International Research Journal of Human Resources and Social Sciences
ISSN(O): (2349-4085) ISSN(P): (2394-4218)
Impact Factor- 5.414, Volume 5, Issue 09, September 2018
Website- www.aarf.asia, **Email** : editor@aarf.asia , editoraarf@gmail.com

BAYESIAN ANALYSIS OF THE GROWTH TRAJECTORY OF STUDENTS' SCIENTIFIC LITERACY AND ACHIEVEMENT IN PHYSICS

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ABSTRACT

Majority of studies investigating the growth of selected variables influencing achievement in science, including Physics have been reported to be limited by estimation techniques that were only rooted in subjectivity, including maximum likelihood. Subjective parameter estimators have been faulted on the grounds of being mechanistic and non-representative of the target population in terms of their results. Therefore, this study used the Bayesian estimation (BE) to analyze a latent growth model of students' scientific literacy and achievement in Physics. BE was chosen because of its robustness in combining subjectivity and objectivity through the use of sample data and non-informative prior distribution respectively in the computation of posterior estimates of model parameters via randomization. Secondly, BE provided information on the size of the target population on which the computation of the parameter estimates were based on. The study adopted a fully Bayesian experimental design. The sample for the study was 158 senior secondary school Physics students, drawn using multi-stage sampling from public secondary schools in three local government areas nested in Agbani education zone of Enugu state. A modified 4 likert test of scientific literacy scale (TOSLS) was used to collect data related to students' scientific

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literacy in Physics whereas the grades of the Physics students each term obtained from the official school records represented the achievement part of the study. The internal consistency reliability of TOSLS was 0.83 obtained using Cronbach's alpha. The data collected were analyzed using mean regression weights and trace plots. The results showed that the growth of scientific literacy with Physics achievement growth was linear. Also, scientific literacy had a positive direct effect on Physics achievement. It was recommended that Physics students' scientific literacy level should be increased by the relevant stakeholders.

Keywords: Bayesian estimation, latent growth modeling, parental involvement, and Physics achievement.

INTRODUCTION

The essence of science education is scientific literacy of every one. Scientific literacy, defined broadly in Program for International Students' Assessment (PISA) 2015 draft science framework by Organization for Economic Cooperation and Development (2013) as consisting of four interrelated aspects:

(i). Context: personal, local, national and global issues, both current and historical, which demand some understanding of science and technology. (ii).knowledge: an understanding of the major facts, concepts, and explanatory theories that form the basis of scientific knowledge. Like knowledge of the natural world and technological artifacts (content knowledge), knowledge of how such ideas are produced (procedural knowledge), and an understanding of the underlying rationale for these procedures and the justification for their use (epistemic knowledge). (ïii).competencies: the ability to explain phenomena scientifically, evaluate and design scientific inquiry, and interpret data and evidence scientifically.(iv).attitudes**:** a set of attitudes towards science, indicated by an interest in science and technology, valuing of scientific approaches to enquiry where appropriate and a perception and awareness of environmental issues

Scientific literacy, (SL) is also conceptualized as the ability to think scientifically and to use scientific knowledge and processes to understand the world around us and to participate in decisions around it (Davis and Carol, 2017). Davis and Carol maintained that a scientifically literate person (i) understands, reflects upon and reasons about scientific concepts needed to solve environmental and social challenges. (ii) asks, finds and determines answers to questions obtained from curiosity using everyday experiences. (iii) poses and evaluates arguments based on evidence. (iv) evaluates the quality of scientific information, based on its source and the method used to generate it. (v) is guided by scientific and technological knowledge in his/her opinions on daily life. (vi) discusses science in an informal setting and (vii) provide equal opportunities for men and women alike to participate and benefit from science and technology. SL not only increases interest in the surrounding world, but also allows for active engagement in discussions of scientific advancements and the ability to be skeptical and questioning the claims made by others (Rennie, 2005). Due to the growing importance of science, many educators have advocated that all students should develop the ability to consider, make rational decisions on, or resolve socio-scientific issues through the additional learning of a more science based course Sadler, (2004). Punia, Omar, Daud and Osmar (2012) asserted that scientific literacy was such an important thing to the extent that the society we live in depends on an ever-increasing technology and the scientific knowledge which makes it possible. At the school level, Bybee (2009) has conceptualized scientific literacy as being made up of four parts: (a) nominal (the students recognizes scientific terms, but lacks their clear understanding. (b) Functional (out of context usage of scientific and technological terms). (c) Conceptual and procedural (an understanding of the meanings of scientific terms and their relationships). (d) Multi-dimensional (an understanding of science and technological concepts plus the nature of the roles of science and technology to the development of the society). This implies that the multi-dimensional level of SL is the highest level and any student who operates on that level is truly scientifically literate.

