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Religiosity and Long-Run Productivity Growth*

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Abstract. In this paper, we show, using a panel of developed countries, that there is a long-run negative association between church attendance and total factor productivity (TFP) with predictive causality running from declining church attendance to increasing factor productivity. According to our preferred estimate, about 18% of the increase in TFP from 1950 to 1990 is caused by declining religiosity. In order to explain this phenomenon, we integrate into standard R&D-based growth theory a micro-foundation of individual cognitive style, which is either intuitive-believing or reflective-analytical. Under the assumption that R&D productivity is positively influenced by a reflective-analytical cognitive style, we find that secularization leads to an increasing labor share in R&D and gradually increasing productivity growth. We use these insights to reflect on trends in religiosity and R&D-based growth in the very long run, from Enlightenment to the present day.

Keywords: religiosity; church attendance; factor productivity; cognitive style; R&D-based growth.

JEL: N30; O11; C23.

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1. Introduction

For a panel of developed countries, investigated over the period 1950 to 1990, we observe a strong negative association between church attendance and total factor productivity (TFP). Surprisingly, we find that the predictive causality runs from church attendance to TFP and not the other way round. According to our preferred estimation method, the decline in church attendance explains about 20 percent of the rise in TFP. It appears perhaps more straightforward to find arguments for reverse causality running from productivity growth – via increasing income and increasing variety of consumer goods – to increasing materialism and declining interest in spiritual achievements like salvation and forgiveness of sins (e.g. Bruce, 2011; Hirschle, 2011; Strulik, 2016a). One could also argue that religiosity appears to have a positive impact on trust, honesty, and other traits (as found, for example, by Guiso et al., 2003). These traits in turn could be conducive to productivity growth through, for example informal norms on the protection of (intellectual) property rights. However, this is not what we find. In order to explain the positive impact of declining religiosity on productivity growth, we develop a new theory that integrates recent developments in cognitive psychology into an economic model of optimal time allocation after work and combine it with a standard R&D-based model of endogenous productivity growth (Romer, 1990).

The theory is briefly explained as follows. The household side of the model consists of a simplified version of Strulik (2016b) where individuals are assumed to experience utility from attending church and from secular leisure activities such as Sunday shopping or attending a football game. Following recent developments in cognitive psychology, we assume that individuals are able to apply one of two possible styles of reasoning, intuitive-believing (fast, Type I) or reflective-analytical (slow, Type II). In contrast to cognitive ability, defined as the *capacity* to engage in analytic reasoning processes, cognitive style, defined as the *willingness* or *disposition* to engage in analytic reasoning processes, is conceptualized as a choice variable (Sloman, 1996; Evans, 2008; Kahneman, 2011). The greatest utility from church attendance is experienced when individuals apply intuitive-believing reasoning. In contrast, applying reflective-analytical reasoning to religious ideas raises doubt and reduces the utility experienced at church. By applying the latter, individuals reduce the opportunity cost of indulging in secular leisure activities. It becomes, for example, less costly to go shopping or to watch the football game on Sunday instead of attending the service at church.[1]

Additionally, the current value of religion is assumed to be determined by its past value and by average church attendance in society. We show that given this setup, there exists a locally stable steady state of high church attendance. However, an exogenous shock that devalues religion (e.g. the Inquisition or the Enlightenment) or appreciates leisure activities (e.g. the innovation of the shopping mall or the football club) can initiate a process by which individuals increasingly apply the analytical-reflective cognitive style, which leads to a decline in church attendance.

On the production side, we assume that the productivity of scientists and engineers is higher when they apply an analytical-reflective cognitive style, i.e. when they try to prove rather than believe that something works.[2] We then show conditions for which market R&D is not worthwhile when the society is situated at the steady state of high church attendance (the Middle Ages). With the gradual decline of believers, however, a stage is reached at which a critical mass of individuals applies the reflective-analytical reasoning style, and market R&D becomes profitable. From then on, TFP starts to grow and productivity in R&D increases, driven by a declining share of people applying the intuitive-believing cognitive style and declining religiosity in society. In other words, declining church attendance (Granger-) causes TFP growth.

In order to determine which cognitive style a person applies, psychologists have developed the cognitive reflection test (CRT; Frederick, 2005). A typical test question is the following: "A bat and a ball cost \$ 1.10 in total. The bat costs \$ 1.00 more than the ball. How much does the ball cost?" Intuitively, many individuals believe that 10 cents is the right answer. A bit of analytical reflection, however, reveals that the ball costs 5 cents. Performance on the CRT is a strong predictor of religiosity. Individuals who believe that the ball costs 10 cents are also more likely to believe that God exists and more likely to have increased their belief in God since childhood (Shenhav et al., 2011; Gervais and Norenzayan, 2012; see Pennycook et al. (2016) for a recent survey and meta-analysis). Moreover, CRT performance, compared with education or cognitive ability, is a better predictor of religiosity (Pennycook et al. (2012).[3]

[1]The choice of cognitive style could be unconscious but "as if" obtained from maximizing behavior as argued by Akerlof and Kranton (2000) for the case of choice of identity. Moreover, our simplifying assumption that individuals decide once and for all on a cognitive style should be seen as an approximation of a reality where some individuals apply the intuitive believing style more frequently than others.

[2]Mokyr (2005, 2011) argues that intellectual development since Enlightenment and the emerging scientific attitude towards technology was key for technological progress and the Industrial Revolution.

[3]Psychology and philosophy offer explanations as to why human beings are predisposed to develop intuitive religious beliefs and how these beliefs are inhibited by purposefully chosen reflective-analytical processes (Boyer, 2001;

Naturally, a reflective-analytical cognitive style is also conducive to understanding science (Shtulman and McCallum, 2014). In our model we thus assume that a reflective-analytical cognitive style is not only detrimental to the experience of utility from religion but also increasing the productivity of science and engineering. This view is furthermore indirectly supported by the observation that U.S. scientists are much less religious than the public at large. According to the Pew Research Center (2009), 33% of scientists and 83% of the general public believe in God. Leading scientists are even less religious than "ordinary" ones. Among elite U.S. scientists, 7% believe in a personal god (Larsen and Witham, 1998) and 19% attend church once a week or more (Ecklund et al., 2008). In terms of our theory, it is interesting to note that the relatively low level of belief and religiosity of U.S. elite scientists was already observed at the beginning of the 20th century (Leuba, 1916). In our model, the critical mass of individuals applying the reflective-analytical style that is needed in order to set in motion the take-off to R&D-based growth could be small. It is thus possible that a small group of scientists and engineers lost their faith relatively early while the society at large maintained an intuitive-believing style and continued to attend church frequently. This is our way of explaining "American exceptionalism", that is, the phenomenon of simultaneously high average church attendance and high productivity growth.[4]

Our study is related to two recent papers by Benabou et al. (2015a, 2015b). Using the World Values Surveys, Benabou et al. (2015a) demonstrate that, at the individual level, various measures of religiosity (including church attendance) are negatively associated with a positive attitude towards science and technology. Benabou et al. (2015b) show a significantly negative association between different measures of religiosity (including belief in God) and patents per capita, which is observed across countries as well as across U.S. states. These findings are consistent with our results and support our theory. Our interpretation is that individuals who prefer an analytical-reflective cognitive style are, on average, less religious and appreciate scientific progress more and that a higher share of such individuals in society is conducive to innovation and productivity growth. Additionally, our empirical work addresses the direction of causality – in the Granger

Dennett, 2006; Pennycook, 2014). See Strulik (2016b) for a longer discussion of the impact education, cognitive ability, and cognitive style on religiosity.

[4]See Lipford and Tollison (2003) and Rupasingha and Chilton (2009) on the negative association between religiosity and economic performance within the U.S. Moreover, actual belief and church attendance may not align perfectly. Strulik (2016b) shows how the the model of cognitive style is also capable to produce the European phenomenon of "fuzzy fidelity" (Voas, 2009) whereby individuals lose their belief but continue to display a casual loyalty to their religious tradition and attend church from time to time.

(1969) sense – and shows that it runs from (declining) religiosity to (increasing) factor productivity.

Benabou et al. (2015b), in order to explain their findings propose a polit-economic theory of conflict between science and religion. The basic idea is that some innovations erode religious beliefs and that there are three ways for the government and the church to deal with this "problem": do nothing and let the intensity of beliefs erode (the modern European way), adjust the religious belief system (the American way), or repress the diffusion of scientific discoveries (the Middle Ages). While we think that the polit-economic mechanism generally complements our proposed mechanism, we also note some differences. According to Benabou et al. a majority of society is assumed to be religious, and religious individuals may suffer from an erosion of the intensity of their beliefs without completely losing their faith (i.e. they never stop believing in supernatural forces and agents or, in our terminology, abandon their intuitive-believing cognitive style). Second, according to Benabou et al., religious beliefs do not affect the productivity of R&D. Innovations happen at an exogenous rate but their diffusion may be repressed by the government. In contrast, we assume that R&D is endogenously determined as a market activity in general equilibrium and that, perhaps more in line with the empirical findings of Benabou et al. (2015a), there is a direct negative influence of religious belief on the scientific attitudes of individuals and therewith on the productivity of R&D. Third, in Benabou et al., the general value of religion (also called religious capital or intensity of belief) is determined by scientific progress and government control while according to our theory, it is determined by history and social norms (its value in the past and average church attendance in society) . Fourth, our theory is designed in order to motivate a one-way causal impact of religiosity on productivity while Benabou et al. predict that causality runs in both direction. Finally, American exceptionalism is conceptualized as a stationary equilibrium of a highly religious society by Benabou et al., while according to our theory, it is conceptualized as slow secularization of a society in which scientists are much less religious than the public at large.[5]

The paper is organized as follows. Section 2 sets up the basic empirical model and explains our data and the empirical strategy. Section 3 examines the effect of religiosity on TFP using panel

[5]Naturally, our paper is also more broadly related to a larger empirical and theoretical literature on the association between religiosity and economic performance, including, among others, Inglehart and Baker (2000); Norris and Inglehart (2004); McCleary and Barro (2006); Becker and Woessmann (2009); Paldam and Gundlach (2013); Becker and Woessmann (2013); Herzer and Strulik (2013); Franck and Iannaccone (2014); and Strulik (2016a, 2016b). The implications of the religiousity-productivity nexus for economic development in the very long run relates our study to unified growth theory (Galor, 2011).

cointegration methods as well as conventional panel methods. It argues in favor of a predictive causality from declining church attendance to increasing TFP. Section 4 sets up the theoretical model and derives the analytical results. Section 5 sets up a numerical version of the model and explores the implications of the religiosity–productivity nexus for the take-off of modern growth and economic development in the very long run. Section 6 concludes.

