Forecasting Changes in Religiosity and Existential Security with an Agent-based Model

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Abstract: We employ existing data sets and agent-based modeling to forecast changes in religiosity and existential security among a collective of individuals over time. Our model includes agents in social networks interacting with one another based on the education level of the agents, the religious practices of the agents, and each agent's existential security within their natural and social environments. The data used to inform the values and relationships among these variables is based on rigorous statistical analysis of the International Social Survey Programme Religion Module (ISSP) and the Human Development Report (HDR). We demonstrate that for the countries and time periods studied, our model provides a more accurate forecast of changes in existential security and religiosity than alternative modeling approaches. The improved accuracy is largely due to the inclusion of social networks with educational homophily which alters the way in which religiosity and existential security change in the model. These dynamics grow societies where two individuals with the same initial religious practices (or belief In God, or supernatural beliefs) evolve differently based on the educational backgrounds of the individuals with which they surround themselves. Finally, we discuss the results of our model in the context of the scientific study of religion and provide direction for future work.

Keywords: Religion, Agent-Based Model, Data Based Modeling, Social Influence, Social Network

Introduction

1.1 Traditional approaches to the social-scientific study of religion have difficulty accounting for the varied ways in which education, existential security, and social networks shape the religiosity of an individual and a collective of individuals. Furthermore, understanding the dynamics of the relationship among these factors over time adds complexity. Simulated environments have been used to test different theories of religious extremism and different proposals for reducing religious violence (Upal 2005; Bainbridge 2006; Iannaccone & Makowsky 2007). However, we are unaware of any previous work to model the relationships of the aforementioned factors with respect to a collective of individuals using an agent-based model. In this paper we explore this issue.

1.2 Our model can be parameterized for a given country and time period. Each agent has variables that reflect their education level, their existential insecurity, and different facets of their religiosity. In addition to these characteristics, each agent is connected to a social network of other agents. Based on their interactions with one another, the existential insecurity and religiosity variables of the agents change over time. We explore the behavior of the model to highlight those conditions that drive a collective of individuals over time to become more or less: (1) religious and (2) existentially secure. Finally, we demonstrate that for the countries and time periods studied our model provides a more accurate forecast of changes in existential security and religiosity than alternative modeling approaches.

Background

2.1 In this section we provide some background on several theories related to the evolution of individual and social expressions of religiosity. Then, in the next section, we review related research where similar theories have been encoded into simulation environments.

2.2 Previous research has established that religion is a cultural universal, in the sense that it arises in an astonishing variety of cultural forms with recognizably recurring features, such as belief in culturally postulated supernatural agents and the binding of people together into close-knit groups (Atran 2004; McCauley & Lawson 2002; Wildman 2009; Shults 2014a). Similarly, we now know that individual religiosity varies with personality in ways that are cross-culturally recognizable (Schuurmans-Stekhoven 2014; Caldwell-Harris 2012; Gebauer et al. 2012; Barber 2014). In the modern period, individual and cultural variations in both religiosity and secularity are also affected by a series of socio-political and economic factors. These factors include: (1) education level, (2) existential security, (3) a pluralistic attitude, and (4) religious freedom. Education level refers to the highest degree achieved by an individual. Existential security is an individual's view of the strength and stability of their government and social safety. A pluralistic attitude embraces cultural and religious diversity. Finally, religious freedom reflects an individual's ability to choose to affiliate religiously or not, and to choose lifestyles, without fear of social reprisals (Wildman et al. n.d.). Large-scale social surveys have been particularly useful for establishing such connections (Norris & Inglehart 2011, 2015; Inglehart et al. 2008).

2.3 Our work explores the relationship among religiosity and two of these factors: education and existential security. In other work we are exploring the pluralism and freedom factors but we focus here on education and existential security because proxy measures for those factors are more readily available.

2.4 Previous work has shown that these relationships can be strong and causal. For example, scientists are less religious than the general population. In general this is attributed to their educational background which trains them to be analytical thinkers. Being trained to think in this manner encourages a materialistic understanding of the world that is mismatched with dominant types of religious belief (Larson & Witham 1998; McCauley 2011; Norenzayan & Gervais 2013). Previous researchers have also argued that the existential security provided by secular institutions has reduced interest in religious institutions causing a decline in religious belief and participation. This is particularly clear in Scandinavian societies like Norway, where people report lower levels of religiosity compared to other countries. Norwegians enjoy high levels of existential security (i.e. strong and stable government, social safety nets) that are provided by secular, rather than religious, institutions (Norris & Inglehart 2011; Norenzayan & Gervais 2013).

2.5 These examples illustrate the traditional approach to analyzing the role of education and existential security in the religiosity of an individual and a collective of individuals. While many such research efforts have included the use of statistics to support their analyses, none have used agent-based models to forecast the way in which these factors affect changes in the religiosity of a population over time. The agent-based model we describe in Section 4 addresses that challenge.

Related Simulation Research

3.1 Other researchers have employed modeling and simulation methodologies to simulate culturally relevant change within individuals and collectives of individuals. Axelrod's *dissemination of culture* model simulated a variety of mechanisms showing how interaction between different cultural features challenges intuitive assumptions about individuals' beliefs and interpersonal behavior (Axelrod 1997).

3.2 In related work, Hegselmann and Krause investigated various models for the time-dependent dynamics of spreading opinions through a population of individuals in a computer simulation (Hegselmann et al. 2002). Suo and Chen proposed an agent-based model of the dynamics of public opinion in complex networks (Suo & Chen 2008). Later, Sobkowicz identified several enhancements to each of these approaches and improved the predictive value of their efforts (Sobkowicz 2009).

3.3 More recently, Upal and Gibbon developed an agent based system for simulating the dynamics of social identity beliefs that aimed at isolating factors that contribute to intergroup conflict (Upal & Gibbon 2015). In addition, Shults et al. developed two different computer simulations to demonstrate the impact of mortality salience on religiosity (Shults et al. 2017).

3.4 Agent-based modeling has also been used to study role of the emergence of a priestly class in solving large-scale social network coordination (Dávid-Barrett & Carney 2016), as well as the mechanisms that shape different modes of ritual interaction (Whitehouse et al. 2012).

Table 1: Model Entities

Model Entity Name	Attributes	Representation
Agent	Religious Formation (RF)	Real number in [0,1]
	Religious Practice (RP)	Real number in [0,1]
	Supernatural Beliefs (SB)	Real number in [0,1]
	Belief In God (BIG)	Real number in [0,1]
	Education (ED)	Integer from (1) *no formal education* to (6) *university level with degree*
	Existential Insecurity (EI)	Real number in [0,1]
Social Network (SN)	Strength of relationship between any two agents	2-D Matrix of Real numbers in [0,1]
Existential Security of Environment (ES)	NA	Real number in [0,1]

The Simulation Model

4.1 The goal of our model is for a given time period and country to predict changes in the existential security and the religiosity of a collective of individuals using an agent-based model. Here we describe the architecture of our model including: (1) the entities within the model, (2) the data sources used to initialize the entities, and (3) the rules that dictate the interactions among them.

