Using Partial Least Squares Regression and Artificial Neural Network Methods To Study Risk Factors Affecting Worldwide Infant Mortality Rates

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Abstract

The infant mortality rate (IMR) commonly serves as a marker to evaluate how well a geographic area is equipped with suitable living and health conditions and additionally, its economic prosperity. The IMR in the United States has been on the decline since the 1950s in lieu of a globally high IMR. Lower IMR globally can be attributed to increases in education about the importance of prenatal care and breastfeeding, along with changing socioeconomic climates across the world.

The objective of this study was to uncover the significant and important risk factors that contribute to infant mortality rates globally. This study used Partial Least Squares (PLS) Regression and Artificial Neural Network (ANN) analysis to assess how these factors: Gross Domestic Product (GDP), adolescent fertility rate, country development status, health care expenditure per capita, and adult literacy rate, contributed to infant mortality rate in 134 countries for which data was accessible through the United Nation's data bank.

It was shown that the findings of PLS were consistent with the finding in ANN model and that adolescent fertility rate was the most important variable contributed to infant mortality rates in the countries studied. Though less important, country development status, GDP, and health care expenditure per capita, also are important in varying IMRs. The study confirms what was found in the literature that high fertility rates and high infant mortality rates are linked, and that the lower a country's development status (1st, 2nd, or 3rd world) the higher infant mortality rates will be.

Introduction

Infant mortality is defined as the death of a live-born infant before age one. The rate of infant mortality is calculated as the number of newborns dying within the first year of life divided by the number of live births during a set time period (i.e. normally one year)-- most research statistics present infant mortality rate (IMR) as the number of deaths per 1,000 live births. The IMR commonly serves as a marker to evaluate how well a geographic area is equipped with suitable living and health conditions and additionally, its economic prosperity.

Background & Previous Findings

Infant Mortality in the U.S.

Infant mortality in the US dropped to its lowest rate in history at 6.06 in 2010 (Central Intelligence Agency, 2011) down from 6.42 in 2009, 6.58 in 2008 (Kochanek, Xu, Murphy, Miniño, & Kung, 2011), and 30.46 in the early 1950's (United Nations World Population Prospectus Report, 2011). Multiple infant lives were lost in the past; however the rates have dramatically dropped due to technological advances, healthcare improvements, healthy pregnancy education, and specialized birth assistance.

International Infant Mortality

In 2010 the infant mortality rate of the United States was approximately seven times lower than the world's average rate of 44.13. World IMR estimates for 2011 range as low as 1.79 in Monaco to a devastating 175.90 in Angola (Central Intelligence Agency, 2011).

U.S. National Vital Statistics reported that the ranking of factors remained constant within the top 10 causes of infant mortality between 2008 and 2009; birth defects and low birth weight were in the top two slots-- which are the same for Iran (Sharifzadeh, Namakin, Mehrjoofard, 2008)-- and neonatal hemorrhage in the last position. In both countries, a large portion of infant deaths were attributed to low birth weight resulting from maternal smoking during gestation, yet a difference lies in the popular agent of consumption-- tobacco for the U.S. versus opiates for Iran.

Research also shows that implementation of policies influencing health and behavior changes, such as reducing barriers to smoking cessation and prenatal care, can reduce infant mortality rates overall (Singh &Kogan, 2007). However, these changes are likely to increase disparities between socioeconomic groups as those from higher socioeconomic strata implement and access the changes quicker than those from lower socioeconomic strata--for example, pregnant women who were not college-educated were initially 7.1 times more likely to smoke versus college educated-women, and over a 8 year span that disparity grew to 11.8 times more likely.

A study of data from multiple nations found that the higher one's education, the better 1) access one has to resources that comprise prosperity (i.e. financial support, quality healthcare, etc), and 2) one is able to use critical thinking and deductive reasoning to identify health complications leading to early intervention and a resulting probability of positive resolution (eg. recognizing risks for premature or low birth weight infants)(Khamis&Hanoon, 2010). The longer one waits to solve a potential medical problem, the likelihood of mortality or permanent injury increase.

In Nepal, education that leads to prevention of medical problems has been an important factor in the lower average IMR in female-headed households-- likely attributed to the women's ability to save a portion of household income for prenatal and healthcare services (Adhikari&Podhisita, 2010). Their ability to visit healthcare facilities (i.e. for preventive services and/or treatment) gives them additional opportunities (through pamphlets and/ or dialogue with their healthcare provider) to learn about family planning (which assists with birth spacing, and consequently lowered infant mortality rates), life saving immunizations, nutrition, and post-partum care.