2. Empirical Model, Data, and Empirical Strategy

2.1. **Basic Empirical Model.** In order to uncover the religiosity–productivity nexus, we specify the following empirical model.

$$\log(TFP_{it}) = \delta_0 \log(Church_{it}) + \delta_1 \log(Pop_{it}) + \delta_2 \log(Open_{it}) + \delta_3 \log(hc_{it}) + \mu_i + \nu_t + \epsilon_{it}, \quad (1)$$

where TFP_{it} is total factor productivity of country i in period t and $Church_{it}$ is church attendance in country i in period t. Both variables are measured in logs such that the coefficient δ_0 represents the elasticity of TFP with respect to church attendance (measuring the percentage change in TFP resulting from a 1% change in church attendance). The log transformation implies that the model not only relates the level of TFP to the level of church attendance with an elasticity of δ_0; it also incorporates a relationship between the growth rate of TFP and the rate of change in church attendance, $\mathrm{d}TFP_{it}/TFP_{it}/(\mathrm{d}Church_{it}/Church_{it}) = \delta_0$.

Our choice of control variables is guided by the existing literature on the determinants of TFP growth (see, e.g., Pritchett 1996; Bernanke and Guerkaynak, 2001; Strulik et al., 2013) and previous studies on the effects of religiosity on economic performance (see, e.g., McCleary and Barro, 2006; Young, 2009; Benabou et al., 2015). Based on these studies, we include the log of population size, $\log(Pop_{it})$, the log of trade openness, $\log(Open_{it})$, and the log of human capital per worker, $\log(hc_{it})$.

Finally, we include country-specific fixed effects μ_i to control for any country-specific omitted factors that are relatively stable over longer periods of time (such as geography, culture, and basic institutions) as well time effects ν_t to control for omitted common factors in a given period across the countries (such as global economic crises and global technological advances). The model is estimated for both a balanced panel and an unbalanced panel.

2.2. **Data.** We define (the log of) total factor productivity in the usual way, as

$$\log(TFP^S_{it}) = \log(Y_{it}) - (1 - \alpha_{it}) \log(K_{it}) - \alpha_{it} \log(L_{it}), \quad (2)$$

where Y is aggregate output, K is capital input, L is labor input, $(1-\alpha)$ is the capital share of income, and α is the labor share of income. The subscripts i and t on α indicate that the factor shares are allowed to vary over time and across countries, and the superscript S indicates that the construction of the TFP measure is based on a standard Cobb-Douglas production function without human capital, as is common practice in the literature (see, e.g., Coe and Helpman, 1995; Madsen, 2007; Luintel and Khan, 2004; Coe et al., 2009; Herzer, 2011; Baltabaev, 2014). However, it should be noted that we always include human capital per worker as an explanatory variable in all of our specifications such that our TFP measure is adjusted for human capital. To see this, insert the definition of the log of TFP from equation (2) into equation (1) and subtract $\gamma \log(hc_{it})$ from both sides:

$$\begin{aligned} &\log(Y_{it}) - (1-\alpha_{it})\log(K_{it}) - \gamma \log(hc_{it}) \\ &= \delta_0 \log(Church_{it}) + \delta_1 \log(Pop_{it}) + \delta_2 \log(Open_{it}) + (\delta_3 - \gamma)\log(hc_{it}) + \mu_i + \nu_t + \epsilon_{it}. \end{aligned} \quad (3)$$

Here γ is the direct effect of human capital on output, while $(\delta_3 - \gamma)$ captures the indirect effect of human capital on output that operates through TFP (via human-capital externalities). Thus, TFP is implicitly measured net of the direct effect of human capital on aggregate output. Nevertheless, as a robustness check, we consider two additional measures of TFP that explicitly account for human capital.

To construct the second measure, we follow Hall and Jones (1999) and assume a Cobb-Douglas production function of the form

$$Y_{it} = TFP_{it}^{HJ} K_{it}^{1-\alpha_{it}} H_{it}^{\alpha_{it}}, \quad (4)$$

where H is the stock of human capital, defined as human capital per worker times labor input: $H_{it} = hc_{it} L_{it}$. Applying this definition to equation (4), the log of TFP can be calculated as follows

$$\log(TFP_{it}^{HJ}) = \log(Y_{it}) - (1-\alpha_{it})\log(K_{it}) - \alpha_{it}\log(L_{it}) - \alpha_{it}\log(hc_{it}), \quad (5)$$

where we add the superscript HJ to the term TFP in order to distinguish it from the definition in equation (2). The third measure is constructed using the production function of Mankiw et al. (1992):

$$Y_{it} = TFP_{it}^{MRW} K_{it}^{1-\alpha_{it}} L_{it}^{\alpha_{it}-\gamma_{it}} H_{it}^{\gamma_{it}}, \quad (6)$$

where γ is the share of human capital in national income and $\alpha - \gamma$ is the unskilled labor share. Defining again $H_{it} = hc_{it}L_{it}$ and assuming, following Mankiw et al. (1992), that the human capital share is 50% of the total labor share,[6] we calculate the log of TFP from equation (6) as

$$\log(TFP_{it}^{MRW}) = \log(Y_{it}) - (1 - \alpha_{it})\log(K_{it}) - \alpha_{it}\log(L_{it}) - 0.5\alpha_{it}\log(hc_{it}). \tag{7}$$

Three points should be emphasized: first, our TFP measures differ only in terms of the assumed coefficient of the log of human capital per worker; second, interpreting this coefficient as the average of individual country coefficients gives us the average (but not necessarily constant) direct effect of human capital on output; and third, the total elasticity of human capital per worker in equation (1) captures both the average direct and indirect effects of human capital on output. It follows from these points that all three measures of TFP should yield similar coefficient estimates for $\log(Church_{it})$, $\log(Pop_{it})$, and $\log(Open_{it})$.

The data used to construct our measures of TFP are from the Penn World Tables (PWT) version 8.1 (Feenstra et al., 2015). Aggregate output (Y) is measured by real GDP in constant (2005) dollars; capital input (K) is measured by the constant dollar value (in 2005) of the stock of real capital (constructed by the perpetual inventory method); labor input (L) is measured by total hours worked (annual hours worked per employed person times the number of employed persons); and the labor share (α) is measured as compensation of employees and self-employed people relative to GDP;[7] Human capital per worker is measured following Hall and Jones (1999) as $hc = \exp(\Phi(e))$, where e is the average years of schooling of the population above 15 years of age, the derivative $\Phi'(e)$ is the return to schooling estimated in a Mincerian wage regression, and Φ is a piecewise linear function, with a zero intercept and a slope of 0.134 through the fourth year of education, 0.101 for the next four years, and 0.068 for education beyond the eighth year.[8] The PWT 8.1 data are available for several years since 1950 and cover up to 167 countries.

Unfortunately, internationally comparable data on church attendance are scarce. The few previous cross-country studies on religiosity and economic performance typically use survey questions

[6] Mankiw et al. (1992) note (on page 417) that "[i]n the United States the minimum wage - roughly the return to labor without human capital - has averaged about 30 to 50 percent of the average wage in manufacturing. This fact suggests that 50 to 70 percent of total labor income represents the return to human capital."

[7] While most TFP studies assume a value of $\alpha = 2/3$ for all countries and time periods, we use country-specific data on the labor share. The data suggest that the labor share is not approximately equal to 2/3 in many countries and time periods (see also Karabarbounis and Neiman, 2013), implying that the common practice of setting $\alpha = 2/3$ can introduce measurement error into the calculation of TFP.

[8] The coefficient on the first four years is the return to schooling in Sub-Saharan Africa (13.4%). The coefficient on the second four years is the world average return to schooling (10.1%). The coefficient on schooling above eight years is the OECD return to schooling (6.8%). All coefficients are taken from Psacharopoulos (1994).

from the World Values Survey (WVS) or the International Social Survey Program (ISSP) to construct data on church attendance rates for a limited number of survey years. Consequently, the data used in previous studies contain little information about the variation of religiosity over time. To account more accurately for the time-varying nature of religiosity, we employ church attendance data from Iannaccone (2003), who uses ISSP data to estimate average church attendance rates for children and their parents for 32 countries at 5-year intervals from 1925 through 1990. More specifically, Iannaccone's estimates are based on retrospective survey questions on attendance rates for respondents and their parents when the respondents were aged 11 or 12. Because respondents were surveyed in the 1990s at ages 16 and over, the retrospective questions provide information on church attendance for varying dates in the past. Iannaccone presents a variety of evidence supporting the accuracy of his data, including tests showing that retrospective estimates of average attendance rates in the mid-1960s and mid-1980s correspond closely with the averages obtained from standard surveys. We use the parental church attendance rate as our measure of religiosity, that is, the percentage of parents who attend religious services at least once a week, because religious commitments typically develop during adolescent years rather than during childhood.