Model Entities

4.2 Our model is made up of agents interacting through social networks in an environment defined by its existential security level. Each agent has an education level, an existential insecurity level, and four variables that reflect their religiosity. Each agent is also connected to a subset of the other agents in the model through a social network. An overview of these entities, with their attributes and representation, is shown in Table 1.

4.3 The four variables that reflect religiosity in each agent are: (1) religious formation, (2) religious practice, (3) supernatural beliefs, and (4) belief in God. The identification of these variables is based on a rigorous statistical analysis of questions and responses from the International Social Survey Programme Religion Module (ISSP) (Davis & Jowell 1989). The goal of this analysis was to filter and aggregate 33 questions related to religion in the ISSP into a lower number of unobserved variables called factors. The analysis results in a *factor score* for each respondent for each factor based on the respondent's answers to the questions included in the factor. We normalize these factor scores on a 0 to 1 scale.

4.4 Ultimately, we identified 13 questions that formed the aforementioned four religiosity factors. These questions and the factors they form are shown in Figure 1. Additional details about the exact wording of the questions, iterative steps within the factor analysis, and the resulting measures of fit and statistical significance are provided in (Lemos et al. 2017).

4.5 Each agent is connected to the existential security level of the environment. The existential security level of the environment reflects the percentage of the agents that feel existentially secure. An agent determines if they feel existentially secure by checking if their value for existential insecurity is below the existential security value of the environment. The initialization of these entities and the variables that make up each agent are described next. Then the description of the interactions among agents and the environment are presented.

Data Sources Used To Initialize Entities

4.6 The initialization of each entity is based on the country and time period being modeled. For a given country and a given year, the existential security level of the environment is initialized using data from the Human Development Report (HDR). The HDR is an annual multi-facetted analysis of wellbeing focused on key dimensions of human development including a long life, a healthy life, and a decent standard of living. The Human Development Index (HDI) is the summary measure used in the HDR for a country's achievement across these dimensions (Anand 1994).

4.7 Similarly, based on a specific country and a specific year, an agent is initialized by randomly sampling an ISSP respondent. Using the respondent's data, the characteristics of an agent are parameterized. Specifically, the factor scores for the four religiosity factors of the chosen ISSP respondent initialize the agent's religiosity variables and the education level of the respondent parameterizes the agent's education level.

4.8 The education level of the respondent is based on the answer to the question: "What is the highest level of education you've achieved?" Responses to the question are coded on a 6-point scale from: (1) *no formal education* to (6) *university level with degree*. We do not employ factor analysis for the education variable because this

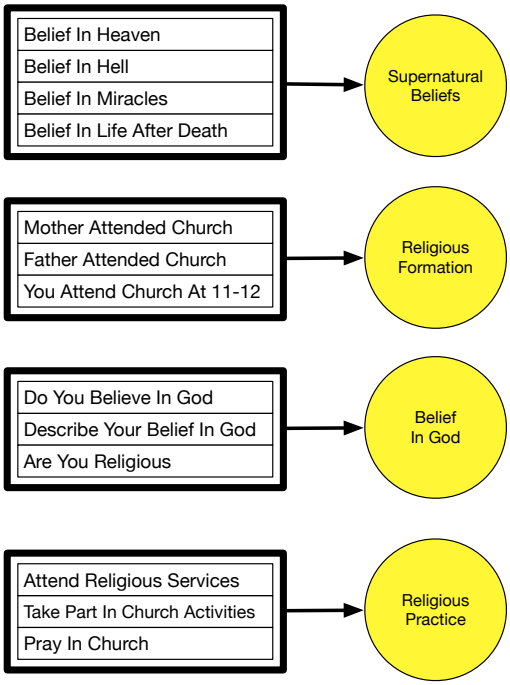

Figure 1: **Religiosity factors and associated questions from analysis of ISSP data. Analysis details, fit statistics, and statistical significance are provided in (Lemos et al. 2017).**

question measures a response that is very close to the variable we want to capture and there are no additional questions related to education within the ISSP.

4.9 Finally, the existential insecurity level of an agent is parameterized by sampling a uniform distribution between 0 and 1. While this parameterization is not based on data, the interactions of the model tie each individual's existential insecurity to the existential security level of the environment. This relationship is described further in Section 4.19.

4.10 Each agent is also assigned a social network. The number of and weight of the links within the network is constructed by an algorithm (Conti et al. 2011) that mirrors human social networks observed in the wild (Hill & Dunbar 2003; Dunbar & Shultz 2007). The degree to which the educational level of the agent limits educational diversity within the agent's network is determined by the parameter, *Education Homophily (EH)* (McPherson et al. 2001, 2006). The source code for this algorithm is included as supplementary material.

Interactions Among Entities

4.11 Given these initialized entities we define rules that govern the interactions among our entities. First, we review rules that dictate how changing religiosity variables influence one another. Next, we describe how agent's interactions within their social network influence their existential insecurity and religiosity. Finally, we describe the rules related to agent interactions with the existential security level of the environment.

Organizing Agent Religiosity

4.12 We use structural equation modeling (SEM) to organize the relationships among the four religiosity factors. SEM enables us to hypothesize an architecture of the relationships among the factors and assess the extent to which the hypothesized architecture matches the observed data from the ISSP. Using our four factors it is possible to construct 588 unique SEM architectures. Of those 588, four models have identical fit statistics that are superior to the other 584. Of the four models with the best fit statistics, one places the factors in an order that is consistent with theories of religiosity posited in the scientific study of religion (Shults 2014b; Holbrook

et al. 2015; Crescentini et al. 2014; Ramsay et al. 2015; Davidson et al. 2003; Lutz et al. 2008; Norenzayan et al. 2012). This model is shown in Figure 2. Additional details and fit statistics for this and other candidate models are provided in Lemos et al. (2017).