In contrast to Nepal, in developing countries like Bangladesh, the father's education level as head of the household is important. The father's education is inversely proportionate to the risk of infant mortality due to the father's heightened ability to understand and provide the proper nutrition and immunizations to their wives and infants (Uddin and Hossain, 2008). Additionally, findings support existing theory that extending breastfeeding and increasing birth spacing increases infant survival rates-- 30 months or more between births proved to be optimal spacing.

In Zimbabwe urban couples and those with higher education were more likely to use birth control methods (Kembo& Van Ginneken, 2009). This implementation of family planning resulted in birth spacing, which, in turn, decreased the urban infant mortality rate. The researchers also noted an inverse relationship between multiple births and infant survival. Thus testing for and referring high-risk pregnancies to specialists as well as improving overall maternal and child health services, especially in rural populations, would improve infant survival.

In Denizli, Turkey strengthening prenatal health through nutrition, pregnancy education, and screening for fetal abnormalities may improve infant mortality rates. Findings indicate the present rate is largely due to congenital defects and premature births (Karabulut, Istanbullu, Karahan, Ozdemir, 2009).

Results also show a wide variability in infant mortality even amongst the wealthy who are thought to be able to afford proper healthcare (Anyamele, 2011). With socioeconomic factors being equal, the differences were evident in geographical location and subsequently access to implemented policy initiatives, largely urban-targeted, which left rural inhabitants having a much higher infant mortality rate than urban inhabitants. Another investigation found that rural girls in Bangladesh are more likely to marry at ages where their bodies lack the maturity to safely harbour a child (Quamrul, Islam, &Hossian, 2010).

Breastfeeding is a strong component of infant nutrition and immunity which both play a massive role in determining infant survival. Birth spacing often has a direct relationship to breastfeeding-- the smaller the interval between births the shorter the amount of time the elder infant is allowed to suckle before s/he is replaced by the new infant, which may leave the elder child undernourished.

Malnutrition is also a pressing issue in Liberia-- which is in the world's top five countries with the highest rate of infant mortality with 15% of children the nation's children dying under the age of 1. This crippling rate is due to the systemic and educational devastation from the 14-year civil war ending in 2003, and the nation’s efforts to resume operations with its broken pieces. The return of many citizens to continue their education, especially young, uneducated mothers, has unfortunately left many infants home alone daily for long hours to perish from malnutrition (Mason, 2010). Additionally, the maternal mortality rates are destructively high with less than half of all births supervised by a healthcare professional.

Studies in Ethiopia found adolescent motherhood, birth spacing, and birth order, were the largest triggers of infant mortality (Sathiyasusuman, 2011). The suggested remedies to these issues include issuing education and warnings about teenage pregnancy and early marriage, making contraceptives available and easily accessible to increase birth spacing, and encouraging breastfeeding amongst women who inhabit areas with poor sanitation and limited access to clean water.

Poor sanitation is also a major factor causing Mozambique to hold the 13th highest infant mortality rate (Central Intelligence Agency, 2011). According to studies, the variables that contribute most to their high rate are viruses/ bacteria, sanitation, and access to specialized birth & pediatric guidance. "Significant risk factors for all-cause infant mortality were mother's death in first year (most commonly due to HIV), death of previous sibling, and an increasing number of household deaths. Being born to a Mozambican mother posed a significant risk for infectious and parasitic deaths, particularly acute diarrhea and malnutrition" (Sartorius, Kahn, Vounatsu, Collinson, &Tollman, 2010).

Evidence from South Africa further emphasizes that neonatal health is largely dependent on maternal health and thus medical, behavioral, and public health policies should target the maternal-infant pair-- this is especially beneficial when considering communities with high rates of HIV infection (Sartorius, Kahn, Vounatsu, Collinson, &Tollman, 2010). Making sure there is constant access to basic sanitation and clean water on legislative and practical levels should always be examined as basic ways to reduce highly preventable infant mortality from diarrhea and malnutrition.

Improving the format of systems that allocate resources to maternal and child health programs as well as making sure that these programs consistently remain funded (even by money from external nations) may be important to reducing infant mortality rates, especially in developing countries and countries going through a recession (Ensor, Cooper, Davidson, Fitzmaurice, & Graham, 2010).

A study of primary care facilities throughout England found that it is not expenditures filtered to these healthcare facilities that determine infant mortality outcomes (Freemantle et al, 2009). Instead the determinants are the primary ethnicity and the resulting social inequalities that come from being an ethnic minority in the communities in which the primary care facilities are located.

Decreasing proximity to healthcare access by establishing branch-healthcare facilities would reduce infant mortality--especially for emergency situations (Sartorius, Kahn, Vounatsu, Collinson, &Tollman, 2010).