Data on population size are also from the PWT 8.1 database, which is also the source of our human capital measure. Data on trade openness, measured as the sum of exports plus imports as a percentage of GDP, are from the PWT 7.1 database (Heston et al., 2012); the data cover up to 189 countries over the period 1950-2010. Combining the data from these sources yields an unbalanced panel data set that includes data at 5-year intervals for the period 1950-1990 for 26 countries. While the number of observations in this data set is relatively small (175), our study includes more observations than most previous cross-country studies on religiosity and economic performance. The countries in our sample are Australia, Austria, Bulgaria, Canada, Chile, Cyprus, Czech Republic, Denmark, France, Germany, Hungary, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, the United Kingdom, and the United States.[9]

An important issue regarding the relatively long sample period is the possibility of spurious regressions due to stochastic trends (or unit roots) in the data. While it is well known that most economic time-series data are stochastically non-stationary, it is less known that residual

[9]Iannaccone (2003) reports church attendance rates for East and West Germany. To construct the church attendance rate for Germany as a whole, we took the average of the two values for East and West Germany.

non-stationarity, and thus, the absence of cointegration can lead to spurious results in standard panel regressions involving non-stationary variables (see, e.g., Entorf, 1997; Kao, 1999).[10]

The cointegration property ensures non-spurious results that are robust to measurement errors (see, e.g., Stock, 1987). The latter is an important advantage for applications such as ours because it is very likely that church attendance rates based on respondents' self-reports are measured with error. Another advantage of the cointegration approach is that a regression consisting of cointegrated variables has a stationary error term, implying that no relevant integrated variables are omitted (any omitted non-stationary variable that is part of the cointegrating relationship would enter the error term, thereby producing non-stationary residuals and failure to detect cointegration). If there is cointegration between a set of variables the stationary relationship also exists in extended variable space (see, e.g., Lütkepohl, 2007). Cointegration estimators are therefore robust (under cointegration) to the omission of variables that do not form part of the cointegrating relationship. This not only justifies a "reduced form" model (if cointegrated) but also identifies core variables that should be included, in our case, for estimating the effect of religiosity on TFP. Finally, the presence of cointegration allows us to estimate long-run coefficients in a manner that is free of endogeneity bias (see, e.g., Engle and Granger, 1987; Stock, 1987), implying that we do not need to control for the potential endogeneity of religiosity through instrumental variable methods.

In order to apply panel unit root and cointegration techniques, we construct a balanced panel containing all countries for which complete time-series data are available over the period 1950-1990. This yields a sample of 17 countries and 9 time-series observations per country (153 total observations). The countries in this balanced panel are Australia, Austria, Canada, Denmark, France, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States.[11]

[10]Strictly speaking, of course, the stochastic process of the church attendance rate cannot be a pure unit root process. The church attendance rate is bounded (between zero and 100 percent), but we know that a unit root process will cross any finite bound with a probability of one. Nevertheless, as argued, among others, by Jones (1995) and Pedroni (2007), it is often the case that in finite sample applications, such variables can be approximated by a unit root process. If, over a given period of time, these variables are strongly influenced by factors that are driven by stochastic processes, then these variables should be treated as integrated.

[11]The relatively small number of time-series observations is not a serious problem for our cointegration analysis because (1) panel cointegration techniques exploit both the time-series and cross-sectional dimensions of the data and can therefore be implemented with a smaller number of time-series observations than their time-series counterparts (critical values for unit root and cointegration tests are available or can be computed for small sample sizes like ours); and (2) it is well known that the total length of the sample period, rather than the frequency of observation, is the important factor for integration and cointegration properties (see, e.g., Shiller and Perron, 1985; Hakkio and Rush, 1991; Lahiri and Mamingi, 1995).

Table 1: Variable Means

Balanced Panel						
Year	TFP	Church attendance	Population (in millions)	Openness	Human capital per worker	Number of countries
1950	3.39	41.94	28.10	40.44	2.18	17
1955	3.84	41.53	29.88	41.38	2.23	17
1960	4.23	40.88	31.73	42.00	2.28	17
1965	4.86	40.65	33.65	42.51	2.38	17
1970	5.70	38.94	35.31	45.86	2.49	17
1975	5.98	36.24	36.95	50.19	2.61	17
1980	6.36	34.00	38.35	57.55	2.71	17
1985	6.11	33.06	39.65	61.14	2.78	17
1990	6.16	32.18	40.91	57.31	2.84	17
Other Countries						
Year	TFP	Church attendance	Population (in millions)	Openness	Human capital per worker	Number of countries
1950	-	-	-	-	-	-
1955	1.55	47.00	6.89	19.68	1.89	1
1960	1.72	43.00	7.75	29.10	1.93	1
1965	1.68	39.00	8.70	26.13	2.02	1
1970	3.76	30.00	43.87	31.02	2.00	2
1975	3.74	29.75	44.55	44.80	2.08	2
1980	4.10	26.50	33.39	55.14	2.36	3
1985	4.24	23.33	33.44	58.90	2.44	3
1990	3.98	27.83	18.62	80.14	2.81	9

Table 1 presents the variable means for all years in our sample for both the balanced panel and the subsample of countries without complete data. The descriptive statistics for the balanced panel, given in the upper part of the table, show a stable upward trend in TFP and a stable downward trend in church attendance. With respect to the other variables, population size and the level of education increased steadily during the sample period; openness increased steadily from 1950 until 1985, and then fell slightly from 1985 to 1990. From the last column in the lower part of the table, it can be seen that the total sample is highly unbalanced, with 6 countries appearing only in 1990 (Bulgaria, Cyprus, Czech Republic, Poland, Slovak Republic, and Slovenia).

2.3. **Empirical Strategy.** We first apply two panel unit root tests to our balanced panel data set to test the variables for unit roots: the standard panel ADF unit root test of Im, Pesaran, and Shin (2003, IPS) and the cross-sectionally augmented IPS (CIPS) test proposed by Pesaran (2007). The first test assumes cross-sectional independence and can exhibit severe size distortions in the presence of cross-sectional dependence due to common shocks or spillovers among countries at the same time. To account for this problem, we "demean" the data by subtracting the average value of x_t from each x_{it} in each period t, $x_{it} - \sum_{i=1}^{N} x_{it}$, which serves to extract common time effects from the data. However, a weakness of this procedure is that it may be ineffective in eliminating the cross-sectional correlation problem when the individual responses to the common shocks differ across countries. The second test is designed to filter out the cross-sectional dependence by augmenting the individual ADF regressions with cross-sectional averages of lagged levels and first differences of the individual series (as proxies for the unobserved common factors). The difference compared to the demeaning procedure is that the individual countries are permitted to respond to the common time effects in a heterogeneous fashion, as reflected by the country-specific coefficients on the cross-sectional averages. As shown by Pesaran (2007), the CIPS test has satisfactory size and power even for relatively small samples.

Provided that all variables are non-stationary, the second step is to test for cointegration using the standard panel and group ADF and PP test statistics of Pedroni (1999, 2004). We use the balanced panel to test for cointegration and apply the Pedroni test statistics to the demeaned data to account for common time effects. As a further robustness check, we also use the estimated coefficients from the third step to test for a unit root in the cointegrating residuals via the CIPS test.

When the cointegrating relationship is established, we estimate the effect of religiosity on TFP, controlling for population size, trade openness, and education. For this purpose, we use three asymptotically efficient cointegration estimators: the panel fully modified OLS (FMOLS) estimator proposed by Phillips and Moon (1999), the panel dynamic OLS (DOLS) estimator suggested by Kao and Chiang (2000), and the group-mean panel FMOLS (GM-FMOLS) estimator of Pedroni (2000). All these estimators correct for serial correlation and endogeneity of regressors. While the FMOLS procedure employs a semi-parametric correction to the OLS estimator using the error term and the first differences of the regressors, the DOLS estimator corrects parametrically for endogeneity and serial correlation by including leads, lags and current values of the first differences of the regressors in the regression. Monte Carlo evidence suggests that the DOLS estimator performs better in finite samples compared to the fully modified estimation procedure (see, e.g., Kao and Chiang, 2000; Wagner and Hlouskova, 2010). However, the use of the DOLS estimator is problematic in our application because the limited number of time-series observations makes it impossible to incorporate leads and lags of the differenced regressors in the DOLS regression. Therefore, we are forced to use only the current values of the first differences to correct for endogeneity and serial correlation. Finally, in contrast to the panel FMOLS and DOLS estimators, which assume that the slope coefficients are homogeneous across countries, the group-mean panel FMOLS estimator has an advantage in that it allows for complete heterogeneity, by first estimating separate time-series regressions for each country, and then averaging the individual country coefficients. An inherent disadvantage of this procedure, however, lies in its inability to achieve efficiency gains from pooling. Comparative studies suggest that the efficiency gains from pooling more than offset the biases due to individual country heterogeneity (see, e.g., Baltagi and Griffin, 1997; Baltagi et al., 2008). Moreover, it is well-known that pooled estimators tend to perform better in small T samples than group-mean estimators (Wagner and Hlouskova, 2010). Therefore, and because the limited number of time-series observations prevents us from including leads and lags in the DOLS regression, our preferred estimator is the homogeneous, pooled FMOLS estimator of Phillips and Moon (1999). All three estimators are applied to the demeaned data from the balanced panel.

Demeaning across the panel, however, does not necessarily eliminate cross-sectional dependence when countries react differently to common shocks, as discussed above. Therefore, we explicitly test for cross-sectional dependence in the residuals of the estimated FMOLS and DOLS regressions using the cross-sectional dependence test of Pesaran (2004). In addition, we apply the CIPS panel unit root test to the residuals of the estimated models from the FMOLS and DOLS regressions as an additional, informal test for cointegration. If the residuals are stationary, it can be concluded that the estimates are not spurious.