Despite the importance of Science, for the overall well being of any nation, students perceive its study as too difficult, boring and irrelevant, believing that it required a lot of background knowledge to comprehend (Illingworth, Burka da Silva, & Amy, 2012). In the

developing countries, including Nigeria, Davies and Carol (2017) reported that science for many was such an alien issue, and the preserve of the school and the educated elite.. The Nigerian secondary school students, including Physics students have been described as having low scientific literacy (Mbajiorgu & Ali, 2002; Nworgu & Ugwuanyi, 2014: Ibe, Nwosu, Obi & Nwoye, 2016). The evidence of students' low level of SL, has been linked to consistent poor achievements of students in the science subjects, including Physics. (Nworgu & Ugwuanyi, 2014; Singh, Singh & Giri, 2016).

With the exception of the reviewed study by Nworgu et al, that utilized windows Bayesian inference using Gibb's sampling (winBUGS) software to analyze the relationship between scientific literacy and science (including Physics) achievement, all the other results were got from classical/non-Bayesian statistics including analysis of covariance and correlation. Classical/non-Bayesian statistics contain higher measurement errors which tend to invalidate their results. In addition, the type of parameter estimator used in classical statistics assumes that all data collected were normally distributed, even when it is not true in practice, thereby introducing errors in their estimations. Unlike the non-Bayesian estimators, including the maximum likelihood, Bayesian estimator uses the *Monte Carlo Markov Chain (*MCMC) method, specifically Gibb's sampling to circumvent the difficulty in multi-dimensional integration. Gibb's sampling on the other hand is an algorithm to generate a data point (mean, variance and covariance) from the conditional distribution of each parameter, conditional on the current values of other parameters (Zang, Hamagami,Wang, Nesselroade, & Grimm, 2007). Another advantage of Bayesian estimation is that it utilizes non-informative prior distribution vis-à-vis the data (technically referred to as data likelihood in Bayesian parlance) in the computation of the marginal posterior values of estimates, in addition to producing reliable estimates with smaller samples (Rolfe, 2010; Arbuckle, 2013). This means that reliable estimates are obtained using a Bayesian estimator, because it overcomes sample–size induced errors in the results of any study due to its non-reliance on the data collected from the sample in computing the posterior estimates. Rather, it combines the data collected and the non-informative prior to generate a posterior distribution, from where the software engine samples from a larger posterior distribution through randomization process. Other non Bayesian estimators do not utilize any prior in its estimation, either can their results be meaningfully generalized on the target population. Most interestingly,

Bayesian estimation empirically determines the size of the target population for any study at the point of convergence of the parameter estimates.

Since SL has been identified as a variable related to science achievement including Physics. No earlier study known to the researchers had attempted to study the growth trajectory/pattern of SL and students' achievement in Physics using Bayesian method of estimation.