Some researchers have also found that the components comprising healthcare facilities themselves play an important role in decreasing infant mortality, as the presence or absence of a Neonatal Intensive Care Unit (NICU) greatly influences the chance of survival for low birth weight infants (Nevacinovic, Skokic, Ljuca,

&Muratovic, 2011). This study of Bosnia also found low birth weight to correlate with reduced neonatal survival.

Low birth weight is contributing to Canada's increase in infant mortality with regard to the increase in multiple births in the past two decades due to in vitro fertilization utilized by a female population who are starting families at older ages (Eggertson, 2010). With numerous embryos implanted to increase the likelihood of pregnancy and improved implantation methods, survival of multiple embryos means less time in the womb due to space as well as the compounded physical and nutritional needs of fetuses. This strain often leads to premature infants of low birth weight.

A suggested solution is to mirror Japan and other countries by restricting the number of embryos that can be embedded per procedure. Also, in efforts to greatly reduce the need for assisted fertilization, Canada can implement France's model of giving incentives (e.g. paid leave from work) to younger couples so they begin families earlier which dramatically reduces the need for medical fertility assistance (Eggertson, 2010).

It is evident that the most underdeveloped countries the world tend to suffer the greatest losses in infant mortality. In these countries pregnant women often lack education regarding: 1) the benefits and importance of breastfeeding to provide nutrients and increase child immunity, 2) keeping the infant from ingesting contaminated fluids (ex. HIV positive breast milk, the local non-filtered water supply ridden with bacteria-borne illnesses), and 3) other methods for preventing vector-based disease transmission (ex. using sleeping nets over beds and insecticides). Access to healthcare facilities as well as funding for the above solutions for mortality prevention are also major challenges in these countries.

Partial Least Squares (PLS) Regression Model

Partial Least Squares Regression (PLS) was introduced by Herman Wold and was further developed with his son, Svante Wold. This technique generalizes and combines features from principle component analysis and multiple linear regression analysis. When the number of predictors is larger than the number of observations, X is likely to be singular and the regression approach is not feasible because of multicollinearity (Abdi, 2003).

PLS find components from X that are also relevant for Y. It searches for a set of components, called latent vectors, that performs a simultaneous decomposition of X and Y with the restriction that the components explain as much as possible of the covariance between X and Y. In this study, PLS regression was used for the data analysis to identify risk factors that affects the infant mortality rates in the world. PLS regression determines which predictor variable contributes most to the outcome. This technique uses the latent variables to explain the predictor and response variation among the data set. This allows the independent variables to be ranked in order based on the variable importance in the projection.

PLS regression coefficients can be used to select relevant predictors according to the magnitude of their absolute values (Chong and Jun, 2005).An alternative method for variable selection based on PLS regression is the so-called VIP, first published (Wold, Johansson, Cocchi, 1993).The majorfunctions involved in the PLS model construction were determining the significant explanatory variables. In addition,the model fitting statistic

(R squared value) and the accuracy of the prediction results (mean absolute percentage error--MAPE) were essentially assessed for selecting thesuitable model.

Artificial Neural Network (ANN) Model

ANN is an information processing paradigm inspired by the function of the human brain (Freeman &Skapura, 1991; Hinton, 1992; Zutada, 1992). ANN processes information using a parallel approach along with the feed forward technique so that information can efficiently flow through the system in one direction from input to hidden and then to the output layer neurons. Also, ANN involves an adaptive learning process that changes its model structure during the training phase. It is an accommodative learning model that allows for the assessment of relationship between input (independent) and output (dependent) variables based on the iterative process. The back-propagation of error is a technique used to minimize the prediction error by adjusting the connection weights from output to hidden layer and from, hidden to input layer.

ANN models were used for the data analysis to identify risk factors that affects the infant mortality rates in the world. Four fundamental steps for the model construction are involved.Step 1: The outcome variable and its seven risk factors were collected in a fixed format flat file. The outcome variable was the infant mortality rate for each country in years 2005-2009. Step 2: A trial and error process was performed by applying all activation for the ANN model. The ANN architecture consisted of eight models from two activation functions between input and hidden layers (hyperbolic tangent and sigmoid), and four activation functions between hidden and output layers (identity, softmax, hyperbolic tangent, and sigmoid).Step 3: All possible ANN candidate models were trained and tested to achieve minimal prediction error. The data set was partitioned into two subsets for training and testing with approximately70% of the data points randomly selected as the training set to estimate parameters. The remaining 30% was used for testing purpose. Step 4: The results of the ANN models were evaluated and compared with each other to determine if they were suitable for the infant mortality study. The benchmark comparison was performed by comparing the normalized importance, the rank order of risk factors, and prediction accuracy.The normalized importance provides a hierarchal viewpoint of the ranking of the risk factors.

