.1122	0.1698	0.1372	0.1873	0.1891	-0.128	0.1830	0.1454	0.1924	0.1625
β_{23}	0.3	0.3588	0.2151	0.1892	0.2178	0.2409	0.3609	0.2387	0.1983	0.2405	0.2007
ρ	-0.2	-0.1241	0.0813	0.0841	0.1097	0.0753	-0.1854	0.0798	0.0659	0.0792	0.0694
ψ_1	-0.2	-0.1736	0.0726	0.0598	0.0755	0.0965	-0.2246	0.0856	0.0733	0.0870	0.0667
ψ_2	0.3	0.2430	0.0766	0.0824	0.0939	0.0727	0.2680	0.0731	0.0648	0.0781	0.0655
σ_{11}	0.4	0.6194	0.1972	0.2690	0.2917	0.4125	0.6111	0.1317	0.2260	0.247	0.1104
σ_{12}	0.5	0.4923	0.4549	0.4163	0.4435	0.6731	0.6669	0.2943	0.2810	0.3318	0.2559
σ_{21}	0.5	0.8026	0.2115	0.3116	0.3661	0.1965	0.7488	0.1340	0.2488	0.2810	0.1223
σ_{22}	0.8	0.6284	0.5158	0.4302	0.5313	0.8472	0.7621	0.2216	0.1694	0.2193	0.2573
T=20	$\bar{\hat{\theta}}$	sd	RMSE	MAE	$\overline{ASD}$	$\bar{\hat{\theta}}$	sd	RMSE	MAE	$\overline{ASD}$	
β_{11}	-0.8	-0.8211	0.2313	0.1732	0.2264	0.2613	-0.8761	0.2356	0.1710	0.2419	0.2440
β_{12}	0.1	0.1046	0.1345	0.1066	0.1311	0.1981	0.1210	0.1499	0.1216	0.1476	0.1866
β_{13}	-0.3	-0.3237	0.2012	0.1652	0.1975	0.2100	-0.3152	0.2208	0.1900	0.2158	0.2185
β_{21}	0.3	0.2602	0.2665	0.2226	0.2628	0.2385	0.3206	0.2014	0.1585	0.1974	0.2031
β_{22}	-0.2	-0.1442	0.1230	0.1021	0.1323	0.1785	-0.1437	0.1235	0.1001	0.1328	0.1695
β_{23}	0.3	0.4139	0.199	0.1746	0.2249	0.1890	0.4075	0.1865	0.1688	0.2112	0.1808
ρ	0.2	0.1371	0.0474	0.0630	0.0780	0.0728	0.2138	0.0526	0.0422	0.0531	0.0806
ψ_1	0.8	0.7511	0.0956	0.0846	0.1053	0.0604	0.7672	0.0601	0.0575	0.0671	0.0474
ψ_2	0.3	0.2627	0.0552	0.0585	0.0655	0.0699	0.2841	0.0647	0.0539	0.0650	0.0668
σ_{11}	0.8	0.6094	0.4645	0.4020	0.4912	0.4795	0.8832	0.3114	0.2576	0.3147	0.3393
σ_{12}	0.5	0.2041	0.2340	0.3289	0.3736	0.7750	0.5611	0.3625	0.3127	0.3586	0.4533
σ_{21}	1	1.0899	0.2540	0.1933	0.2634	0.2148	1.0368	0.1963	0.1608	0.1949	0.1453
σ_{22}	0.2	0.3309	0.2768	0.2443	0.2998	0.4701	0.2971	0.2772	0.2486	0.2871	0.593
T=20	$\bar{\hat{\theta}}$	sd	RMSE	MAE	$\overline{ASD}$	$\bar{\hat{\theta}}$	sd	RMSE	MAE	$\overline{ASD}$	
β_{11}	-0.8	-0.7811	0.1012	0.0750	0.1004	0.1378	-0.8442	0.1227	0.0974	0.1275	0.1377
β_{12}	0.1	0.1130	0.1325	0.1010	0.1298	0.1675	0.1239	0.1375	0.1080	0.1361	0.1635
β_{13}	-0.3	-0.2828	0.1552	0.1194	0.1522	0.1844	-0.3046	0.1686	0.1269	0.1644	0.1739
β_{21}	0.3	0.2693	0.2593	0.1846	0.2546	0.1666	0.3041	0.1897	0.1293	0.1850	0.1686
β_{22}	-0.2	-0.1279	0.1710	0.1520	0.1816	0.1690	-0.1597	0.1829	0.1553	0.1828	0.1606
β_{23}	0.3	0.3534	0.2381	0.1900	0.2382	0.1967	0.3400	0.2175	0.1815	0.2158	0.2067
ρ	0.6	0.4378	0.0567	0.1622	0.1714	0.0582	0.5953	0.0727	0.0543	0.0710	0.0623
ψ_1	-0.5	-0.4369	0.0544	0.0705	0.0824	0.0556	-0.51	0.0568	0.0452	0.0562	0.0457
ψ_2	0.5	0.4633	0.0546	0.0541	0.0647	0.0617	0.4918	0.0422	0.0317	0.0420	0.0534
σ_{11}	0.2	0.3856	0.1158	0.1897	0.2172	0.0861	0.4315	0.1005	0.2333	0.2513	0.0807
σ_{12}	0.1	0.2978	0.2693	0.2568	0.3287	0.2978	0.2909	0.2386	0.2293	0.3009	0.2627
σ_{21}	0.5	0.7103	0.2107	0.2570	0.2939	0.1298	0.7217	0.1407	0.2218	0.2606	0.1408
σ_{22}	0.8	0.7096	0.5119	0.3932	0.5071	0.3974	0.8114	0.2765	0.2093	0.2697	0.2544