We then address the question of causality. In particular, we are interested in whether permanent changes in religiosity lead to permanent changes in TFP, or whether causality is bidirectional between permanent changes in religiosity and permanent changes in TFP. To answer this question, we estimate two error correction models (using demeaned data) by regressing $\Delta \log(TFP^S_{it})$ and $\Delta \log(Church_{it})$ on $\Delta \log(TFP^S_{it})$, $\Delta \log(Church_{it-1})$, ΔX_{it-1}, country dummies, and $\hat{\mu}_{it-1}$, where $\hat{\mu}_{it-1}$ represents the error correction term, which is the lagged residual from the panel FMOLS long-run relation (estimated in the third step). From the Granger representation theorem (Engle and Granger, 1987), it follows that if our five variables are cointegrated and either $\log(TFP^S_{it})$ or $\log(Church_{it})$ or both are not weakly exogenous, then at least one of the error correction terms in the two models must be statistically significant. Hall and Milne (1994) show that weak exogeneity in a cointegrated system is equivalent to the notion of long-run Granger non-causality. Thus, an insignificant error correction term implies weak exogeneity of the explanatory variables and long-run Granger non-causality from the independent variables to the dependent variable, whereas a significant error correction term is indicative of long-run Granger causality (see also Granger, 1988), in this case either from $\log(Church_{it})$ to $\log(TFP^S_{it})$, or from $\log(TFP^S_{it})$ to $\log(Church_{it})$, or in both directions. Hence, the null hypothesis of weak exogeneity or no long-run causality can be tested by testing for the significance of the error correction terms in each model.

A possible problem with the balanced panel analysis is that it does not fully exploit the available information. Therefore, to make maximum use of the variation in our data and to check the robustness of our results, we also use the unbalanced panel data. Here, we apply conventional fixed effects models with time dummies (two-way fixed effects),[12] as is standard in unbalanced panel analyses such as this. More specifically, we estimate four models: a model with contemporaneous regressors, a model with lagged independent variables (to account for possible endogeneity issues), a model with the contemporaneous, lead and lag values of church attendance (to test for strict exogeneity), and a dynamic panel model (with lagged TFP).

Including time dummies is important in order to control for cross-sectional dependence arising from omitted common factors. However, the use of time dummies (which for balanced panels is equivalent to the use of demeaned data) may be ineffective in completely removing cross-sectional dependence when the impact of the common factors differs across countries. Unfortunately, it is not possible to test for cross-sectional dependence in highly unbalanced panels such as the one used here. Therefore, we use the pooled common correlated effects (PCCE) estimator proposed by Pesaran (2006) as a final robustness check. The purpose of using this estimator is to account for unobserved common factors by augmenting the original model with cross-sectional averages of the dependent and independent variables (as proxies for the unobserved common factors), and to interact these with country-dummies in order to allow for country-specific effects.

3. Empirical Results

3.1. **Panel Unit Root and Cointegration Tests.** The results of the IPS and CIPS panel unit root tests reported in Table 3 suggest that the unit root hypothesis cannot be rejected for all variables. It can therefore be concluded that $\log(TFP^S_{it})$, $\log(Church_{it})$, $\log(Pop_{it})$, $\log(Open_{it})$,

[12]We retain all countries in our fixed effects models, including those with a single observation because even though countries with only one observation will not contribute any information to the slope coefficients, they affect the estimated standard errors.

and $\log(hc_{it})$ are non-stationary stochastic processes. Since in the absence of cointegration, regressions involving non-stationary variables may be spurious (often producing statistics that suggest significant relations when, in fact, none exist), it is important to test for cointegration.

Table 3: Panel Unit Root Tests

	IPS	CIPS
$\log(TFP^S)$	0.957	-1.933
$\log(Church)$	-0.235	-1.902
$\log(Pop)$	-0.675	-1.537
$\log(Open)$	-0.345	-2.871
$\log(hc)$	-0.048	-2.206

IPS: panel ADF unit root test suggested by Im, Pesaran and Shin (2003); CIPS: cross-sectionally augmented IPS test suggested by Pesaran (2007). The unit root tests include individual intercepts and trends. The IPS tests were computed using demeaned data. Given the small number of time-series observations, only one lag was used. Large negative values lead to rejection of a unit root in favor of (trend) stationarity. The IPS statistic is asymptotically normally distributed. For the CIPS statistic, the relevant 5% (1%) critical value is -3.220 (-3.805) with an intercept and a linear trend. The critical values (for panels with N = 17 and T = 9) were calculated from the response-surface estimates of Otero and Smith (2013).

The results of Pedroni's (1999, 2004) ADF and PP tests for cointegration are displayed in Table 4. All four statistics reject the null hypothesis of no cointegration at the 1% level. The conclusion is that there is a non-spurious relationship between total factor productivity and church attendance (if population size, openness, and education are included).[13]

Table 4: Pedroni Panel Cointegration Tests

	Panel statistics	Group-mean statistics
ADF t-statistics	-6.786***	-6.852***
PP t-statistics	-7.018***	-9.815***

The dependent variable is $\log(TFP^S)$. The tests were computed using demeaned data. Given the small number of time-series observations, the number of lags was determined by the Schwarz criterion with a maximum number of one lag. Large negative values lead to rejection of the null hypothesis of no cointegration. The test statistics are distributed as standard normal. *** indicate rejection of the null hypothesis of no cointegration at the 1% level.

3.2. **Panel Cointegration Estimates.** The panel cointegration estimates of the elasticities of TFP with respect to church attendance, population size, openness, and education are given in Table 5. The first column presents the results of the pooled FMOLS estimator (which is our

[13]We find no evidence of a bivariate cointegrating relationship between $\log(Church_{it})$ and $\log(TFP^S_{it})$, nor do we find evidence of trivariate and quadrivariate cointegration; all four explanatory variables are necessary to achieve cointegration with $\log(TFP^S_{it})$.

preferred estimator), the second prsents the pooled DOLS regression, and the third, that of the group-mean FMOLS procedure. We first discuss the estimates from the pooled FMOLS method.

Table 5: Estimates of the Long-run Relationship between Religiosity and TFP and Diagnostic Tests

	FMOLS (1)	DOLS (2)	GM-FMOLS (3)
log(Church)	-0.3257***	-0.2340***	-0.4762***
	(0.0807)	(0.0748)	(0.0743)
log(Pop)	-1.0398***	-1.4451***	-1.5837***
	(0.2236)	(0.2386)	(0.5004)
log($Open$)	0.2219**	0.1326**	-0.1550*
	(0.0885)	(0.0701)	(0.0885)
log(hc)	0.9823***	1.2377***	0.0051
	(0.3248)	(0.3897)	(0.4504)
CIPS	-2.518**	-2.836***	-2.699**
CD	-1.61	2.21**	-1.69*
Countries	17	17	17
Observations	136	136	136
Adj. R^2	0.92	0.95	

The dependent variable is log(TFP^S). FMOLS: pooled FMOLS estimator proposed by Phillips and Moon (1999); DOLS: pooled DOLS estimator of Kao and Chiang (2000); GM-FMOLS: group-mean panel FMOLS estimator of Pedroni (2000). All regressions include fixed effects and are based on demeaned data. Given the limited number of time-series observations, no leads and lags were used in the DOLS regression; only current values of the first differences of each right-hand side variable were included. CD is the cross-sectional dependence test of Pesaran (2004); the CD test statistic is normally distributed under the null hypothesis of no cross-sectional dependence in the residuals of the estimated models. CIPS is the cross-sectionally augmented IPS unit root test (with an intercept) on the residuals from the estimated long-run relations. In columns 1 - 3, these residuals were calculated using the reported long-run coefficients. In column 4, the residuals were calculated using the country-specific long-run parameters from the individual FMOLS regressions. For the CIPS statistic, the relevant 5% (1%) critical value is -2.424 (-2.817) with an intercept. The critical values (for panels with N = 17 and T = 9) were calculated from the response-surface estimates of Otero and Smith (2013). Newey-West heteroskedasticity and autocorrelation consistent (HAC) standard errors in parentheses. *** (**) [*] indicate significance at the 1% (5%) [10%] levels.

As can be seen from column 1, the religiosity variable is negative and significant with an elasticity of -0.3257. To evaluate the magnitude of this effect, consider the average 5-year change in the log of church attendance, -0.0479, and the average 5-year change in the log of TFP in the sample, 0.0824. Multiplying the estimated elasticity with the average change in log($Church_{it}$) yields values of 0.0156, implying that the decrease in log($Church_{it}$) between 1950 and 1990 has led to an increase in log(TFP^S_{it}) by 0.0156 units for the average country in the sample. With an average increase in the log of TFP of 0.0824 units, this means that the decrease in church attendance has been responsible for 18.94 percent of the increase in TFP. Of course, this quantitative estimate must be interpreted with caution given the relatively small number of observations. However, what can be safely concluded is that the estimated effect is both economically and statistically significant.

The control variables in column 1 perform largely as expected. Population size is significantly negatively related to TFP, a result that is consistent with the results of, for example, Pritchett (1996), Bernanke and Guerkaynak, 2001; and Strulik et al. (2013). The coefficients for openness and education are positive and significant, as expected. The coefficient estimates and significance levels reported in column 2 are very similar to those in column 1; the coefficients for $\log(Open_{it})$ and $\log(hc_{it})$ are positive and significant, and the coefficients for $\log(Church_{it})$ and $\log(Pop_{it})$ are negative and significant. In contrast, in column 3, the coefficient for $\log(Open_{it})$ is negative but only marginally significant, and education has the expected positive sign but is statistically insignificant. More importantly, the coefficient for the $\log(Church_{it})$ variable is still negative and statistically significant at the 1% level in column 3. Thus, all three estimators suggest that religiosity has a negative effect on TFP.

Below the coefficient estimates, we also report the results of the CIPS test for a unit root in the residuals of the estimated relationships and the results of Pesaran's (2004) cross-sectional dependence (CD) test. The CIPS test rejects the null hypothesis of a unit root in the cointegrating residuals for all three estimations, confirming the results from the previous subsection that there is a non-spurious relationship between the variables. However, while the null of no cross-sectional dependence is not rejected for the pooled FMOLS results, the CD test rejects the null hypothesis of no cross-sectional dependence for both the results of the pooled DOLS regression and the results of the group-mean FMOLS procedure. The implication is that the pooled DOLS and group-mean FMOLS results could be biased by cross-sectional dependence. Consequently, these results are less reliable than the pooled FMOLS results.