Study Method

Although previous studies have uncovered numerous variables to consider, this study examined 6 variables in 134 countries for which data was accessible through the United Nations' data bank-- the model was based on the availability of quantify variables. The objectives of this study were to: a) uncover the significant risk factors that contribute to infant mortality rates globally; b) to determine which of those significant risk factors is the most influential. Variables targeted included: 1) the country's income as evidenced by Gross Domestic Product (GDP), 2) education levels revealed by literacy rate, 3) health care expenditures, 4) adolescent fertility rate, 5) developmental status (i.e. developed, developing, and underdeveloped), and 6) corresponding year (2005-2009).

PLSregression is a suitable method for constructing predictive models when the factors are numerous and highly collinear. It seeks to explain the linear relationship between an outcome variable of interest (i.e. a dependent variable) and independent variables. In this analysis, the dependent variable was infant mortality rates (IM_RT) for 134 countries throughout years 2005 – 2009.

Table 1.
Variables in PLS Regression Model

Variables Names	Variable Descriptions	Source
LOG_GDP	Natural Logarithm of Gross Domestic Product	World Health Organization
FERT_RT	Adolescent Fertility Rate	World Health Organization
DEV_CD	Country Development Code: 1 = Underdeveloped 2 = Developing 3 = Developed	World Health Organization
HCEX_PCAP	Health Care Expenditure per Capita	World Health Organization
LITER_RT	Adult Literacy Rate	World Health Organization
YEAR	Calendar year (2005 – 2009)	World Health Organization

This specific XLSTAT software version 2012 is presented to study what affect various risk factors-- log of gross domestic product (LOG_GDP), literacy rate (LITER_RT), health care expenditure per capita (HCEX_PCAI), fertility rate (FERTI_RT), country development (DEV_CODE), and year (YEAR)-- have on infant mortality rates in 134 countries between 2005-2009. Data interpretation in this study focused on the tools of PLS including: Variable Importance Projection (VIP), Model Parameter (i.e. Regression Coefficients), Goodness of Fit statistics, and Standardized Coefficients (95% C.I. Chart).

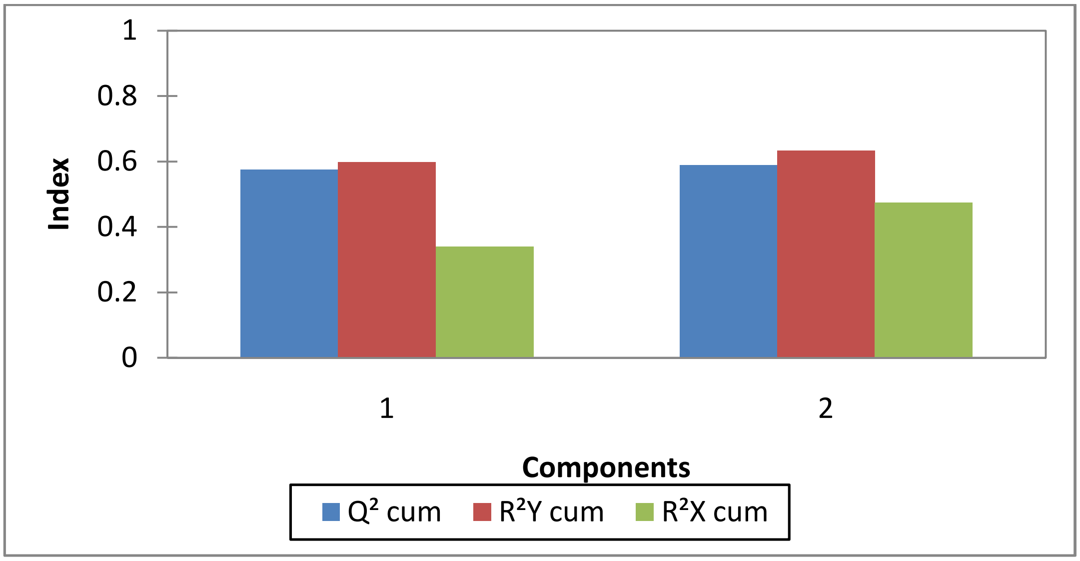
Statistical correlation was also considered; correlation refers to a number between -1 and +1 that measures the degree of association between two variables (X and Y). A positive value for the correlation implies that there is a positive association, that is, large values of X tend to be associated with large values of Y, and similarly small values of X then to be associated with smaller values of Y. Conversely, a negative value for the correlation implies a negative or inverse association, that is, large values of X tend to be associated with small values of Y, and vice versa.

Major Findings Using PLS

The first bar chart (Figure 1) allow researchers to visualize the quality of the PLS regression as a function of the two components selected automatically. As shown in this graph, Q^2 remains fairly high which is close to 0.6 (ideally it should be close to 1). This suggests that the quality of the fit slight varies depending on the explanatory variables.