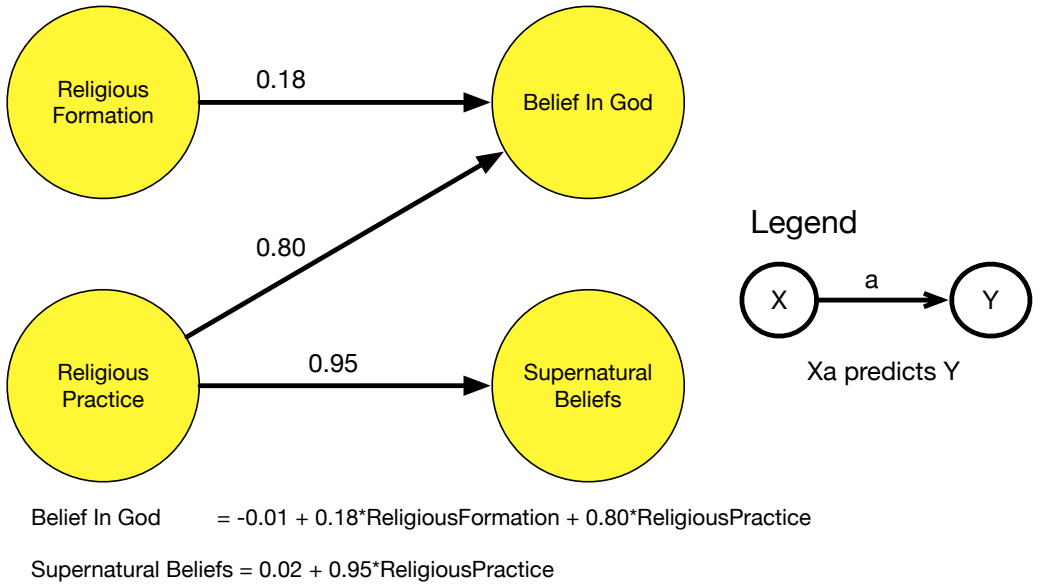

Figure 2: **Structural equation model that organizes the four religiosity variables within an agent.**

4.13 The model describes quantitatively how changes in religious practices and religious formation factors of an agent predict changes in the agent's belief in God and the agent's supernatural beliefs. Religious formation reflects questions related to the religious upbringing of the agent. Since this factor reflects events that have happened in the agent's past, we do not update the value of this variable in our model. Next, we describe how the value of an agent's religious practice and existential insecurity variables can change based on influence from the social network.

Updating Agent Religiosity Values Based On Social Network Interactions

4.14 At each time step agents interact with the agents in their social network. Each time step corresponds to one week. In this interaction the religious practice variable and existential insecurity within the agent are influenced by the respective values of these variables in other agents within their social network. The extent to which the variable is influenced is determined by a time-dependent weighted average. Given a matrix IN that includes an entry for the influence of each of the N agents on every other agent, the total influence exerted on agent i is show in Equation 1.

$$TotalInfluence_i = \sum_{\substack{j=1 \\ i \neq j}}^{N} INi,j \tag{1}$$

4.15 $TotalInfluence_i$ and a set A that includes all agents enables us to define, $A_{SN_{v,t,i}}$. Set A contains the value of each variable v, at each time step t, for each agent j, throughout the simulation ($A_{v,t,j}$). $A_{SN_{v,t,i}}$ is the influence exerted on agent i by his/her social network (SN) for a given variable v at time t. Formally it is shown in Equation 2.

$$A_{SN_{v,t,i}} = \sum_{\substack{j=1 \\ i \neq j}}^{N} \frac{A_{v,t,j} \times INi,j}{TotalInfluence_i} \tag{2}$$

4.16 Based on the influence exerted on the agent's religious practice variable from their social network at time t ($A_{SN_{RP,t,i}}$), new values for the agent's supernatural belief ($A_{SN_{SB,t,i}}$), and belief in God ($A_{SN_{BIG,t,i}}$) variables are generated using the equations in the model shown in Figure 2.

4.17 Finally, each of the values based on the influence of the agent's interaction with the social network ($A_{SN_{RP,t,i}}$, $A_{SN_{SB,t,i}}$, $A_{SN_{BIG,t,i}}$, $A_{SN_{EI,t,i}}$) is combined with the agent's existing value for the respective variable. This combination is computed using Cobb-Douglas function (Cobb & Douglas 1928). We employ the Cobb-Douglas function because it is an established, flexible, and widely used method to aggregate the influence of the environment with the existing value of a variable. Formally, given a variable v, this combination is shown in Equation 3.

$$A_{v,t+1,i} = {A_{v,t,i}}^{\beta} \times {A_{SN_{v,t,i}}}^{1-\beta} \tag{3}$$

Interacting With The Environment

4.18 Once every agent has computed the influence of their social network on the applicable variables, every agent interacts with the environment. An agent interacts with the environment by checking if their value for existential insecurity is below the existential security value of the environment. Recall for a given country and a given year, the environment is initialized with the country's HDI value. Also, recall that the existential insecurity value of agents is initialized with a random number sampled from a uniform distribution between 0 and 1.

4.19 This check reflects whether or not the agent is provided sufficient existential security by the environment to be healthy and feel safe. Formally, the process of applying this check to all N agents at time step t to determine the influence of the agents on the existential security level of the environment ($ES_{agentInf,t}$) is shown in Equation 4. Agents with high EI values are less likely to be provided sufficient existential security, while agents with low EI values are more likely to be provided sufficient existential security.

$$ES_{agentInf,t} = \frac{1}{N} \times \sum_{i=1}^{N} \begin{cases} 1 & \text{if } A_{EI,t,i} < ES_t \\ 0 & \text{if } A_{EI,t,i} \geq ES_t \end{cases} \tag{4}$$

4.20 Finally, the value for the existential security of the environment in the next time step ($t+1$) is computed by combining the value of the existential security value of the environment at time t with $ES_{agentInf,t}$ at time step t. This combination is also done with Cobb-Douglas function as described in Equation 3. The choice to reuse this function and its parameter, β, improves parsimony by reducing the total number of parameters in our model. Recall, it also an established and widely used method to combine the intrinsic value of a variable with an environmental influence on the variable. An overview of the model and the data sources used to initialize the entities within the model is shown in Figure 3.

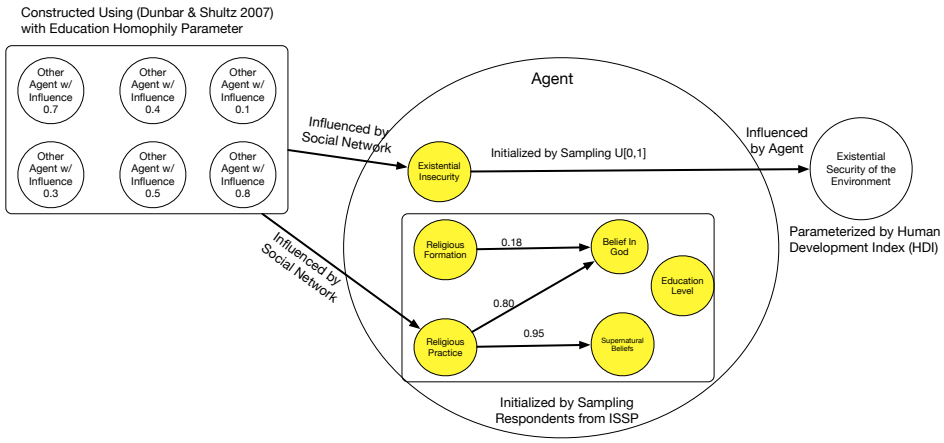

Figure 3: **Overview our of model and the data sources used to initialize the entities.**

Evaluation

5.1 The effectiveness of our agent-based forecasts for changes in religiosity and existential security is elucidated through empirical evaluation against alternative modeling approaches. Specifically, we compare our agent-based approach to: (1) a baseline approach based entirely on historical data and (2) a statistical approach that uses linear regression modeling (LR).