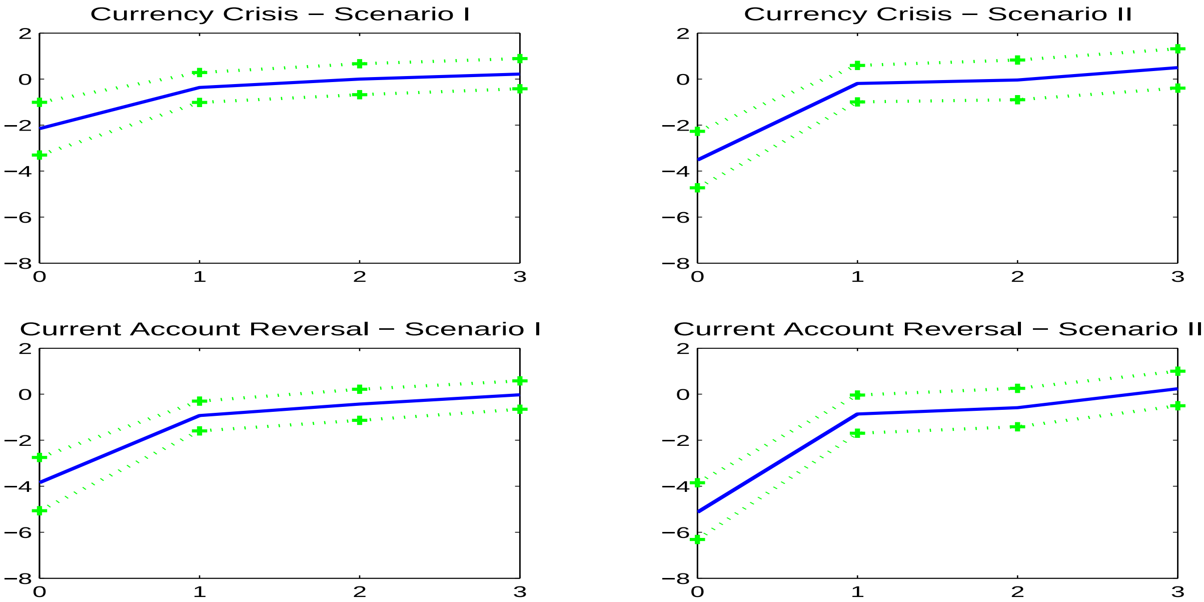
Note: Estimation of parameters for simulated data using the different parameter sets *I-III*.