Purpose of the Study

The purpose of the study was to use Bayesian estimation to analyze hypothesized model of growth trajectory of students' scientific literacy and achievement in Physics. Specifically, the study sought to determine the

1. nature of the growth trajectory of the students in Physics per term from SS1 to SS3
2. nature of the growth trajectory of the Physics students in scientific literacy per term from SS1 to SS3
3. value of the direct effect of scientific literacy growth on students' achievement growth in Physics
4. Monte Carlo Markov Chain (MCMC) sample at which the model converged

Research Questions

Three research questions guided the study. The research questions included: 1. What is the nature of the growth trajectory of the students in Physics per term from SS1 to SS3? 2. What is the nature of the growth trajectory of the students in scientific literacy per term from SS1 to SS3? 3. What is the value of the direct effect of scientific literacy growth on students' achievement growth in Physics? 4. At what Monte Carlo Markov Chain (MCMC) sample did the model converge?

Method

The study adopted a fully Bayesian experimental design. A fully Bayesian experimental design is an applied simulation method that uses the product of prior probability distribution and data to generate posterior distribution from where random samples can be drawn by the software engine for estimation of unknown parameters using Markov Chain Monte Carlo (MCMC) algorithm, specifically Gibb's sampling procedure (Ryan, 2014). The design was deemed most appropriate for the study because it empirically determined the target population for the study at the level of convergence of the unknown values of parameters, using randomization. Secondly, the design produces reliable results, since its result is not dependent on the sample size used. This means that reliable results are got even with smaller or moderate samples (Rolfe, 2010). The accessible population for the study comprised three thousand, three hundred and twenty four (3324) senior secondary Physics students (SS1-3) in Agbani Education zone of Enugu state for 2016/2017 academic session. The choice of the education zone was because a similar study had not been conducted in the area prior to the present study. However, the target population for the study was one hundred and eighty three thousand and one (183,001). 158 SS1-3 Physics students (74 males and 84 females) nested in 9 schools (5 urban and 4 rural) were sampled using simple random sampling with replacement from the three local government Areas (Nkanu West, Nkanu East and Enugu South) nested within Agbani education zone. The instruments used to collect data were two in number. They included (1) Test of scientific literacy scale (TOSLS) adapted from Impey, Buxner, Antonellis, Johnson and Courtney (2011). The instrument was developed by Chris Impey (1988). It was tried on 10000 undergraduates of the Department of Astronomy, University of Arizona USA for 20 years. The adaptation was in terms of simplifying the grammatical structures of the items to suit the comprehension level of secondary school students. Secondly, the scale of the instrument was reduced from five to four. The instrument consisted of 49 items split into parts 1 and 2. Part I was made up of 25 dichotomous items, while part was made up of five point likert scale. The students' result pro-forma was used to collect the Physics students' results from the official school records every term. The internal consistency reliabilities of dichotomous part of TOSLS tried on a parallel sample and determined using Kuder-Richardson's formula 21 was 0.79, whereas the polytomous part of TOSLS determined using Cronbach's alpha had a value of 0.68. The

regular Physics teachers in each school administered and collected the instruments in their respective schools, at the end of the 1 –day exercise per term.

Results

Research questions one to three were answered using regression weights. Research question four was answered using trace plots.

Research Question One

What is the nature of growth trajectory of the students' achievement in Physics per term from SS1 to SS3?

Table 1: Scientific literacy and Physics achievement growth indices

Time point	0	1	2	3	4	5	6	7	8
Scientific literacy growth	-	-0.10	-0.10	-0.06	-0.05	-0.14	1.12	0.89	-
Physics achievement growth	-	1.25	1.03	1.06	1.06	0.96	1.20	1.17	-