5.2 For a given period of time, each model predicts changes in the religious practice, supernatural beliefs, belief In God, and existential security of the population of a given country. The baseline approach assumes there will be no changes in these factors from the most recent previous data. This approach mirrors predicting that the weather tomorrow will be the same as the weather today. The statistical approach uses regression to predict future changes in a variable using a weighted linear combination of the current variables (religious practice, education level, religious formation, existential security, supernatural beliefs, and belief in God).

5.3 We evaluate each of these candidate models using a three part process. First, we identify similar time periods of measurement between the ISSP and HDR data. ISSP data was collected in 1991, 1998, and 2008 while HDR data was collected in 1980, 1985, 1990, 1995, 2000, 2005, 2010, and 2011-2014. Given that there is no intersection of common data collection we use time periods of HDR data that are closest to the ISSP time periods. These time periods are ISSP: 1991 - 1998 / HDR: 1990 - 2000 and ISSP: 1998 - 2008 / HDR: 2000 - 2010.

5.4 Next, for these time periods we identify the countries where data was collected in the ISSP and the HDR. There are 11 countries where data is collected in both time periods for both data sources. These countries are: Germany, Hungary, Ireland, Italy, Netherlands, New Zealand, Norway, Philippines, Poland, United Kingdom, and United States. The full availability of all country data within the ISSP and HDR is described in Appendix A.

5.5 Finally, we fit the parameters of each model. The baseline approach does not require this final step because it does not have any parameters. However, to fit the parameters of the LR models and our agent-based model, we perform an automated search over all the combinations of possible values for the parameters using data for all countries in the previous time period for which there is both ISSP and HDR data.

5.6 The automated search identifies the parameters for the model that minimize the root mean squared error (RMSE) of the absolute error of the mean forecast ($\bar{e_a}$) for each variable for each country. The $\bar{e_a}$ for a country is determined taking the absolute value of the difference between the mean value of a forecasted variable and the mean of the actual data for the variable in the ISSP and HDR.

5.7 For the LR models this entails identifying the regression coefficients for each variable used as input. For our agent-based model this entails identifying values for the parameters: (1) Education Homophily (EH) and (2) Douglas-Cobb Function β. Since the ABM is stochastic, 100 replications of each trial are performed and the mean of the 100 outputs is used.

5.8 To avoid overfitting the LR models, we only include LR models with statistically significant variables. Furthermore, since the ISSP does not collect longitudinal data, each LR model is only trained on country-level data (i.e. mean RP, mean SB, mean BIG) as opposed to individual-level data. These two factors (statistical significance and only country-level data) result in LR models which include only one variable, the current country-level value of the variable being predicted.

5.9 Recall, our data set only has two different time periods (ISSP: 1991 - 1998 / HDR: 1990 - 2000 and ISSP: 1998 - 2008 / HDR: 2000 - 2010). As a result, we fit the parameters of the regression models and the agent-based model using data from the first time period. Then we evaluate the accuracy of each model's forecasts using data from the second time period. Since one time step in our agent-based model corresponds to one week, we simulation 520 time steps (10 years) in training and evaluation. The models and their parameters are shown in Table 2.

5.10 Next, we use the identified parameters to forecast the ISSP and HDR values for the upcoming time period. Accuracy of a forecast is measured by the RMSE of the $\bar{e_a}$ for each variable for each country from the actual data (ISSP: 1998 - 2008 / HDR: 2000 - 2010). In addition, we evaluate the RMSE of the absolute error of the standard deviation of the forecast (σe_a) for each country for the variables religious practice, supernatural beliefs, and belief in God from the actual data. We cannot evaluate the RMSE of σe_a for the existential security variable because the HDR data is recorded on a per country level, not a per person level. This limitation means that the existential security data for each country is a single number and does not have a distribution or variance. The overall accuracy of each model is reported in Table 3. The results for each individual country for all approaches are reported in Appendix B and the results for our ABM are shown in Figure 5.

5.11 Table 3 shows that our parameterized ABM outperforms the baseline and LR approaches. Recall, each approach forecasts changes in the four variables for a given country over a given time period. For each of the four variables that each model predicts, the ABM has the lowest RMSE for the: (1) $\bar{e_a}$ - absolute error of the mean forecast and

Table 2: Parameterizations of models from competing approaches

Model Type	Parameters
Baseline	None, fitting is unnecessary.
LR $\overline{RP}$ Prediction	$0.053 + (0.90 \times \overline{RP_{current}})$
LR $\overline{SB}$ Prediction	$0.01 + (0.89 \times \overline{SB_{current}})$
LR $\overline{BIG}$ Prediction	$-0.01 + (0.91 \times \overline{BIG_{current}})$
LR ES Prediction	$0.07 + (0.99 \times ES_{current})$
ABM Predictions	EH = 0.40; $\beta = 9.4 \times 10^{-4}$

$\overline{RP}$ = Mean Religious Practice, ES = Existential Security, $\overline{SB}$ = Mean Supernatural Beliefs, $\overline{BIG}$ = Mean Belief In God, EH = Education Homophily

Table 3: Evaluation of the accuracy of predictions from competing approaches for countries on which models were trained

RMSE	Religious Practice			Supernatural Beliefs			Belief In God			Existential Security		
	Base	LR	ABM	Base	LR	ABM	Base	LR	ABM	Base	LR	ABM
RMSE												
$\bar{e_a}$	0.052	0.059	**0.039**	**0.058**	0.070	**0.058**	0.057	0.037	**0.028**	0.039	0.024	**0.008**
σe_a	**0.032**	0.035	**0.032**	0.034	0.040	**0.030**	0.020	0.020	**0.018**	NA		

$\bar{e_a}$ = absolute error of the mean forecast; σe_a = absolute error of the standard deviation of the forecast

(2) σe_a - absolute error of the standard deviation of the forecast. This means that the forecasts for each of the four variables from the ABM better match the central tendency and variation of changes observed in the ISSP and HDR than the competing alternatives. Based on the factor and the evaluation measure, the ABM ranges from as accurate ($RP_{\sigma e_a}$) to 3 $\times$ more accurate ($ES_{\bar{e_a}}$) than the next best alternative.