The cumulated R^2Y cum that correspond to the correlations between the dependent (Ys) variables with the components are slight greater than 0.6 with 2 components. The cumulated R^2X cum that correspond to the correlations between the explanatory (Xs) variables with the components are less than 0.5 with 2 components. This indicates that the 2 components generated by the PLS regression summarize well for the Ys, but Xs.

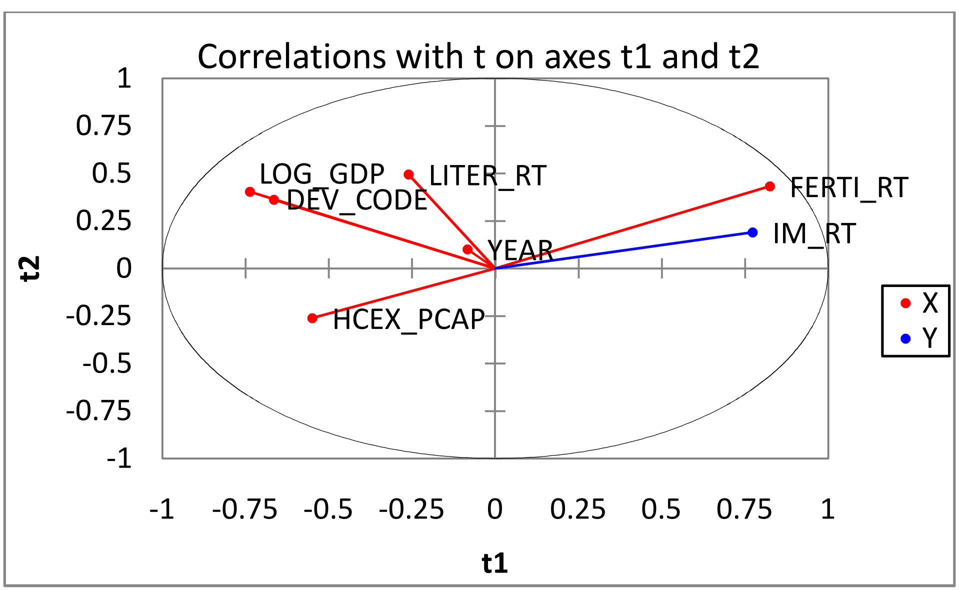
Figure 1.
Model Quality by Number of Components



As shown in Figure 2, we can see that for one variable (YEAR) displayed near the center of the map, the correlation is low that is globally little correlated with the explanatory variables (Xs). Regarding the explanatory variables we notice that the LITER_RT is not well represented on the first two dimensions. We can interpret this as the fact that this variable explains only little the rate of infant mortality, which is not surprising as it does not have a strong effect on infant death that could easily influence the infant mortality rate.

We notice the strong correlations between the DEV_CODE and the LOG_GDP, the FERTI_RT and IM_RT, and the negative correlation between the IM_RT and the two variables DEV_CODE and the LOG_GDP. One should also notice how different the explanatory variables are: they are not concentrated on one part of the correlations circle, but well distributed all around it.