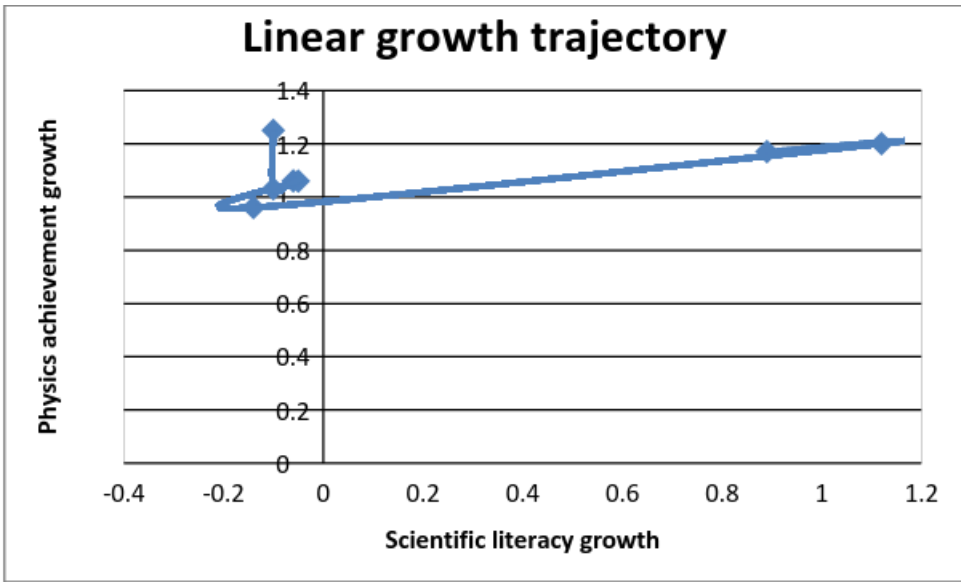

Fig1: Graphical plots of scientific literacy and Physics achievement growths.

From Table 1, the mean regression weights of the growth in Physics achievement from second term of SS1 to second term of SS2 were 1.25, 1.03, 1.06, 1.06, 0.96, 1.12 and 1.17 respectively.

Research Question Two

What is the nature of the growth trajectory of the Physics students in scientific literacy per term from SS1 to SS3?

From Table 1, the mean regression weights of the growth in scientific literacy from second term of SS1 to second term of SS2 were -0.10, -0.10, -0.06, -0.05, -0.14, 1.12 and 0.89 respectively.

Research Question Three

What is the value of the direct effect of scientific literacy growth on students' achievement growth in Physics?

Table 2: The direct effect of scientific literacy growth on achievement growth in Physics.

Path	Mean regression weight
SGROWTH ⟶ AGROWTH	0.27

The mean posterior regression weight of the path between scientific literacy growth (SGROWTH) and achievement in Physics growth (AGROWTH) was 0.27

Research Question Four

At what Monte Carlo Markov Chain (MCMC) sample did the model converge?