5.12 Next, we evaluate how effectively each of the trained models forecast changes in the four factors for a set of countries they have *not* been trained on. In this evaluation we use the 11 countries for which we have ISSP and HDR data from the most recent time period (ISSP 1998 - 2008 / HDR 2000 - 2010), but do not have data from the training time period (ISSP: 1991 - 1998 / HDR: 1990 - 2000). These countries are: Chile, Cyprus, Czech Republic, France, Portugal, Slovenia, Spain, Sweden, Switzerland, Denmark, and Japan.

5.13 This evaluation gives us insight into the robustness of the parameterizations identified in training. We use the term robust to reflect forecast accuracy for previously unseen countries and time periods. Again, we evaluate the RMSE of $\bar{e_a}$ and σe_a of each of the three modeling approaches for the 11 new countries. The overall accuracy of each model is reported in Table 4. The results for each individual country for all approaches are reported in Appendix C and the results for our ABM are shown in Figure 5.

Table 4: Evaluation of the accuracy of predictions from competing approaches for countries on which models were not trained

RMSE	Religious Practice			Supernatural Beliefs			Belief In God			Existential Security		
	Base	LR	ABM	Base	LR	ABM	Base	LR	ABM	Base	LR	ABM
RMSE												
$\bar{e_a}$	**0.032**	0.041	**0.032**	**0.065**	0.105	**0.065**	0.039	0.037	**0.033**	0.41	0.024	**0.011**
σe_a	0.024	0.029	**0.019**	0.023	0.035	**0.017**	0.029	0.028	**0.012**	NA		

$\bar{e_a}$ = absolute error of the mean forecast; σe_a = absolute error of the standard deviation of the forecast

5.14 The evaluation shows that the ABM continues to perform as well as the best approach even when it is applied to forecast countries where training data did not exist. Furthermore, for several evaluation measures it continues to be multiple times more accurate than the best alternative. These results are significant. They provide some

evidence that our model can be used to forecast current changes in the religiosity and existential security for other countries not included in the evaluation. Next, we discuss the features of our model that distinguish it from alternative approaches included in the evaluation.

Model Validation and Exploration

6.1 Three features distinguish our model from the alternative approaches included in the evaluation. These features are: (1) the existence of social networks with educational homophily, (2) the ability of agents to influence the religious practice and existential insecurity variables of one another via social networks, and (3) the ability of agents to influence the existential security level of the environment. To highlight how these features create conditions that enable accurate forecasts we explore the dynamics of our ABM predictions.

6.2 First, we consider how the existence of social networks with educational homophily affect change in the agent's religious practice variable throughout the simulation. Existing research has shown that the level of education one has is inversely correlated with the extent of one's religious practice (Albrecht & Heaton 1984; Larson & Witham 1998; Glaeser & Sacerdote 2008; McCauley 2011; Norenzayan & Gervais 2013). This relationship also exists within the ISSP dataset where the two variables have a -0.14 correlation with a p-value less than 0.01.

6.3 Our ABM implements this correlation through the educational homophily (EH) parameter. Recall, the EH parameter controls the degree of educational uniformity within one's social network. This feature is important because it provides a means for the sustained existence of groups of individuals with high religious practices, belief in God, and supernatural beliefs in countries where the majority of the population has low religious practices, belief in God, and supernatural beliefs. In other words, this feature ensures that every agent in the population does not take on all the preferences of the majority.

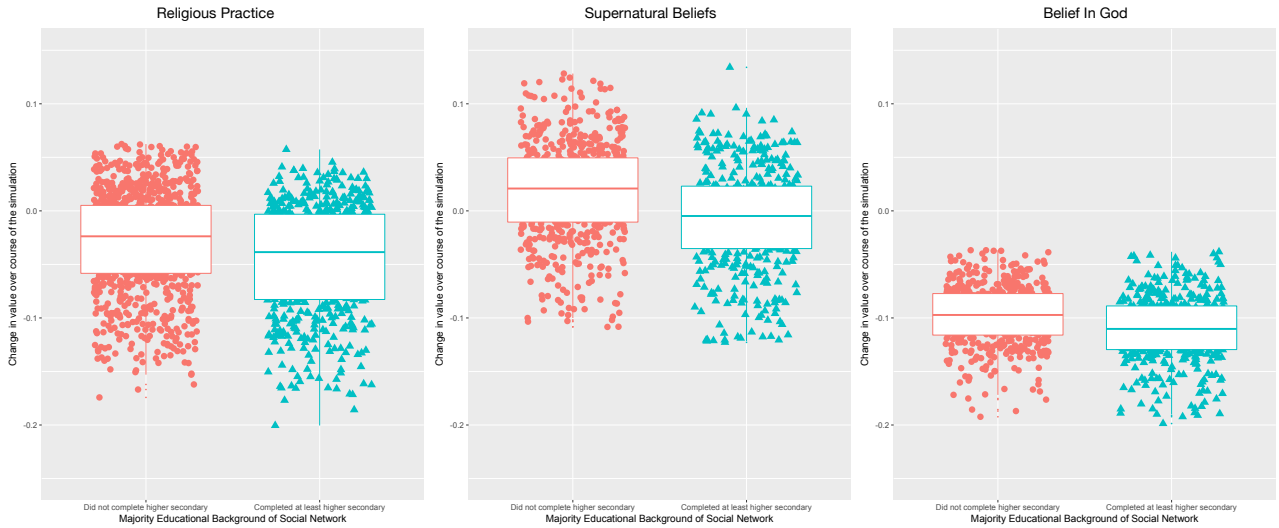

Figure 4: **Change in the religious practices, belief in God, and supernatural beliefs of agents from all countries for agents with similar initial respective variable values, broken down by education level.**

6.4 Figure 4 elucidates this feature in our ABM. It shows the amount of change for agents in the ABM with similar initial values for their religious practices, belief in God, and supernatural beliefs broken down by education level. For each variable (religious practice, belief in God, and supernatural beliefs) the population is formed by running the ABM for all 22 countries and then matching each agent attached to a network where the majority of the members completed higher secondary education with a similar agent attached to a network where the majority of the members did not complete higher secondary education. Agents are considered similar if the initial values of the variable for the two agents differs by less than 0.01.

6.5 Figure 4 shows that within our ABM, in social networks where the majority of agents have completed post secondary education, agents have on average a steeper decline in their religious practices and belief in God than

agents connected to social networks where the majority of agents have not completed post secondary education. Furthermore, Figure 4 shows that agents connected to social networks where the majority of agents have completed post secondary education, on average, do not increase their supernatural beliefs, while those agents connected to social networks where the majority of agents have not completed post secondary education, do increase their supernatural beliefs.

6.6 These dynamics are partially responsible for our ABM's ability to make more accurate predictions by growing a society where two individuals with the same initial religious practices (or belief In God, or supernatural beliefs) evolve differently based on the educational backgrounds of the individuals with which they surround themselves.