In Table 6, we examine whether the FMOLS results are robust to alternative measures of TFP. Column 1 reports the results using the TFP index from the approach of Hall and Jones (1999). In column 2, we use the TFP measure based on the production function suggested by Mankiw et al. (1992). As expected, both measures yield coefficient estimates on the religiosity, population, and openness variables that are very similar to those reported in column 1 of Table 5, while the coefficient estimate on $\log(hc_{it})$ differs between the specifications. Moreover, the CD statistics show no evidence of cross-sectional dependence in the residuals of both specifications, and the CIPS statistics suggest that the error processes of the estimated relationships are stationary. Thus, our results are robust to alternative measures of TFP.

Table 6: FMOLS Estimates Using Different Measures of Total Factor Productivity

	Dependent variable: $\log(TFP^{HL})$ (1)	Dependent variable: $\log(TFP^{MRW})$ (2)
$\log(Church)$	-0.3035***	-0.3146***
	(0.0731)	(0.0766)
$\log(Pop)$	-0.8594***	-0.9496***
	(0.2024)	(0.2120)
$\log(Open)$	0.1833***	0.2026**
	(0.0801)	(0.0839)
$\log(hc)$	0.2883	0.6352**
	(0.2940)	(2.0626)
CIPS	-3.032***	-2.766**
CD	-1.59	-1.61
Countries	17	17
Observations	136	136
Adj. R^2	0.89	0.90

$\log(TFP^{HL})$ is the log of TFP calculated using equation (5); $\log(TFP^{MRW})$ is the log of TFP defined by equation (7). Both regressions include fixed effects and are based on demeaned data. CD is the cross-sectional dependence test of Pesaran (2004); the CD test statistic is normally distributed under the null hypothesis of no cross-sectional dependence in the residuals of the estimated models. CIPS is the cross-sectionally augmented IPS unit root test (with an intercept) on the residuals from the estimated long-run relations; these residuals were calculated using the reported long-run coefficients. For the CIPS statistic, the relevant 1% (5%) critical value is -2.817 (-2.424) with an intercept. The critical values (for panels with N = 17 and T = 9) were calculated from the response-surface estimates of Otero and Smith (2013). Newey-West heteroskedasticity and autocorrelation consistent (HAC) standard errors in parentheses. *** (**) indicate significance at the 1% (5%) level.

3.3. **Causality.** In Table 7, we test for weak exogeneity of TFP and church attendance, and thus for long-run Granger non-causality between $\log(TFP^S_{it})$ and $\log(Church_{it})$, by evaluating the t-statistics of the error correction terms in the error correction models for TFP and church attendance. As noted above, the residual from the panel FMOLS long-run relation (in Table 5) is used as the error correction term. We find that the t-statistics reject the null hypothesis of weak exogeneity for $\log(TFP^S_{it})$ but not for $\log(Church_{it})$. Subsequently, we conclude that the direction of causality runs from church attendance to TFP, and not the other way around.

3.4. **Unbalanced Panel Regressions.** Finally, in order to maximize the number of observations in the analysis and to provide a further robustness check, we apply conventional two-way fixed effects models and the Pesaran (2006) CCE approach to the unbalanced panel. The results are presented in Table 8. In column 1, where we estimate a two-way fixed-effects model that includes only contemporaneous explanatory variables, the religiosity variable has a negative and significant coefficient. When we re-estimate the model using lagged explanatory variables to

Table 7: Long-run Causality Tests

Null hypothesis	t-value of the error correction term
Weak exogeneity of $\log(TFP^S)$	-5.40***
(Dependent variable: $\Delta \log(TFP^S)$)	
Weak exogeneity of $\log(Church)$	0.79
(Dependent variable: $\Delta \log(Church)$)	

The error correction term is the residual from the panel FMOLS long-run relation (in Table 5). The results are based on demeaned data. The t-values are based on Newey-West heteroskedasticity and autocorrelation consistent (HAC) standard errors. *** indicate significance at the 1% level.

control for potential endogeneity biases, the coefficient becomes smaller (in absolute value) but is still statistically significant (see column 2). A conclusion from these results is that religiosity predicts TFP not only contemporaneously, but also for at least five years after church attendance is measured.

Table 8: Unbalanced Panel Regression Results

	2FE (1)	2FE (2)	2FE (3)	2FE (4)	PCCE (5)
$\log(TFP^S)$ (t-1)				0.5305***	
				(0.1288)	
$\log(Church)$ (t+1)			-0.0530		
			(0.0595)		
$\log(Church)$	-0.2547***		-0.1883**	-0.1583***	-0.2193***
	(0.0562)		(0.0725)	(0.0410)	(0.0479)
$\log(Church)(t-1)$		-0.1678**	-0.1564**		
		(0.0740)	(0.0603)		
$\log(Pop)$	-1.1280***		-1.1506***	-0.8139***	1.0141***
	(0.3181)		(0.1957)	(0.2305)	(0.3008)
$\log(Pop)(t-1)$		-1.1925***			
		(0.3140)			
$\log(Open)$	0.1268***		0.1052	0.0939	-0.0519
	(0.0412)		(0.0702)	(0.0588)	(-0.4241)
$\log(Open)(t-1)$		0.1243***			
		(0.0405)			
$\log(hc)$	1.0198***		1.1246***	0.2975	-0.1418
	(0.2627)		(0.2337)	(0.2521)	(-0.4095)
$log(hc)$ (t-1)		0.9216***			
		(0.2269)			
Observations	175	153	132	149	175
Countries	26	23	20	20	26
Adj. R^2	0.95	0.95	0.95	0.96	0.99

The dependent variable is $\log(TFP^S)$. 2FE: two-way fixed effects estimator (with time dummies); PCCE: pooled common correlated effects estimator proposed by Pesaran (2006). All regressions include fixed effects. White cross-section standard errors in parentheses. *** (**) indicate significance at the 1% (5%) level.

In column 3, we examine the issue of reverse causality by conducting a simple test for strict exogeneity. More specifically, as suggested by Wooldridge (2010), we estimate a two-way fixed-effects model with contemporaneous, lagged and lead values of church attendance. As before, the coefficients on contemporaneous and lagged church attendance are significantly negative. In contrast, the one period lead value of church attendance is not significant. Thus, we again find that the direction of causality is not from TFP to church attendance, but from church attendance to TFP.

In column 4, we present results from a dynamic fixed-effects specification with lagged TFP on the right-hand side of the equation. We are aware that this specification suffers from the well-known Nickell (1981) bias, which plagues panels with few time periods. When interpreting the results in column 4, it is thus important to note that the coefficient on the lagged dependent variable is biased due to the correlation between the fixed effects and the lagged dependent variable and that if the remaining regressors are correlated with the lagged dependent variable to some degree, their coefficients may be biased as well. Fortunately, the results in column 3 imply that the current value of TFP is not significantly correlated with the future value of church attendance and thus that lagged TFP is not significantly correlated with current church attendance. Therefore, the estimate of the coefficient on the religiosity variable should (at least) not be biased in the dynamic panel framework; this estimate is negative and statistically significant.

Lastly, column 5 presents estimates from the PCCE regression. As discussed above, while the use of time dummies assumes that all panel units react identically to common disturbances, the PCCE estimator allows for heterogeneous responses across countries. Again, the estimated coefficient on church attendance is negative (and similar in size to that reported in column 1).

4. A Theory of Religion, Factor Productivity, and Long-run Development

4.1. **Setup of Society.** We next propose a theory that offers an explanation for the observed impact of religiosity on factor productivity. The model can be conceptualized as a discrete time version of the Romer (1990) model of endogenous technological change with a new focus on the special role of scientists, engineers, and other people with a similar talent in R&D, called, for simplicity, scientists. Consider a society of non-overlapping generations of adults, each alive for one period (generation). A fixed measure of unit size is (highly) educated and potentially suitable as scientists. For completeness, there is also a measure L of individuals not suited as scientists, called workers, $L > 0$. While the L-types play a passive role, the potential scientists are the focus of the analysis. As in the original Romer (1990) setup, there is no population growth nor endogenous education. The level of education is implicitly contained in the measures of types. Our extension of Romer (1990) focusses on the heterogeneity of educated people, their attitudes towards science and religion, and their leisure behavior.[14]

Individuals $\in H$ are heterogenous with respect to their religiosity, denoted by r, and with respect to their analytic cognitive ability, denoted by a. Acknowledging that religiosity is a multi-dimensional phenomenon, we focus on one particular characteristic of religiosity, namely the propensity to experience utility from spending time at church or other religious activities. In order get analytical results (but without loss of generality), we assume that both traits are uniformly distributed in the unit interval, $r \in [0, 1]$, $a \in [0, 1]$. Individuals are endowed with two units of time. One unit of time is inelastically supplied on the labor market (as in the Romer model). The other unit of time is spent on either religious activities or on secular leisure activities. For simplicity, we call time-consuming religious activities, church attendance.

4.2. **Leisure Activities.** In any period t, individuals decide how to spend their leisure time and whether to apply a reflective-analytical or intuitive-believing cognitive style. Analytical thinking reduces the value of religious activities. Only believers experience the full potential utility from church attendance (and other religious activities). For believers, the experienced value of religion is the product of the time τ_t spent at church (and other religious activities) times the idiosyncratic weight given to pleasure derived from these kind of activities r times the general value of religion R_t, $\tau_t r R_t$. While the distribution of individual religious propensities r is constant, the general value of religion $R_t \in (0, 1)$ is potentially time varying and will be later introduced in detail. If individuals apply a reflective-analytical cognitive style, utility derived from religious activities is declining in cognitive ability a such that experienced utility is $(1 - a)\tau_t r R_t$.