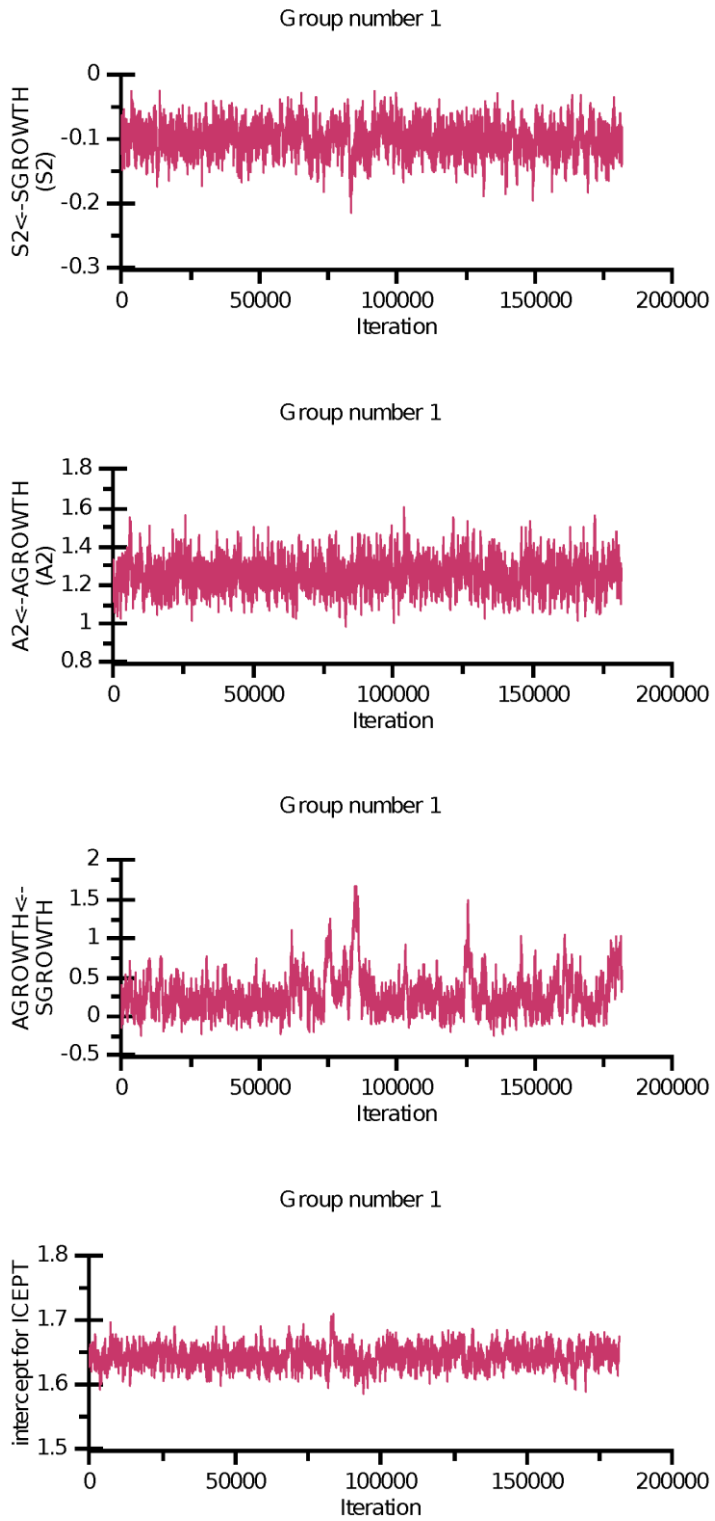

Figure 2: Sample trace plots of the model's parameters

From the trace plots in figure 1, the vertical axis corresponds to the mean of the posterior regression weight whereas the horizontal axis is the iteration, representing the MCMC sample

at the point of convergence. The scientific literacy parameter (S2) for the second term of SS1 converged when the mean posterior density was -0.01 when the MCMC was 183,001 samples For Physics achievement growth in the second term of SS1, the model converged when the mean posterior density was 1.25. The MCMC at that instance was also 183,001. The direct effect of scientific literacy growth on achievement in Physics growth converged at a mean posterior density of 0.27 giving MCMC value of 183,001. The intercept for the initial status converged when the posterior mean was 1.65 and the MCMC was 183,001.

Discussion

The result of the study in respect of the nature of growth trajectory of the students' achievement in Physics per term from SS1 to SS3 (Table 1 and Figure 1) showed that there was growth in second term of SS1. By the third term, the achievement growth depreciated slightly to 1.03. A slight increase in Physics achievement growth occurred in the first term of SS1. The growth remained constant throughout second term and also depreciated in the third term of SS3. In the first term of SS3, there was an appreciable increase in Physics achievement growth, but the growth depreciated slightly in the second term. The resultant trend in Physics achievement growth was approximately linear.

For the scientific literacy growth (Table 1 and Figure 1), the result indicated that a negative growth occurred from second term of SS1 to the third term of SS2. There was a quantum growth in scientific literacy in the first term of SS3. In the second term of the same class, there was a slight depreciation in the growth of scientific literacy. The resultant trend in scientific literacy growth was also approximately linear.