6.7 Next, we explore: (1) how the social networks in our ABM create changes in existential security for each of the countries and (2) how those changes in the existential security level of the ABM environment correlate with changes in religious practice, supernatural beliefs and, belief In God. For each of the 22 countries presented in our evaluation, the ABM predicts that the existential security of the environment will increase over time. The extent of that increase, how accurate the prediction is, and how the predictions correlates with predicted changes in the religiosity variables are shown in Figure 5.

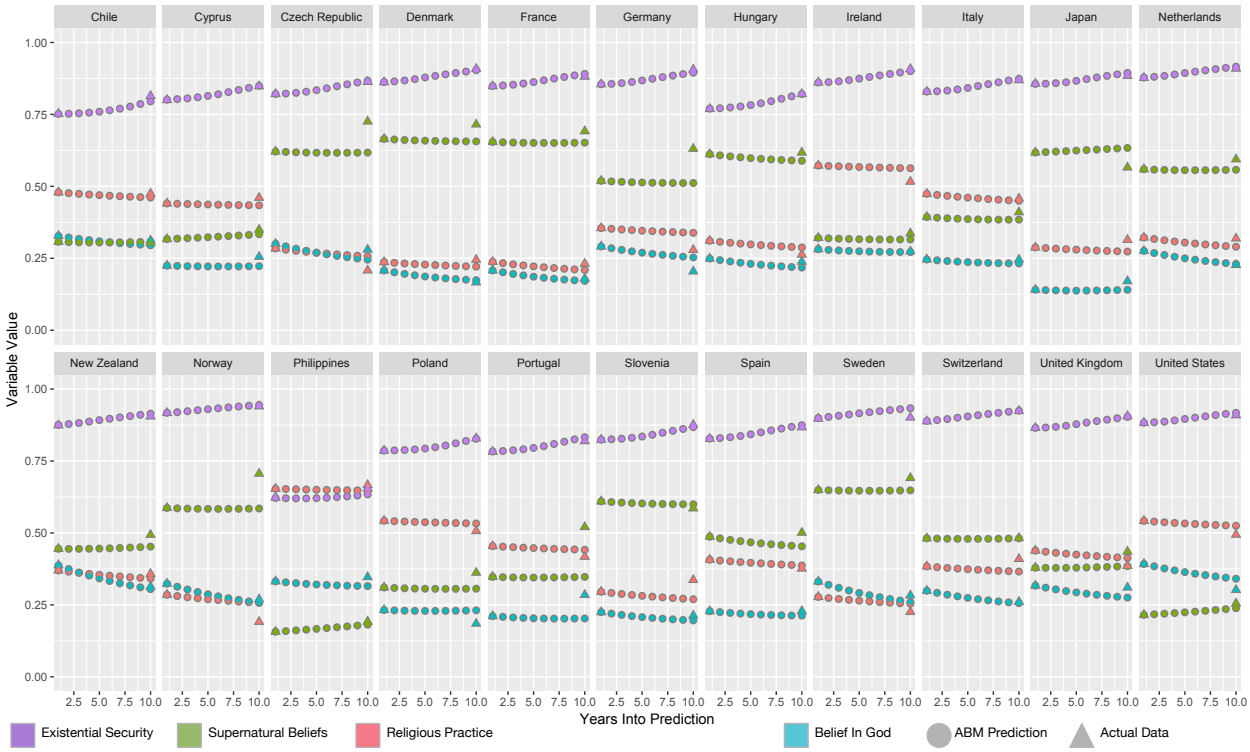

Figure 5: **Predicted change from our ABM for the existential security, mean religious practices, mean belief in God, and mean supernatural beliefs of agents for each country from 2000 - 2010.**

6.8 Figure 5 shows that when the existential security level of the environment in our ABM is high (>0.80) almost all agents feel existentially secure and the existential security level of the environment immediately increases. These types of predictions for our ABM are seen for countries including: Denmark, France, Germany, Ireland, Japan, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom, and United States.

6.9 However, if the initial existential security level of the environment is less than 0.80, there is not any growth in the existential security of the environment during the first three years. Eventually, the social network interactions of the agents within the ABM result in fewer agents with extreme existential insecurity values, creating fewer agents that feel existentially insecure and ultimately creating an increase in the existential security of the environment starting after year three. This increase continues through year ten. These types of predictions for our ABM are seen for countries including: Chile, Cyprus, Hungary, Italy, Poland, Portugal, Slovenia, and Spain.

6.10 This pattern of predicting staggered existential security growth is even more pronounced for countries where the initial existential security value is less than 0.65. This is the case with our ABM's prediction for the Philippines. Here there is no growth in the existential security of the environment for the first seven years of the prediction until finally there are enough social network interactions of the agents within the ABM to create a sufficient number of agents that feel existentially secure resulting in an increase in the existential security of the environment from years seven to ten.

6.11 It is important to note that our ABM does not predict existential security growth for countries where the initial existential security value of the environment is below 0.50. Under these conditions the existential security of the environment decreases over time. Recall, the existential insecurity level of agents is uniformly distributed from [0,1]. As the agents interact, the existential insecurity level of each agent becomes less extreme, but since the existential security of the environment is below 0.50 most agents in the population still feel existentially insecure despite less extreme existential insecurity values.

6.12 The behavior of our model under these conditions needs to be explored further and refined. The HDR data shows that the existential security value of the environment increases for many countries with an initial value less than 0.50. As currently constructed our ABM cannot replicate this behavior. However, it is also important to note that all the countries in the HDR that show a decrease over time in the existential security value of the environment are countries where the initial value is less than 0.50. In future work we will look to produce a more refined algorithm that takes into account each of these possible trajectories for countries with low existential security.

6.13 Figure 5 also shows that each increase in existential security predicted by our ABM is coupled with predictions for a decrease in belief in God. Furthermore, the magnitude of the predicted increase in existential security is almost exactly the same as the magnitude of the predicted decrease in belief in God. It is important to note that this relationship between existential security and belief in God is not encoded in any of the rules or interactions within our model. It emerges from the model interactions and the data that parameterizes the model for each of the countries. We discuss this result further in the next section and hypothesize as to why the same trend does not exist for supernatural beliefs and religious practice.

Discussion

7.1 For each of the countries we studied our ABM predicts an increase in existential security and decrease in belief in God. This same pattern is reflected in the data provided by the ISSP and the HDR. This relationship does not hold to the same extent between existential security and religious practice. In most countries the ABM and data demonstrate that religious practice decreases overtime. However, in several countries the ABM accurately predicts that it will remain constant and in three cases (Switzerland, Slovenia, and Japan) the data shows that religious practices increase.