Figure 2.
Correlation of X and Y with Latent Vectors

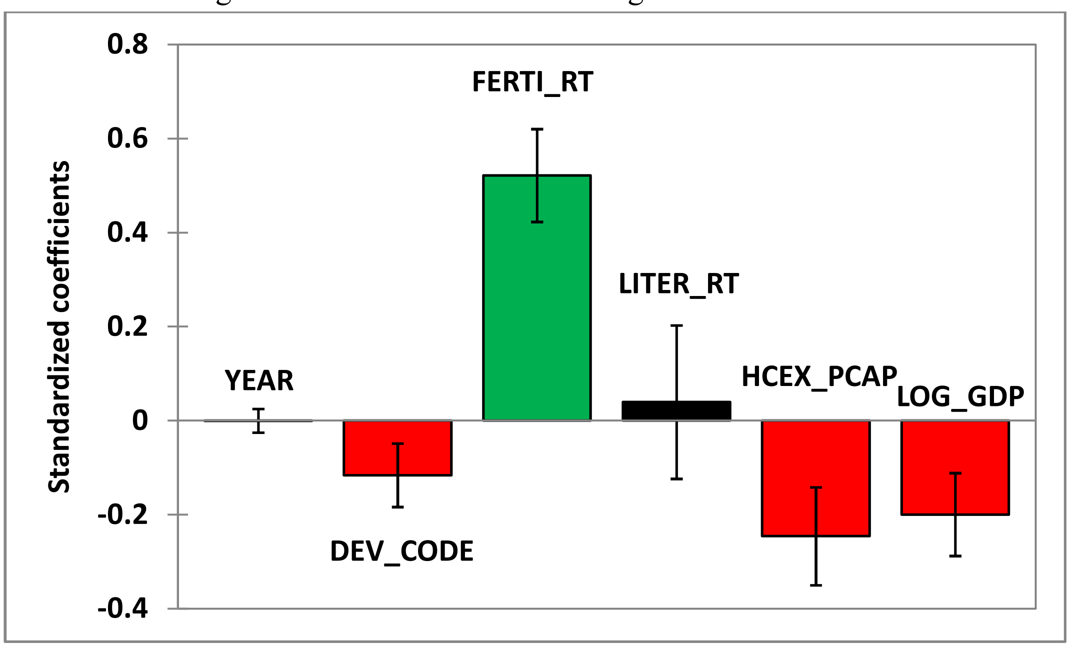


For each model, PLS displays the goodness of fit coefficients, the standardized coefficients table, and the table of predictions and residuals. The analysis of the model corresponding to infant mortality allows researchers to conclude that the model is well fitted (R^2 equals to 0.88).

The standardized coefficients graph, as shown in Figure 3, reveals the significance, direction, and magnitude of the association between IM_RT and the risk factor. A null hypothesis states that the risk factors do not have a statistically significant relationship with IM_RT. The alternative hypothesis states that a significant association does exist between the outcome and independent variable of interest. If zero is within the confidence interval, the null hypothesis is rejected because there is no statistical association between that variable and the outcome of interest.

In the analysis of the standardized regression coefficients, all variablessignificantly contributed to IM_RT except YEAR and LITER_RT. In other words, YEAR and LITER_RT do not have a significant relationship with IM_RT because zero is within the 95% confidence interval of their standardized regression coefficient.

Figure 3.
Standardized Regression Coefficients of PLS Regression Model



Variable Importance in the Projection (VIP) scores estimated the importance of each variable in the projection and was often used for variable selection. A variable with a VIP score close to or greater than one was considered to be important in a model. On the contrary, variables with VIP scores significantly less than one were less important and might be candidates for exclusion from the model.

In the VIP table (Figures 4 & 5), most variables had a high level of importance in their relationship to IM_RT. FERTI_RT is of highest importance in the model with a VIP score of 1.640. DEV_ CODE (1.061), LOG_GDP (1.068), and HCEX_PCAI (0.976) were also important variables though not as important as FERTI_RT. YEAR had the lowest level of importance (0.105), but was still statistically significant.