From the sample trace plots in figure 2, it was shown that the iteration level for each and parameter estimate was one hundred and eighty three thousand and one. The iteration level represents the MCMC sample (Arbuckle, 2013). The value of the iteration level being 183001, therefore suggests that the result of the study can be generalized on a target population of 183001.

The result of the direct effect of scientific literacy on Physics achievement showed that a positive and moderate relationship existed between scientific literacy growth and Physics achievement growth. The result has shown that scientific literacy growth is a predictor of Physics achievement growth. The finding of this study is in agreement to earlier

assertions by Zembylas (2002) and Bybee (1997) that scientific literacy is important in daily human lives and its promotion is important in boosting science including Physics achievement.

Conclusion

From the findings of this study, the following conclusions were made. The scientific literacy with Physics achievement growth was linear. Over time, both scientific literacy and Physics achievement growths were approximately linear. Also a linear growth was observed when the two were taken together. Scientific literacy growth was a determinant of Physics achievement growth. This means that an increase in scientific literacy growth brings about an increase in Physics achievement growth. The result of the study is valid on a target population of 183001. It was recommended that students' scientific literacy levels of Physics students in senior secondary school one and two needs to be beefed up by the school counselors and Physics teachers.

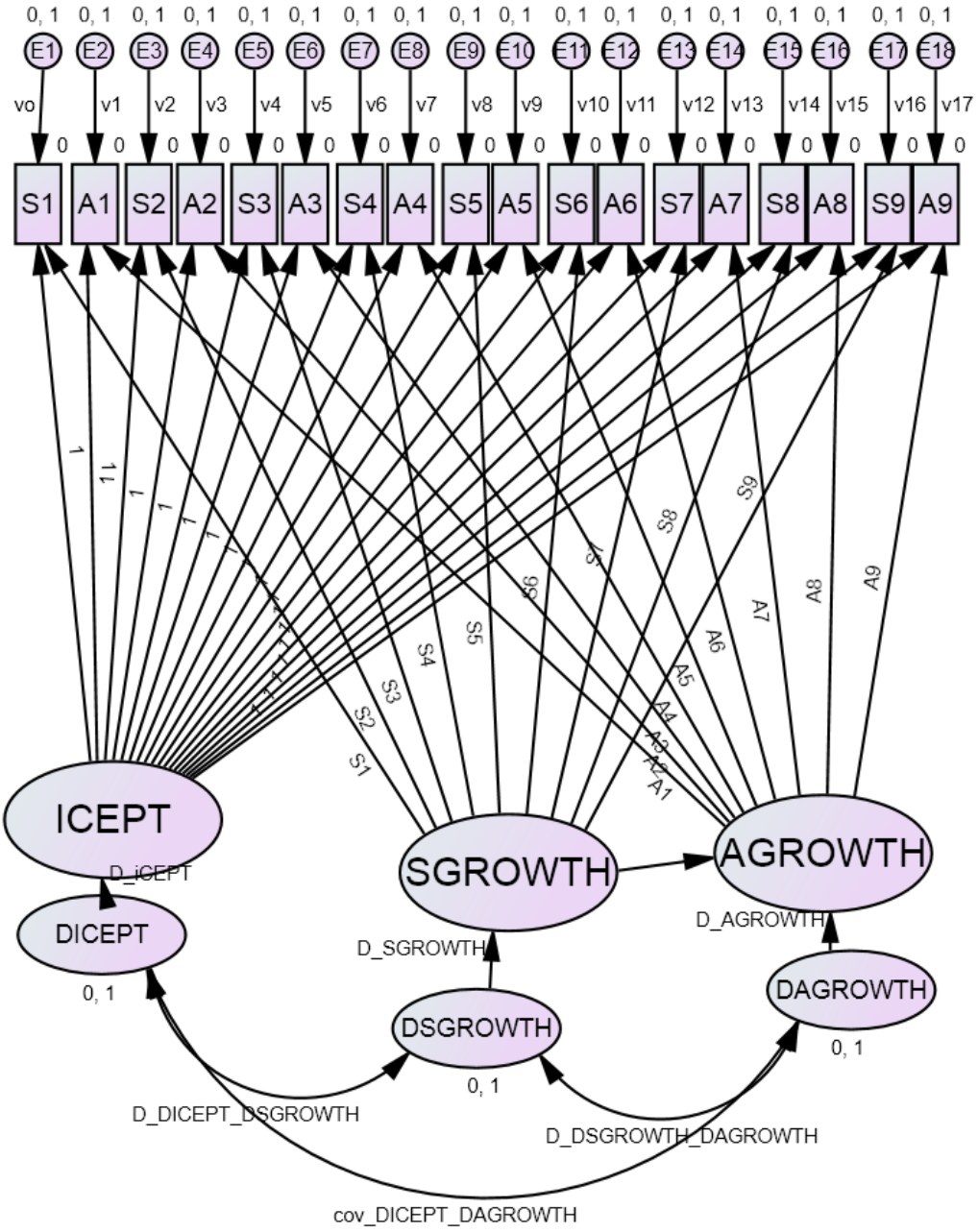

Figure 3: The hypothesized latent growth model.
KEY:Key. S1-3; First –third term scientific literacy for SS1.
S4-6: First –third term scientific literacy for SS2. S7-8:
First –second term scientific literacy for SS3 Physics students.
A1-3: First –third term Physics achievement for SS1.
A4-6: First –third term Physics achievement for SS2.
A7-8: First –second term Physics achievement for SS3.
V- Error variance. INCEPT-Initial status. SGROWTH-scientific literacy growth.
AGROWTH- Physics achievement growth. D-disturbance. Cov-covariance.