7.2 There is even less evidence of an inverse relationship between existential security and supernatural beliefs. The increase in existential security predicted by the ABM and shown in the data has very little bearing on the ABM's predictions and the actual data values for supernatural beliefs. The ABM predicts an increase in supernatural beliefs as often as it predicts a decrease and the ISSP data shows that supernatural belief values increase more often than they decrease or stay the same.

7.3 Research in the cognitive science of religion helps explain the differences in the relationships between these three religiosity variables and existential security. This is discussed in the next subsections.

Existential Security and Supernatural Beliefs

7.4 Previous work has shown that, since ancient times, humans have tended to believe in supernatural agents who have the power to reward or punish (Yilmaz & Bahçekapili 2016; Saleam & Moustafa 2016; Purzycki et al. 2016). Belief in a 'God,' however, is far more recent, having emerged only in the wake of the axial age (c. 800-200 BCE). When humans lived in small-scale, hunter-gatherer societies, the threat that relatively localized and familial supernatural forces (animal-spirits or ancestor-ghosts) might be watching was enough to maintain cooperation and commitment. As groups grew, however, so did the size of their gods. Although scholars disagree on precisely what factors were most decisive in the emergence of cooperation within large-scale societies, there is general consensus that belief in one God (or an Ultimate Reality such as Dharma or the Dao) - who is watching over, and capable of punishing, everyone regardless of their ingroup - is correlated with life in contexts strongly influenced by the so-called axial traditions (Norenzayan 2015; Baumard et al. 2015; Morris 2015).

7.5 Research in these fields suggests that general beliefs in supernatural forces are relatively easily born in human minds, but belief in a 'God' requires more cultural scaffolding. As a result, it makes sense that the latter sort of belief would dissolve more quickly than the former as capable secular institutions take over the work of providing existential security (Shults 2017).

Existential Security and Religious Practice

7.6 For most countries, the data and the ABM showed an inverse relationship between existential security and religious practice. This is consistent with the literature outlined about in sections 2.1-2.4 which highlights how religious and secular institutions compete for fulfilling the demands of individuals (Stolz et al. 2016). This creates an inverse relationship between the demand for God and the demand for government; increased confidence in the latter consistently predicts lower religiosity in a population, while decreased confidence predicts higher religiosity (Habel & Grant 2013).

7.7 However, in several cases the ABM predicted and the data showed no change in religious practice. In each of these cases, the initial religious practice level of the country is low (less than 0.40). These cases provide evidence that the existence and social influence of even a small group of religious practitioners within a country can create a floor for the level of religious practice that will not erode despite increases in existential security.

7.8 We believe natural disasters (earthquakes, tsunami, flooding, etc.) are the cause for the three cases (Slovenia, Japan and Switzerland) where the data showed there was an increase in religious practice despite an increase in existential security. Natural disasters have been shown to cause basic psychological conflict that results from having a desire to live, but realizing that death is inevitable. This conflict produces terror, and this terror can be managed by religious practice (Pyszczynski et al. 2015; Shults et al. 2017). We will explore this more extensively in future work.

Norway as an Example

7.9 To further highlight the relationship among existential security and the religiosity variables in our ABM we consider Norway as an example. As indicated in Figure 5, the mean existential security in Norway began high and increased during the period measured. Both the mean belief in God and the mean religious practice began low and decreased during the same period. This is expected. Over the last 20 years there has been a drastic decrease in traditional religiosity in Scandinavian welfare societies.

7.10 However, the stability of Norwegians' supernatural beliefs warrants further consideration. Many Norwegians still believe in axiologically relevant disembodied forces (e.g., angels, spirit-guides) as part of their alternative modes of religiosity or spirituality (Furseth 2015). Such beliefs are a natural deliverance of evolutionary stabilized cognitive tendencies, and given the relatively high levels of freedom of expression and tolerance for plurality in Norway, it is not surprising that some Norwegians would continue to maintain them, even as belief in God and participation in traditional religious rituals decrease within the population as a whole (Shults 2015).

Conclusion

8.1 Our work employs existing data sets and agent-based modeling to forecast changes in the religiosity and existential security among a collective of individuals over time. Our model includes agents in social networks interacting with one another based on the education level of the agents, the religious practices of the agents, and each agent's existential security within their natural and social environments. The data used to inform the values and relationships among these variables is based on rigorous statistical analysis of the International Social Survey Programme Religion Module (ISSP) and the Human Development Report (HDR). Our results show that for a given country and a given time period, our model provides a more accurate forecast of changes in the existential security and the religiosity than alternative modeling approaches.

8.2 We highlight those conditions and interactions in the model that create changes in religiosity and existential security. Furthermore, we explain why data and our model show a strong negative correlation between existential security and belief in God, but not between existential security and supernatural beliefs. In future work, we hope to explore additional mechanisms that may help to further clarify these changes in religiosity and the possible adaptive role of secularization.

Appendix A - Country Data Availability

Table 5: Data Availability By Country, Year, and Source

Country	Data Availability ISSP 1991 / HDR 1990	Data Availability ISSP 1998 / HDR 2000	Data Availability ISSP 2008 / HDR 2010
Austria	NO / YES	YES / YES	NO / YES
Chile	NO / YES	YES / YES	YES / YES
Cyprus	NO / YES	YES / YES	YES / YES
Czech Republic	NO / YES	YES / YES	YES / YES
France	NO / YES	YES / YES	YES / YES
Germany	YES / YES	YES / YES	YES / YES
Hungary	YES / YES	YES / YES	YES / YES
Israel	NO / YES	NO / YES	YES / YES
Latvia	NO / YES	YES / YES	YES / YES
Netherlands	YES / YES	YES / YES	YES / YES
Poland	YES / YES	YES / YES	YES / YES
Portugal	NO / YES	YES / YES	YES / YES
Slovenia	NO / YES	YES / YES	YES / YES
Spain	NO / YES	YES / YES	YES / YES
United Kingdom	YES / YES	YES / YES	YES / YES
United States	YES / YES	YES / YES	YES / YES
New Zealand	YES / YES	YES / YES	YES / YES
Sweden	NO / YES	YES / YES	YES / YES
Switzerland	NO / YES	YES / YES	YES / YES
Ireland	YES / YES	YES / YES	YES / YES
Denmark	NO / YES	YES / YES	YES / YES
Japan	NO / YES	YES / YES	YES / YES
Australia	YES / YES	NO / YES	YES / YES
Italy	YES / YES	YES / YES	YES / YES
Norway	YES / YES	YES / YES	YES / YES
Philippines	YES / YES	YES / YES	YES / YES