The preference for secular leisure activities is type-independent. In order to obtain a closed form solution, we assume declining marginal utility of the log form such that the sub-utility function is given by $\lambda \log(1 - \tau_t)$, in which λ denotes the general importance of secular leisure activities. The parameter λ is taken as given by individuals but it may change occasionally. For example, if the leisure activity is shopping, λ may increase through the invention of the department store or the repeal of Sunday retail laws (Gruber and Hungerman, 2008). Furthermore, individuals experience utility $u(c_t)$ from consumption (consuming their wage income $w_t a$) and an ego-rent

[14] See Strulik et al. (2013) for a Romer (1990)-type model with endogenous education and population growth.

from being a scientist (from exploring the world scientifically) ηa. The ego-rent is increasing in analytic cognitive ability and its existence is non-crucial for the results, $\eta \geq 0$. The ego-rent captures the phenomenon that scientists may need less self-enhancement through religion because of their status derived from being a scientist (see the discussion in Zuckerman et al. (2013).

Let $\sigma \in \{0, 1\}$ denote the choice of cognitive style with $\sigma = 0$ for believers. Style-specific utility can then be summarized as

$$U(\sigma) = u(w_t a) + \lambda \log(1 - \tau_t) + (1 - a\sigma)rR_t\tau_t + \eta a\sigma. \tag{8}$$

Notice that utility is assumed to be additive in its components and that labor income depends on ability but not on the choice of cognitive style (confirmed below). These features allow us to focus on one particular channel through which religiosity affects behavior. Non-separability or wage differentiation between believers and analytic thinkers would introduce more channels that would potentially amplify the mechanism developed below.[15] Solving the first order condition with respect to church attendance, we obtain:

$$\tau_t = \max\left\{0, 1 - \frac{\lambda}{(1 - a\sigma)rR_t}\right\}. \tag{9}$$

Church attendance is type-specific but neither high cognitive ability nor a reflective-analytical cognitive style precludes church attendance. Specifically, we observe:

Proposition 1. *Ceteris paribus, church attendance is low if the general value religion R_t is low or if the weight of secular leisure activities λ is high. It is low for individuals of high cognitive ability a, for individuals with low religious propensity r, and for individuals adopting a reflective-analytical cognitive style.*

4.3. **Implications for the Structure of Society.** Inserting the solution (9) into (8) we obtain the indirect utility function:

$$U(\sigma) = u(w_t a) + \lambda \log\left(\frac{\lambda}{(1 - a\sigma)rR_t}\right) + (1 - a\sigma)rR_t - \lambda. \tag{10}$$

[15] Alternatively, utility from church attending could be concave as well, i.e. $U(\sigma) = u(w_t a) + \lambda \log(1 - \tau_t) + (1 - a\sigma)rR_t \log(\tau_t) + \eta a\sigma$. While this would lead to qualitatively similar results, it would preclude a corner solution. The quasi-linear form (8) is a simple device to capture the fact that (some) individuals stop attending church completely when the value of religion R is low enough.

Individuals compare utility for $\sigma = 0$ and $\sigma = 1$ and adopt an analytical-reflective cognitive style if $U(1) > U(0)$, that is if

$$f(a, R_t) := \frac{1}{R_t}\left(\eta - \frac{\lambda \log(1-a)}{a}\right) > r. \tag{11}$$

However, what is the benefit from abandoning the intuitive-believing style? Clearly, it reduces the utility experienced at church; formally, the third term of $U(\sigma)$ in (10) declines. But from inspection of (10) we also see that the utility experienced from secular leisure increases in σ. This is so because invoking a reflective-analytical cognitive style raises doubt about religious doctrines and reduces the opportunity cost of secular leisure. For example, the pleasure from Sunday shopping increases when consumerism and absence from Sunday service is no longer conceived as a sinful activity. Inspect (10) to see that the incentive to abandon faith is high when R_t is low and when λ is high (e.g. after the repeal of Sunday retail bans).

In the a–r-space, $f(a, R_t)$ is the threshold separating the cognitive styles. The threshold is increasing with increasing slope, originates from $(0, (\eta + \lambda)R_t$ and reaches infinity before ability reaches unity. It is shown in Figure 1 by the blue line for three different values of R_t. Individuals, characterized by an (a, r)-tuple above the threshold apply an intuitive-believing cognitive style where individuals below the threshold apply a reflective-analytical cognitive style. On average, individuals of high cognitive ability are less likely to be believers but we can also identify individuals of high cognitive ability and high religious propensity who prefer to be intuitive believers.

Since maximum religious propensity is 1, there exists a cutoff value $\bar{a}$ above which individuals adopt a reflective-analytical cognitive style irrespective of their religiosity. The cutoff value is implicitly observed as:

$$F(\bar{a}, \lambda, \eta) = \eta - R - \lambda \frac{\log(1-a)}{a} = 0. \tag{12}$$

The area below the threshold provides the population share of individuals who apply the reflective-analytical cognitive style, denoted by s_t. It is obtained as:

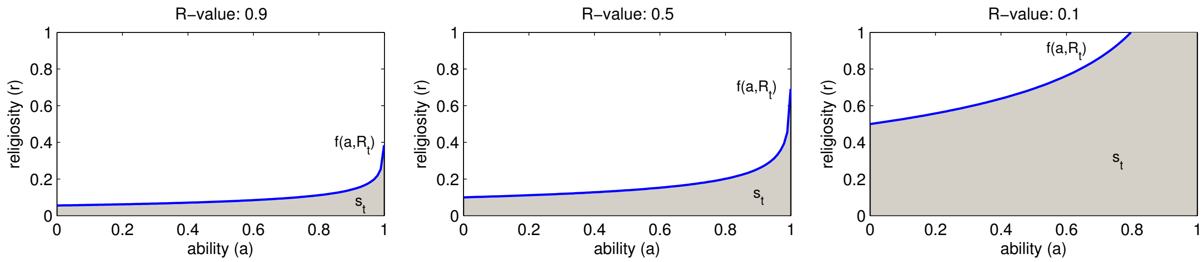
$$s_t = 1 - \bar{a} + \frac{1}{R_t}\int_0^{\bar{a}} \eta - \lambda \frac{\log(1-a)}{a} \mathrm{d}a. \tag{13}$$

Although the expression is relatively simple, there exists no closed-form solution. The comparative statics, however, are easily inferred from the diagrammatic exposition of the $f(a, R_t)$-curve.

Proposition 2. *The population share of individuals applying the reflective-analytical cognitive style s_t is declining in the general value of religion R_t and increasing in the value of secular leisure λ.*

For the proof, notice that declining R_t leaves the slope of $f(a)$ unaffected and shifts the curve upwards. Increasing λ shifts the curve upwards and increases the slope. As a consequence, the area below the curve, i.e. s_t, gets larger.

Figure 1: Ability-Threshold and Share of Type-II individuals



Parameters: Blue line: ability threshold $f(a, R_t)$, gray area: share of type-II individuals, white area: share of type-I individuals (believers). Parameters: $\eta = 0$, $\lambda = 0.05$. Notice that for $R_t = 0.9$ and $R_t = 0.5$, the cutoff level $\bar{a}$ is close to 1. For $R_t = 0.1$, it is around 0.8.

4.4. **The Value of Religion.** The value of religion is conceptualized as a slow moving state variable, which is partly pre-determined by history. This "reduced-form" modeling captures a general feature of path-dependency of institutions. The value of religion, however, depends also on aggregate religious activity in society. This "reduced-form" modeling captures the social aspect of religion, i.e. the strength of the social norm to attend church (and to participate in other religious activities). In order to obtain closed-form solutions, we capture the strength of the social norm by the frequency of church attendance of the median citizen, denoted by τ_t^m. Specifically, we assume that next period's value of religion is given by $R_{t+1} = (\rho + \tau_t^m)^\omega R_t^{1-\omega}$. Here, ω measures the relative contribution of history and social norms to the value of religion, $0 < \omega < 1$. By $\rho \geq 0$ we acknowledge that religion may attain a positive value although the median citizen completely stopped attending church. The parameter ρ is also the gateway for exogenous shocks that reduce religious value.

Noticing that ability of the median is 1/2 and inserting church attendance from (9) we obtain the law of motion for the value of religion:

$$R_{t+1} = \begin{cases} \left(\rho + 1 - \frac{2\lambda}{R_t}\right)^{\omega} R_t^{1-\omega} & \text{for } R_t > 2\lambda \\ \rho^{\omega} R_t^{1-\omega} & \text{otherwise.} \end{cases} \tag{14}$$

Inspection of (14) shows that if the initial value of religion is sufficiently low or the value of secular leisure activities is sufficiently large such that $2\lambda \geq R_t$, then the value of religion declines gradually to a low value of $\rho^{1/\omega}$. If the initial value of religion is sufficiently high, in contrast, there may exist a steady state of high religious value and frequent church attendance. To see this explicitly, we solve (14) for $R_t > 2\lambda$ and $R_{t+1} = R_t = R^*$ and obtain the solutions $R^* = \rho$ and

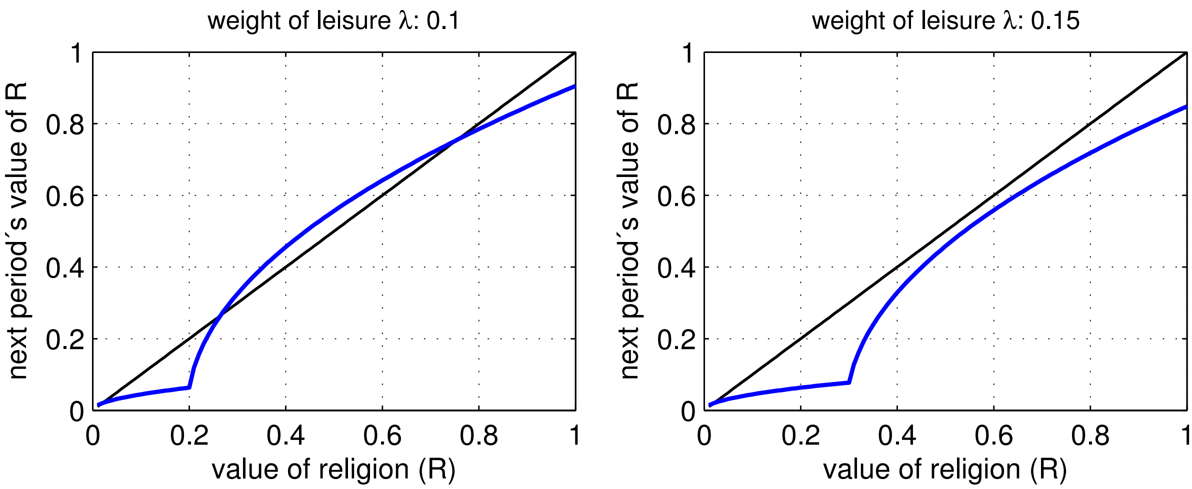
$$R^* = \frac{1+\rho}{2} \pm \sqrt{\frac{(1+\rho)^2}{4} - 2\lambda} \tag{15}$$

for $\lambda < (1+\rho)^2/8$.