Table 3: Full posterior summaries

	Mean	S.E.	S.D.	C.S.	Median	95% Lower bound	95% Upper bound	Skewness	Kurtosis	Min	Max	Name
Regression weights												
S2<--SGROWTH	-0.10	0.00	0.02	1.00	-0.10	-0.15	-0.06	-0.28	0.21	-0.21	-0.02	S2
S3<--SGROWTH	-0.10	0.00	0.02	1.00	-0.10	-0.15	-0.06	-0.13	0.00	-0.22	-0.02	S3
S4<--SGROWTH	-0.06	0.00	0.02	1.00	-0.06	-0.11	-0.02	-0.14	0.05	-0.15	0.02	S4
S5<--SGROWTH	-0.05	0.00	0.02	1.00	-0.05	-0.09	-0.01	-0.26	0.74	-0.18	0.03	S5
S6<--SGROWTH	-0.14	0.00	0.02	1.00	-0.14	-0.19	-0.09	-0.19	0.25	-0.25	-0.05	S6
S7<--SGROWTH	1.12	0.00	0.07	1.00	1.12	1.00	1.26	0.15	0.01	0.88	1.38	S7
S8<--SGROWTH	0.89	0.00	0.06	1.00	0.88	0.78	1.01	0.29	0.35	0.64	1.13	S8
S1<--E1	0.30	0.00	0.01	1.00	0.30	0.28	0.33	0.13	-0.03	0.26	0.35	vo
S2<--E3	0.28	0.00	0.01	1.00	0.28	0.26	0.30	0.10	-0.10	0.24	0.31	v2
A2<--E4	0.88	0.00	0.03	1.00	0.88	0.83	0.93	0.12	0.02	0.76	0.99	v3
S3<--E5	0.28	0.00	0.01	1.00	0.28	0.26	0.30	0.10	-0.19	0.25	0.32	v4
A3<--E6	0.92	0.00	0.03	1.00	0.91	0.86	0.98	0.24	0.20	0.82	1.07	v5
S4<--E7	0.29	0.00	0.01	1.00	0.29	0.27	0.31	0.15	-0.13	0.26	0.33	v6
A4<--E8	0.92	0.00	0.03	1.00	0.92	0.86	0.98	0.11	-0.04	0.80	1.03	v7
S5<--E9	0.25	0.00	0.01	1.00	0.25	0.23	0.27	0.16	0.02	0.22	0.29	v8
A5<--E10	0.90	0.00	0.03	1.00	0.90	0.84	0.96	0.25	0.26	0.80	1.03	v9
S6<--E11	0.29	0.00	0.01	1.00	0.29	0.27	0.31	0.05	-0.11	0.25	0.32	v10
A6<--E12	0.88	0.00	0.03	1.00	0.88	0.83	0.94	0.12	0.00	0.79	1.00	v11
S7<--E13	0.82	0.00	0.03	1.00	0.82	0.77	0.89	0.08	-0.10	0.72	0.95	v12
A7<--E14	0.82	0.00	0.03	1.00	0.82	0.77	0.87	0.20	0.04	0.71	0.93	v13