Appendix B - Results For Countries Models Were Trained On

Table 6: Accuracy of predictions from competing approaches

Country	Religious Practice			Supernatural Beliefs			Belief In God			Existential Security		
	Base	LR	ABM	Base	LR	ABM	Base	LR	ABM	Base	LR	ABM
Germany												
$\bar{e_a}$	0.088	0.102	0.067	0.119	0.175	0.124	0.085	0.056	0.046	0.051	0.009	0.009
σe_a	0.006	0.029	0.005	0.003	0.035	0.009	0.004	0.026	0.021		NA	
Hungary												
$\bar{e_a}$	0.048	0.068	0.022	0.020	0.051	0.006	0.013	0.013	0.023	0.051	0.009	0.006
σe_a	0.01	0.014	0.004	0.001	0.034	0.018	0.010	0.032	0.028		NA	
Ireland												
$\bar{e_a}$	0.067	0.059	0.059	0.023	0.127	0.039	0.006	0.022	0.005	0.047	0.013	0.006
σe_a	0.048	0.064	0.013	0.013	0.039	0.005	0.014	0.008	0.019		NA	
Italy												
$\bar{e_a}$	0.019	0.022	0.011	0.022	0.065	0.037	0.004	0.021	0.014	0.040	0.020	0.007
σe_a	0.01	0.016	0.018	0.013	0.021	0.012	0.044	0.021	0.032		NA	
Netherlands												
$\bar{e_a}$	0.002	0.021	0.036	0.039	0.101	0.038	0.072	0.042	0.011	0.032	0.028	0.006
σe_a	0.023	0.005	0.001	0.091	0.055	0.084	0.032	0.007	0.002		NA	
New Zealand												
$\bar{e_a}$	0.011	0.025	0.006	0.035	0.086	0.034	0.091	0.052	0.008	0.031	0.029	0.007
σe_a	0.009	0.038	0.006	0.006	0.044	0.003	0.015	0.013	0.017		NA	
Norway												
$\bar{e_a}$	0.081	0.106	0.052	0.106	0.172	0.096	0.051	0.019	0.023	0.023	0.037	0.005
σe_a	0.081	0.055	0.025	0.049	0.012	0.044	0.015	0.010	0.017		NA	
Philippines												
$\bar{e_a}$	0.023	0.038	0.031	0.027	0.044	0.010	0.007	0.041	0.028	0.031	0.031	0.013
σe_a	0.020	0.003	0.090	0.020	0.037	0.021	0.012	0.037	0.008		NA	
Poland												
$\bar{e_a}$	0.039	0.035	0.046	0.043	0.078	0.071	0.053	0.029	0.049	0.043	0.018	0.007
σe_a	0.023	0.041	0.032	0.014	0.043	0.001	0.015	0.007	0.021		NA	
United Kingdom												
$\bar{e_a}$	0.057	0.06	0.028	0.054	0.096	0.053	0.022	0.011	0.029	0.041	0.019	0.002
σe_a	0.007	0.033	0.009	0.007	0.052	0.010	0.005	0.019	0.002		NA	
United States												
$\bar{e_a}$	0.049	0.045	0.028	0.045	0.068	0.006	0.097	0.058	0.035	0.026	0.034	0.010
σe_a	0.003	0.028	0.031	0.029	0.054	0.006	0.015	0.010	0.016		NA	
RMSE												
$\bar{e_a}$	0.052	0.059	0.039	0.058	0.070	0.058	0.057	0.037	0.028	0.039	0.024	0.008
σe_a	0.032	0.035	0.032	0.034	0.040	0.030	0.020	0.020	0.018		NA	

Appendix C - Results For Countries Models Were Not Trained On

Table 7: Accuracy of predictions from competing approaches

Country	Religious Practice			Supernatural Beliefs			Belief In God			Existential Security		
	Base	LR	ABM	Base	LR	ABM	Base	LR	ABM	Base	LR	ABM
Chile												
$\bar{e_a}$	0.001	0.003	0.019	0.015	0.046	0.004	0.033	0.001	0.012	0.062	0.001	0.014
σe_a	0.003	0.021	0.023	0.002	0.026	0.015	0.016	0.007	0.023		NA	
Cyprus												
$\bar{e_a}$	0.018	0.012	0.026	0.024	0.059	0.001	0.040	0.062	0.040	0.048	0.012	0.004
σe_a	0.054	0.067	0.004	0.049	0.074	0.030	0.044	0.062	0.005		NA	
Czech Republic												
$\bar{e_a}$	0.067	0.091	0.035	0.096	0.166	0.080	0.024	0.006	0.039	0.042	0.018	0.006
σe_a	0.010	0.016	0.023	0.018	0.018	0.004	0.012	0.036	0.008		NA	
France												
$\bar{e_a}$	0.012	0.039	0.020	0.032	0.105	0.019	0.037	0.014	0.007	0.033	0.027	0.010
σe_a	0.014	0.011	0.037	0.009	0.027	0.001	0.038	0.013	0.009		NA	
Portugal												
$\bar{e_a}$	0.042	0.046	0.026	0.170	0.208	0.166	0.066	0.088	0.081	0.037	0.024	0.012
σe_a	0.030	0.051	0.002	0.035	0.065	0.028	0.030	0.005	0.011		NA	
Slovenia												
$\bar{e_a}$	0.031	0.010	0.061	0.029	0.040	0.003	0.033	0.008	0.008	0.052	0.008	0.006
σe_a	0.010	0.014	0.012	0.024	0.012	0.016	0.044	0.019	0.005		NA	
Spain												
$\bar{e_a}$	0.023	0.034	0.009	0.014	0.068	0.055	0.002	0.022	0.017	0.040	0.020	0.006
σe_a	0.004	0.026	0.010	0.010	0.023	0.009	0.010	0.032	0.006		NA	
Sweden												
$\bar{e_a}$	0.047	0.071	0.020	0.031	0.104	0.036	0.053	0.02	0.028	0.004	0.050	0.029
σe_a	0.032	0.009	0.005	0.017	0.016	0.015	0.002	0.024	0.027		NA	
Switzerland												
$\bar{e_a}$	0.019	0.007	0.040	0.003	0.056	0.004	0.042	0.012	0.006	0.036	0.020	0.001
σe_a	0.026	0.002	0.027	0.032	0.001	0.029	0.045	0.021	0.002		NA	
Denmark												
$\bar{e_a}$	0.004	0.023	0.024	0.047	0.121	0.061	0.04	0.018	0.006	0.046	0.010	0.002
σe_a	0.004	0.015	0.020	0.003	0.034	0.006	0.022	0.003	0.005		NA	
Japan												
$\bar{e_a}$	0.024	0.002	0.041	0.049	0.019	0.065	0.029	0.044	0.031	0.027	0.033	0.005
σe_a	0.014	0.004	0.027	0.005	0.023	0.001	0.009	0.029	0.012		NA	
RMSE												
$\bar{e_a}$	0.032	0.041	0.032	0.065	0.105	0.065	0.039	0.037	0.033	0.41	0.024	0.011
σe_a	0.024	0.029	0.019	0.023	0.035	0.017	0.029	0.028	0.012		NA	

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