Table 10: Monte Carlo Experiment 3 - Accuracy of Efficient Importance Sampler

pseudo true values		GHK			GHK-EIS		
T=20	$\bar{\hat{\theta}}$	sd	bias	$\bar{\hat{\theta}}$	sd	bias	
β_{11}	-0.6539	-0.6661	0.0786	0.0624	-0.6528	0.0006	0.0011
β_{12}	0.1365	0.1330	0.0210	0.0174	0.1364	0.0003	0.0002
β_{13}	-0.1850	-0.2155	0.0757	0.0671	-0.1843	0.0014	0.0011
β_{21}	0.2257	0.2559	0.1236	0.1023	0.2252	0.0004	0.0005
β_{22}	-0.0561	-0.0588	0.0203	0.0160	-0.0564	0.0002	0.0003
β_{23}	0.2463	0.2318	0.0792	0.0604	0.2457	0.0006	0.0008
ρ	-0.2202	-0.1739	0.0361	0.0481	-0.2195	0.0006	0.0007
ψ_1	-0.1268	-0.1057	0.0248	0.0266	-0.1251	0.0008	0.0017
ψ_2	0.2459	0.2272	0.0260	0.0275	0.2471	0.0010	0.0014
σ_{11}	0.6198	0.6534	0.1105	0.0872	0.6149	0.0023	0.0049
σ_{12}	0.6650	0.5008	0.3682	0.3377	0.6580	0.0107	0.0102
σ_{21}	0.8702	0.8850	0.1257	0.0992	0.8678	0.0017	0.0026
σ_{22}	0.7464	0.5343	0.4896	0.4471	0.7334	0.0069	0.0131
T=20	$\bar{\hat{\theta}}$	sd	bias	$\bar{\hat{\theta}}$	sd	bias	
β_{11}	-0.7715	-0.6756	0.0788	0.0960	-0.7703	0.0012	0.0014
β_{12}	0.2733	0.2633	0.0224	0.0201	0.2733	0.0010	0.0009
β_{13}	-0.1599	-0.1556	0.0578	0.0442	-0.1593	0.0012	0.0012
β_{21}	0.0163	0.1145	0.1083	0.1155	0.0168	0.0007	0.0007
β_{22}	-0.2389	-0.2358	0.0292	0.0201	-0.2391	0.0003	0.0003
β_{23}	0.4499	0.4441	0.0906	0.0673	0.4495	0.0013	0.0011
ρ	0.1671	0.1157	0.0393	0.0547	0.1657	0.0011	0.0016
ψ_1	0.7559	0.7121	0.0565	0.0574	0.7533	0.0015	0.0027
ψ_2	0.3121	0.2925	0.0332	0.0316	0.3123	0.0010	0.0008
σ_{11}	0.7318	0.5426	0.3717	0.3183	0.7349	0.0057	0.0049
σ_{12}	0.816	0.3078	0.3386	0.5183	0.808	0.0068	0.0091
σ_{21}	1.1484	1.1252	0.1260	0.0967	1.1406	0.0045	0.0079
σ_{22}	0.4806	0.4057	0.3871	0.3517	0.4743	0.0114	0.0095
T=20	$\bar{\hat{\theta}}$	sd	bias	$\bar{\hat{\theta}}$	sd	bias	
β_{11}	-0.8985	-0.8285	0.0589	0.0795	-0.8942	0.0013	0.0043
β_{12}	0.1964	0.1448	0.0313	0.0516	0.1941	0.0010	0.0023
β_{13}	-0.294	-0.3123	0.0425	0.0385	-0.2931	0.0013	0.0013
β_{21}	0.2307	0.2242	0.0766	0.0605	0.2304	0.0007	0.0006
β_{22}	-0.0837	-0.0794	0.0414	0.0307	-0.0836	0.0008	0.0006
β_{23}	0.2195	0.1901	0.0928	0.0661	0.21854	0.0011	0.0013
ρ	0.5806	0.4172	0.0295	0.1634	0.5740	0.0032	0.0066
ψ_1	-0.4678	-0.3813	0.0241	0.0865	-0.4636	0.0011	0.0041
ψ_2	0.5144	0.4803	0.0409	0.0464	0.5131	0.0017	0.0016
σ_{11}	0.4283	0.4524	0.0897	0.0765	0.4161	0.0032	0.0122
σ_{12}	0.6017	0.3426	0.2753	0.3147	0.5934	0.0047	0.0101
σ_{21}	0.7400	0.7477	0.1624	0.1323	0.7389	0.0020	0.0019
σ_{22}	0.9393	0.6277	0.3754	0.3574	0.9288	0.0060	0.0105

Note: Estimation of parameters for simulated data using the different parameter sets *I*-*III*.

Figure 1: Impact of crises on growth over Time



Notes: Scenario I corresponds to high OECD growth rates and high US real interest rates; Scenario II corresponds to low OECD growth rates and low US real interest rates.