Figure 4.
VIP in Component 1 of PLS Regression Model

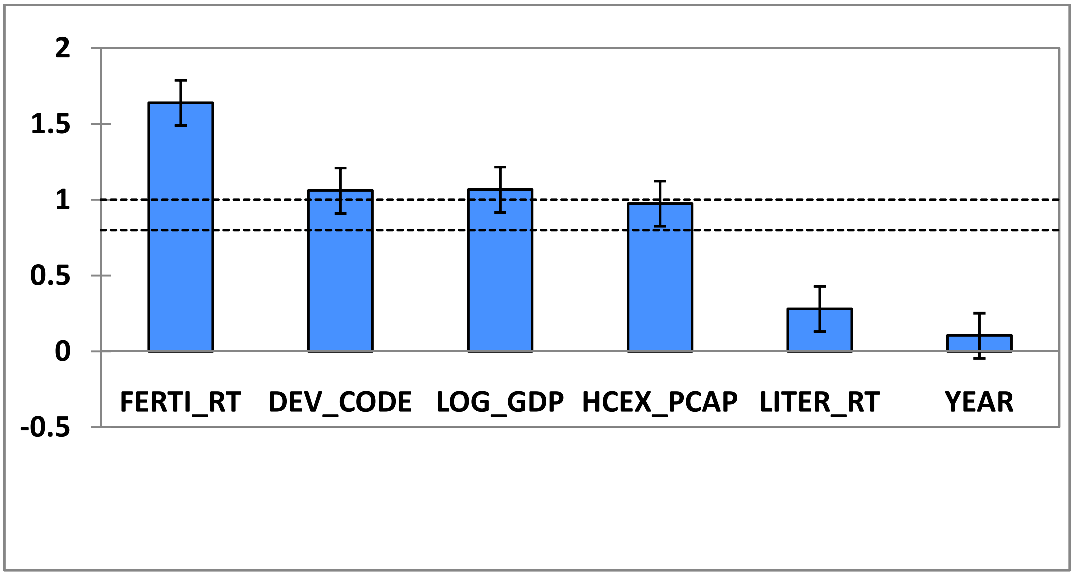


Figure 5.
VIP in Component 2 of PLS Regression Model

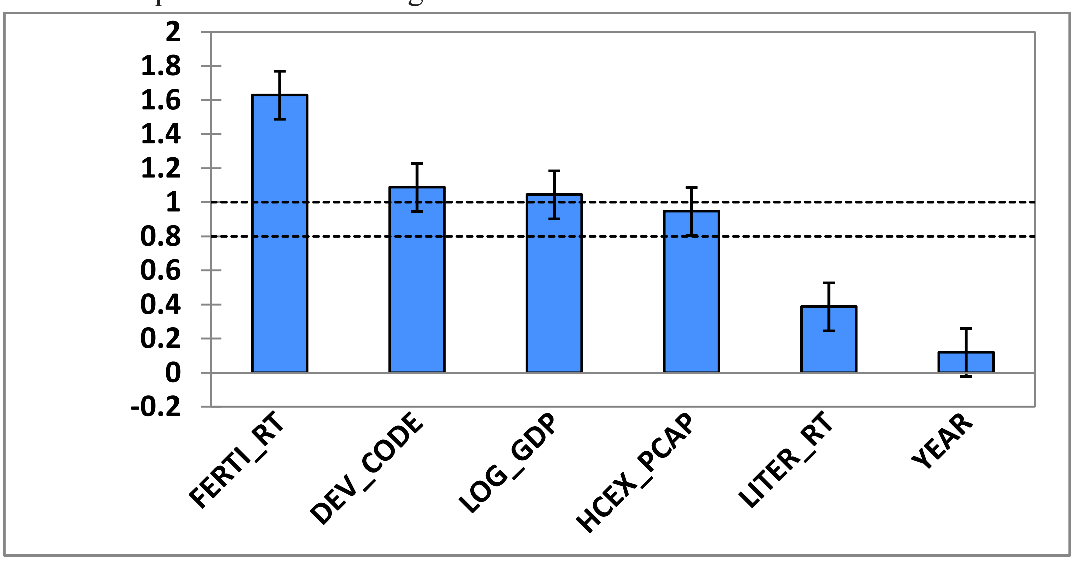
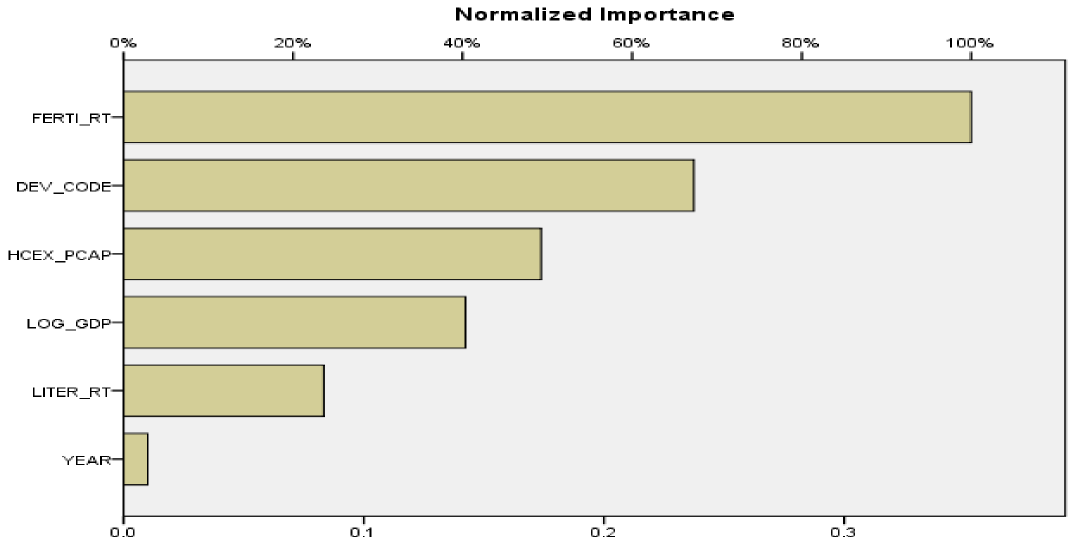


Figure 6 shows which variables are important to IM_RT. Consistent with the VIP projections in PLS, FERTI_RT, DEV_CODE, and HCEX_PCAP, are all very important in determining IM_RT, with values that are greater than 50%. LOG_GDP, LITER_RT, and YEAR are all important, also consistent with PLS, though much less important than FERTI_RT, DEV_CODE, and LOG_GDP.