PROPOSITION 3. *If the value of secular leisure is sufficiently high, $\lambda > (1+\rho)^2/8$, there exists a unique stable steady state of low religiosity, $R^* = \rho$. Otherwise, there exist three steady states, the low-religiosity steady state $R^* = \rho$, an unstable steady steady of medium religiosity, and a locally stable steady state if high religiosity.*

For the proof, consider Figure 2 showing the two possible cases. The R_{t+1}-curve is given by the concave curve (blue line); the identity-line is shown in black. At $R_t = 2\lambda$, the median citizen stops going to church and the R_{t+1}-curve displays a kink. Intersections of the two curves identify steady states. For a sufficiently low value of λ (here $\lambda = 0.1$) there exist three intersections, as shown in the panel on the left-hand side of Figure 2. Let the intersection at the largest R be denoted by R_1^* (and R_2^* is the intermediate steady state). Observe that R_{t+1} is strictly concave for large R_t. This means that it lies below the identity line for large values where $R > R_1^*$, implying convergence towards R_1^* from the initial value above and (mildly) below R^*. The upper steady state is locally stable. At the intermediate intersection, the R_{t+1}-curve lies above the identity line for values $R > R_2^*$, implying movement away from the steady state. The intermediate steady state is unstable. For sufficiently high values of λ (here $\lambda = 0.15$) there exists only an intersection at a (very) low level of religiosity ρ. This case is shown in the panel on the right-hand side of Figure 2.

Figure 2: Law of Motion for Value of Religion



Blue curve: law of motion (14) for $\rho = 0.02$, $\eta = 0$, $\omega = 1/2$. Left panel: 3 intersections (steady states); a locally stable steady state at $R_1^* = 0.755$, an unstable steady state at $R_2^* = 0.265$, and a locally stable steady state at ρ. Right panel: Unique steady state at low religiosity level.

4.5. **Firms.** The production side of the economy is a discrete time version of the well-known Romer (1990) model, in which we neglect the role of physical capital accumulation and emphasize the role of scientists. Capital accumulation could be added without loss of generality (see Strulik et al., 2013). The production side of the economy is organized in three sectors: final goods, intermediate goods, and R&D. In the final goods sector, competitive firms produce output Y_t given a Cobb-Douglas production technology, i.e. $Y_t = (H_t^Y)^\alpha L^\beta \int_0^{A_t} x_t(i)^{1-\alpha-\beta} \mathrm{d}i$, in which L are workers and H_t^Y are educated individuals employed in final goods production. The variable $x_t(i)$ describes the amount of the intermediate good i in the final goods production. The parameters α and β denote the share of workers and educated types in final goods production. We assume that $A_0 = 1$ such that there is final goods production even in the absence of market R&D. Individuals are paid according to ability such that w_t denotes the wage per unit of ability supplied. Notice also that input of educated types in final goods production is potentially time-varying, a further deviation from the original Romer setup. In order to have some economic growth even in the absence of market R&D, we could introduce technological progress through learning-by-doing (as in Strulik et al., 2013) but we ignore this gain in realism here for the sake of simplicity. Profit maximization provides the indirect demand functions for educated types $w_t = \alpha Y_t / H_t^Y$, and intermediate goods $p_t(i) = (1-\alpha-\beta)(H_t^Y)^\alpha L^\beta x_t(i)^{-\alpha-\beta}$.

In the intermediate goods sector, firms produce under monopolistic competition. A firm that buys a blueprint from the R&D-sector is allowed to produce one specific intermediate good.

Firms use a production technology that transfers one unit of the final good into one unit of the intermediate good. Hence, profits of an intermediate goods producer are $\pi_t(i) = p_t(i)x_t(i) - x_t(i)$. Profit maximization provides optimal quantities $x_t(i) = [(1-\alpha-\beta)^2 (H_t^Y)^\alpha L^\beta]^{1/(\alpha+\beta)}$ and prices $p_t(i) = 1/(1-\alpha-\beta)$. Henceforth, the firm-specific index i is dropped, because all firms produce the same quantity and sell their products at the same price.

New knowledge is created in an R&D-sector by educated individuals. As Romer, we assume that H-types can be alternatively employed in final goods production and R&D. Thus, if the R&D-sector is operative, there are $H_t^A = H_t - H_t^Y$ individuals employed in R&D. Individuals are paid according to ability but not according to cognitive style, i.e. intuitive believers earn the same wage as reflective-analytical thinkers of the same cognitive ability. There is thus no reason to abandon religiosity and to assume a reflective-analytical cognitive style in order to raise one's income. However, we assume that productivity of R&D is larger when more individuals adopt rigorous analytical thinking. This approach acknowledges that that the overall output of innovations is larger when more people base their thinking on reason, empiricism, and evidence rather than on intuitive beliefs and faith (Mokyr, 2005). Notice that this view is compatible with the observation that some innovations are made by deeply religious individuals (of allegedly high cognitive ability). Summarizing, R&D production is given by

$$A_{t+1} - A_t = \delta_t H_t^A, \qquad \delta_t \equiv \bar{\delta} + \phi s_t. \tag{16}$$

For $\phi = 0$ we have the original Romer setup and for $\phi > 0$, R&D-output is increasing in the prevalence of analytical thinking in society. Maximization of profits in the R&D-sector implies wages $w_t = p_t^A \delta_t$, in which p_t^A denotes the price of a blueprint for a new intermediate product. Following Aghion and Howitt (2009, Chapter 4) and Strulik et al. (2013) we assume that a patent holds for one generation (in the quantitative part, this will be 20 years) and that afterwards, in any future period $t+1$, the monopoly right is sold at price π_{t+1} to someone chosen at random from the currently active generation. The revenue is spent unproductively on public consumption. This simplification helps to avoid intertemporal (dynastic) problems of patent holding and patent pricing while keeping the basic incentive to create new knowledge intact.

4.6. **Market Equilibrium.** Aggregate human capital is obtained as $H_t = \int_0^1 a \mathrm{d}a = 1/2$. Free entry to intermediate goods production implies that operating profits equal the price of a blueprint, i.e. $\pi = (\alpha+\beta)(1-\alpha-\beta)Y_t/A_t = p_t^A = w_t/\delta_t$. If the R&D-Sector is operative, wages of educated types are equalized across sectors such that $(\alpha+\beta)(1-\alpha-\beta)Y_t/A_t = \alpha Y_t/H_t^Y(\bar{\delta}+\phi s_t)$. Solving for employment in goods production, we obtain:

$$H_t^Y = \min\left\{1/2,\ \frac{\theta}{\bar{\delta}+\phi s_t}\right\}, \qquad \theta \equiv \frac{\alpha}{(\alpha+\beta)(1-\alpha-\beta}. \tag{17}$$

From this we conclude:

Proposition 4 (Take-off of Market R&D). *i) For $s_t \leq (2\theta-\bar{\delta})/\phi$, there are too many intuitive-believers in society for market R&D to be worthwhile. All individuals are absorbed in goods production. ii) For $s_t > (2\theta-\bar{\delta})/\phi$, employment in R&D is positive and declining in the population share of intuitive believers.*

The proof follows from inspection of (17) and noting that $H_t^A = 1/2 - H_t^Y$. If there are too few people applying the reflective-analytical cognitive style, productivity of R&D is too low for (market) R&D to be worthwhile. Everyone is occupied with goods production. Technology advances only through learning by doing activities (which are absent in our simplified model). Using the labor market clearing condition and noting that $H_t^A \geq 0$, we obtain the growth rate of R&D output, $g^A \equiv (A_{t+1}-A_t)/A_t$, as

$$g_t^A = \max\left\{0,\ \phi s_t + \bar{\delta} - \theta\right\}. \tag{18}$$

This leads to the following conclusion.

Proposition 5 (Church Attendance (Granger-) causes TFP). *The growth rate of total factor productivity (TFP) at time t is a positive function of the share of scientists in the economy at time t that is a negative function of (median) church attendance at time $t-1$.*

For the proof we note that intermediate input is constant across sectors such that aggregate output is $Y_t = A_t(H_t^Y)^\alpha(L_t)^\beta x_t$, and g_t^A is the growth rate of TFP. We then apply proposition 4 to obtain TFP as a positive function of s_t and Proposition 2 to obtain TFP as a positive function of R_t. Finally, we recall that median church attendance is $\tau_t^m = 1 - 2\lambda/R_t$ and conclude from (14) that R_t is a positive function of last period's church attendance of the median (and thus also of aggregate church attendance), as long as the median attends church at least occasionally. This establishes the predictive causality that we found for our panel of countries.