S8<--E15	0.87	0.00	0.03	1.00	0.87	0.81	0.93	0.09	0.06	0.76	1.01	v14
A8<--E16	0.94	0.00	0.03	1.00	0.94	0.88	1.00	0.04	-0.05	0.82	1.06	v15
S9<--E17	0.89	0.00	0.03	1.00	0.89	0.83	0.95	0.12	0.02	0.77	1.01	v16
A9<--E18	0.90	0.00	0.03	1.00	0.90	0.85	0.96	0.31	0.18	0.79	1.03	v17
A2<--AGROWTH	1.25	0.00	0.08	1.00	1.25	1.11	1.42	0.32	0.20	0.97	1.61	A2
A3<--AGROWTH	1.03	0.00	0.07	1.00	1.03	0.90	1.18	0.24	0.01	0.81	1.31	A3
A4<--AGROWTH	1.06	0.00	0.07	1.00	1.06	0.93	1.21	0.21	-0.04	0.79	1.36	A4
A5<--AGROWTH	1.06	0.00	0.07	1.00	1.06	0.92	1.22	0.26	0.48	0.80	1.40	A5
A6<--AGROWTH	0.96	0.00	0.07	1.00	0.96	0.83	1.10	0.23	0.17	0.74	1.30	A6
A7<--AGROWTH	1.20	0.00	0.08	1.00	1.19	1.06	1.36	0.31	0.16	0.96	1.53	A7
A8<--AGROWTH	1.17	0.00	0.08	1.00	1.17	1.03	1.33	0.23	0.05	0.92	1.51	A8
ICEPT<--DICEPT	0.09	0.00	0.01	1.00	0.09	0.07	0.10	-0.10	-0.13	0.06	0.12	D_iCEPT
SGROWTH<--DSGROWTH	-0.23	0.00	0.05	1.00	-0.23	-0.32	-0.12	0.28	-0.13	-0.41	-0.05	D_SGROWTH
AGROWTH<--DAGROWTH	-0.08	0.01	0.05	1.01	-0.09	-0.15	0.07	1.44	2.58	-0.19	0.15	D_AGROWTH
AGROWTH<--SGROWTH	0.27	0.03	0.25	1.01	0.21	-0.06	0.89	1.57	3.93	-0.28	1.67	

Intercepts

ICEPT	1.64	0.00	0.02	1.00	1.64	1.61	1.67	0.08	0.21	1.58	1.71
SGROWTH	0.86	0.00	0.04	1.00	0.86	0.77	0.95	-0.09	0.04	0.70	1.02
AGROWTH	0.59	0.02	0.22	1.01	0.64	0.05	0.90	-1.38	3.06	-0.63	1.09

Covariances

DICEPT<->DSGROWTH	0.45	0.02	0.21	1.00	0.44	0.07	0.89	0.19	-0.37	-0.26	1.00	D_DICEPT_ DSGROWTH
DAGROWTH<->DICEPT	0.69	0.05	0.34	1.01	0.79	-0.49	0.98	-2.42	6.19	-0.96	1.00	cov_DICEPT_ DAGROWTH

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