Figure 6.
Normalized Importance in ANN



When utilizing model parameters, the signs that correspond to the independent variables determine the mathematical operation found in the equation. For instance, for the negative relationship that exists between IM_RT and YEAR, subtraction is the mathematical operation done. For a positive relationship with FERTI_RT, addition is the operation of choice. According to PLS, the relationship between the dependent and independent variables is shown by the following equation:

IM_RT = 116.596 - 4.19 x 10^{-3} *YEAR - 8.36 *DEV_CODE + 0.38 *FERTI_RT + 6.08 x 10^{-2} *LITER_RT - 0.38 *HCEX_PCAI - 2.47 *LOG_GDP

Goodness of fit statistics reveal how well the model and the variables explain IM_RT. Using this analysis, 63.4% of the variation in IM_RT was explicable by all the risk factors of interest (FERTI_RT, DEV_CODE, LOG_GDP, HCEX_PCAI, YEAR, and LITER_RT) and vice versa. The accuracy of the model is revealed by the root mean square error (RMSE); in this instance, it was equivalent to 18.07. This value is relatively small compared to its mean square error and standard deviation. Therefore, it can be stated that the model that shows the relationship between IM_RT and the variables of interest was relatively accurate. This was also indicated by the calculation of a reduced chi-square statistic.

To determine the chi squared statistic the weighted sum of squared errors (670) was divided by the degrees of freedom (667). When dividing the values of 670/667 a reduced chi-square of 1 is calculated , which indicates that the error variance was appropriately estimated for the observed and predicted values, thus indicating a good fit of the applied model to the observations for infant mortality.

In summary, the XLSTAT software for this study revealed DEV_CODE, HCEX_PCAI, LOG_GDP, and FERT_RT to have a considerable impact on infant mortality rates from the 134 countries reviewed in the model created from quantitative data available from 2005-2009.

Conclusion

This study confirms findings from previous studies in the literature linking high fertility rates with high infant mortality rates. In Zimbabwe and Canada, researchers have found an inverse relationship between fertility rates and infant survival (Kembo& Van Ginneken, 2009 and Eggertson, 2010). Some remedies for reducing fertility rates include: 1) improving education of and access to prophylactics, 2) and instilling hope for possibilities outside of motherhood by allowing young women equal opportunities for formal education.

However, interestingly, on the other side of the dichotomy exists the problem of alarmingly low fertility rates for countries like China, Taiwan, and Japan.These countries may want to consider France's model of giving incentives to younger couples to begin families when their bodies, finances, and mental maturity are in prime alignment to reproduce and support offspring at lowest risk for infant mortality.

This study also validates former studies with respect to the inverse relationship between healthcare expenditure (which is influenced by a country's Gross Domestic Product) and infant mortality. The more funds allocated to provide adequate healthcare access and service to all communities, the lower the infant mortality rate. The researchers in Bosnia found that expenditures allowing hospitals to house a Neonatal Intensive Care Unit greatly increase the chance of infant survival for low birth weight infants (Nevacinovic, Skokic, Ljuca, &Muratovic, 2011).

However, there are some cases in which increased healthcare expenditure leads to increased infant mortality as researchers are finding in Canada (Eggertson, 2010). The increase in the expensive procedure of in vitro fertilization by older women, creates more embryos to vie for space, time, and nutrients in the limits of the womb, which therefore precipitates early delivery of resultant low birth weight infants who are at highest risk for infant mortality.

Additionally, this study is also consistent with previous research in its finding that the lower a country's developmental status the higher its infant mortality. In the underdeveloped countries of Mozambique and Liberia, infant mortality rates are extremely high (Central Intelligence Agency, 2011). The living conditions dictated by being in an underdeveloped or developing country-- poor sanitation, exposure to disease, poor healthcare access, lack of education, etc-- often negatively influence birth outcomes and hence increase infant mortality rates.

Worldwide, previous studies have found that environmental factors are the most significant contributors of higher infant mortality rates-- substandard water quality, lack of adequate food, and high proliferation of infectious and parasitic diseases. Pneumonia, the number one infectious infant killer, proceeds malaria and measles.

Strengthening this study, the objectives were accomplished as we were able to identify a subset of the significant risk factors that contribute to infant mortality rates, and rank the factors in order of relative importance in contributing to infant mortality rates in the 134 countries reviewed. The findings from the traditional, linear approach of the PLS statistical model are consistent with the findings of the artificially intelligent, non-linear approach of the ANN mathematical model. This model verification approach demonstrated the validity of the research findings.A weakness of this study is lack of data on more quantitative risk factors for the large sample size, such as data on infectious disease death rates for infants and measurements of environmental quality (e.g., water, sanitation, food supply) for the 134 countries studied.

Perhaps a universal grading system could be created for which the score reflects measures on various components of each country's 'fitness' such as water quality, communicable disease transmission and death rates, vector-based disease transmission and death rates, food supply, and sanitation. A grading system of this sort would be helpful to this study, other studies, and those involved in policy change and implementation within each respective country; it would be easier to see and address areas that needed the most improvement, attention, and funding to keep the population functioning at optimal levels.

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