5. The Transition to Modernity

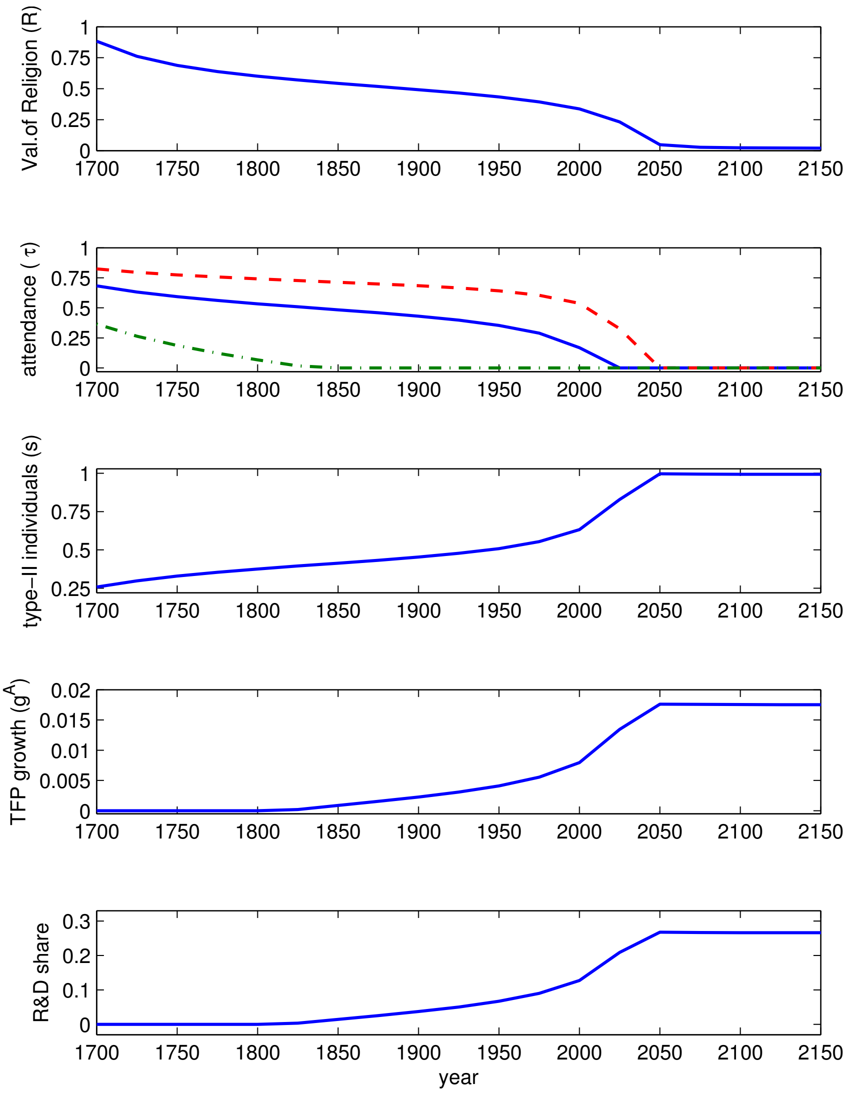
We next discuss the implications of the religiosity-productivity nexus for economic development in the very long run. Pre-modern times are conceptualized as a society resting at the steady state of high value of religion. Church attendance is frequent and widespread across all social strata and most people are intuitive believers. Productivity of R&D is too low for market R&D to be worthwhile. Then, R_t shifts down, motivated either by a downward shift of ρ (the Enlightenment; demystification of natural phenomena leaves less for religion to explain) or by an upward shift of λ (e.g. the invention of the department store), or both. As a result, the steady state R^* disappears and society gradually converges towards more secular leisure activities and less time spend on religious activities.

In order to derive the full pleasure of secular leisure it is helpful to abandon the intuitive-believing cognitive style. Analytical reflection of, for example, the theodicy dilemma or specific church behavior (the inquisition) or specific doctrines (indulgence letters, purgatory) raises doubt and depreciates the experience at church (and the utility derived from, say, the forgiveness of sins or salvation from worldly desires). Likewise, cognitive reflection leaves less room for religion to "explain" natural phenomena and historic and political events. In any case, analytical reflection reduces the opportunity cost of indulging in secular leisure, and the effect is strongest for individuals of high cognitive ability (who are able to arrive at more doubt-raising conclusions through reflection). Ceteris paribus, individuals of high cognitive ability thus respond strongest to these incentives.

When a critical mass of people try to understand the world rationally and apply the reflective-analytical cognitive style, scientific research as a market activity becomes worthwhile. As a consequence of declining church attendance, the value of religion declines further and provides in the next period an incentive for further individuals to abandon the intuitive believing cognitive style. As the reflective-analytical approach becomes more popular, productivity in R&D rises and an increasing share of educated workers is employed in the R&D-sector. As a consequence, the rate of innovation and thus aggregate factor productivity rises further. Gradually, society secularizes and, driven by secularization, TFP takes off.

We next illustrate these developments with a numerical example. We set $\omega = 0.65$, $\lambda = 0.14$, $\eta = 0$, $\alpha = \beta = 1/3$, $\phi = 1.8$, $\bar{\delta} = 2.3$. Enlightenment is captured by an exogenous shock such that $\rho = 0.2$ until the year 1700 (supporting a steady state of high religiosity and church

Figure 3: The Transition to Modernity

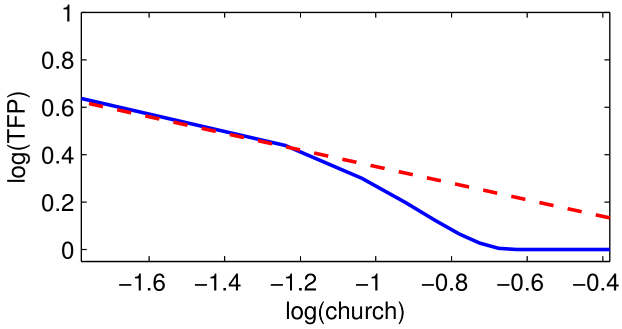


Attendance: blue: median individual; green: median of individuals applying the reflective-analytical style; red: median individual from the top decile of the religiosity distribution (with $r = 0.95$).

attendance) and $\rho = 0.02$ from 1700 onwards. We assume that a generation takes 25 years and convert generational growth rates to annual ones.

Figure 3 shows the resulting trajectories. The drop in ρ eliminates the steady state of high religiosity and religious value declines gradually (first panel), in line with declining church attendance of the median citizen (second panel, solid line). Consequently, a rising share of people applies the reflective-analytical cognitive style (third panel). A century after the Enlightenment shock, R&D productivity has reached a sufficiently high level and market R&D becomes worthwhile. As a result, TFP growth takes off and grows at an initially increasing, then declining rate (fourth panel). TFP growth is propelled by increasing productivity of R&D and by an increasing share of people working in R&D (bottom panel).[16]

Figure 4: Church Attendance and TFP



Blue (solid) line: model prediction; parameters as for Figure 4 and $A(1) = 1$; log(church) is $\log(\tau^m)$; log(TFP) is $\log(A)$. Red (dashed) line: estimated long-run partial correlation between $\log(\tau)$ and $\log(A)$.

The solid line in Figure 4 shows the implied trajectory in a $\log(\tau^m)$–$\log(A)$ diagram, that is, in notation of our empirical model, in a $\log(church)$–$\log(TFP)$ diagram. The dashed line in Figure 4 shows the estimated partial correlation between $\log(church)$ and $\log(TFP)$ from our preferred empirical model (FMOLS). For the 20th century, the two lines are well aligned, showing that it is possible to specify the model such that it provides a decent quantitative prediction in light of our empirical estimates.

6. Conclusion

In this paper we established a strong negative association between church attendance and TFP with predictive causality running from declining church attendance to TFP growth. We have documented that our result is robust to alternative estimation methods, different samples, and different measures of factor productivity. An advantage of cointegration analysis is that results are not biased by omitted variables. In our context this means that results are not biased by the missing consideration of, for example, measures of religious supply or other drivers of factor productivity.

[16]The figure also reveals that the model is too stylized to accurately capture all details for the take-off of modern growth. In particular, if the model is calibrated to predict take-off of R&D-based growth at about 1850 (the second industrial revolution), then it overestimates growth and the R&D-share at the steady state. The reason for this behavior is the assumed divisibility of human capital (for example, two persons with $a = 0.4$ innovate as much as one person with $a = 0.8$). In reality, individuals of low ability – who contribute to s_t later – are likely to innovate less (We could address this by making the model slightly more complicated by assuming $\delta_t \equiv \bar{\delta} + \phi s_t^{\psi}$ and $\psi < 1$).

We then proposed a theory that rationalizes this finding and use the theory to reflect on trends in religiosity and R&D-driven growth in the very long run. The theory is based on insights from evolutionary psychology that religiosity is strongly associated with an intuitive believing cognitive style and that cognitive style is a choice variable. When the value of religion declines, or the value of secular leisure increases, individuals move gradually from an intuitive-believing to a reflective-analytical cognitive style, in order to reduce the opportunity costs of secular leisure. Reflective analytical thinking increases the productivity of R&D such that R&D-based growth takes off when sufficiently many individuals apply a reflective-analytical cognitive style.

Several extensions of the theory are conceivable. For example, the value of secular leisure, λ, could be treated as an endogenous variable such that declining religiosity and rising demand for secular leisure leads to utility enhancing innovations of the leisure industry. Likewise, education could be endogenous such that reflective analytical thinking and human capital demand for R&D increases the return to higher education. Finally, a fully-endogenous unified growth theory could be created by considering learning-by-doing during the pre-modern period such that the onset of the transition to modern growth relies no longer on an exogenous event (the Enlightenment). We are convinced that a consideration of these feedback mechanisms would amplify the positive impact of secularization on factor productivity growth.

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