The role of neighbourhood relations in confessionalisation

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Abstract

By means of a statistical model we study the adoption of Protestantism during the Reformation for 262 territories of the Holy Roman Empire. Our unit of analysis is a territory and the dependent variable indicates whether and when the territorial ruler adopted Protestantism. The independent variables are based on seven theoretical factors that historiographical research has identified to be important for the adoption of Protestantism [49], and on neighbourhood relations. We use an Event History Model to track changes in the variables over time and compute the importance of each driving factor. Our results reveal that geographic neighbourhood relations explain the adoption of Protestantism best. The more neighbours had become protestant in the recent past, the more likely is a territory to become protestant itself. This effect is strongest for weak territories, which may point towards a strategic hesitation to adopt Protestantism in politically uncertain times.

1 Introduction

1.1 Characterising the problem

The adoption of Protestantism during the Reformation can be described from two different perspectives. The event perspective associates the adoption of Protestantism with specific events, such as the Confessio Augustana in 1530 or the Peace of Augsburg in 1555. In contrast, the process perspective sees the adoption of Protestantism as a socio-cultural process. Based on Zeeden's work on confessional formation (Konfessionsbildung), [55, 56, 57], Reinhard and Schilling extended this view to also account for political drivings factors (cf. institutionalisation of Protestantism), captured in their theory of confessionalisation [40, 44] [45, pp.129–209]. Recently, Leppin characterised the Reformation as transformation and Kaufmann described it as inbetween radical change with medieval change and continuity [31, 28, 27].

Process oriented studies have been conducted on a vast number of territorial states and cities of the Holy Roman Empire (HRE) [53, 43, 46, 51, 52, 17]. Research has identified many different factors driving the adoption of Protestantism in the territories, such as the prince's claim to power (County of Lippe) [43], continuity of time (Palatinate) [46, ch.3], and close cooperation between state and reformers (e.g., Duchy of Württemberg) [46, ch.3].

An obvious limitation of this research is its focus on isolated and comparative case studies. By analysing individual territories, these studies only account for developments *within* territories, but neglect developments *between* them on a larger scale. In fact, territories are not independent in their denominational choice but influenced each other. For example, marriages were strategically arranged between ruling families, ideas were exchanged on trade routes, and geopolitical neighbourhoods established power relations. To capture the interdependencies between territories, we need a systemic approach to analyse the effect of their relations and interactions on their denominational choice. This approach implies that the outcome of this denominational decision is explained by relations between many territories, rather than by individual characteristics of them. Therefore, combining case studies is not sufficient to achieve this overarching perspective. To say it in the words of Aristotle: The whole is more than the sum of its parts.

1.2 Reflections on our methodological approach

To study the adoption of Protestantism in territories with a systemic approach, we propose an Event History Model. This type of model infers reasons for the adoption of Protestantism from the history and characteristics of territories in the HRE. It allows us to analyse the developments in and relations between a large number of territories simultaneously.

The first step to develop this model is to operationalise existing historiographical theories that have already proposed driving factors for the adoption of Protestantism. Our contribution is not to add new driving factors to the list, but rather to provide weights for existing ones, i.e., to quantify their importance in the adoption of Protestantism. Specifically, our statistical model tests to what extent these driving factors explain the adoption of Protestantism. Our results implicitly lend evidence to historiographical theories and helps to differentiate between them.

The process of quantification requires us to accomplish two steps: (1) select and (2) operationalise qualitative driving factors. As a result of our selection process, described in detail in section 2.2, we choose eight driving factors for further operationalisation. Seven of these were identified in a historiographical theory on causes of the adoption of Protestantism [49]. These factors are: the resistance of catholic forces from within the territory, power relations between territories, dynastic relations between territories, the influence of top reformers, ideological closeness to the emperor, characteristics of the territorial ruler, and characteristics of the subjects. In addition, we also account for spatial interdependencies between territories by testing how geographic neighbourhood relations affected the adoption of Protestantism.

To operationalise these factors we use two data sets: one on letter correspondences of reformers and the other on socio-economic and spatial characteristics of territories. As a measure of the adoption of Protestantism, we use the denominational decision of territorial rulers, i.e., whether and when the ruler became protestant. The aim of our model is to weight the importance of the eight driving factors on this decision in a statistical framework.

Our results reveal that geographic neighbourhood relations explain the adoption of Protestantism best. The more neighbours had become protestant in the recent past, the more likely is a territory to become protestant itself. This effect is strongest for weak territories, which may point towards a strategic hesitation to adopt Protestantism in politically uncertain times.

Our approach can be criticised in various respects. First, one may object that our selected driving factors are incomplete. But our selection is based on previous historiographical research which has identified those eight factors as the most important ones. By inheriting these factors, this study builds on previous ground work.

Second, one may object that the way we operationalise abstract concepts is oversimplified. Although we can think of more complex ways to measure the adoption of Protestantism, available data often prevents us from doing it in practice, and therefore requires to use proxies instead. We show in our work that these proxies lead to interpretable results. Therefore, we argue that they capture the essential characteristics of the underlying concept, rather than oversimplifying it.

1.3 Previous quantitative studies and our extensions

Previous research has quantitatively studied the effect of driving factors on the adoption of Protestantism in territories of the HRE.[1] Initially, analyses focused on single factors, such as the Ottoman invasion [26], but quickly included several socio-economic, political, and spatial control factors introduced by Pfaff and Corcoran [37] in their theory of religious disestablishment.

In this theory, the authors use economic models for the collapse of monopolies to develop explanatory factors for the adoption of Protestantism during the Reformation. Results revealed that the number of monasteries (supply side) and the distance to Wittenberg (demand side) negatively influenced the adoption of Protestantism, whereas the status 'free' or 'imperial' city (political incentive) positively influenced it.

Subsequent studies adopted many factors of this theory as controls, while focusing on other single explanatory factors, such as printing [42], cult of saints [36], competition between cities [15], agricultural potential [13], Hanseatic diets [54], and travelling students [30]. Recent studies have extended this work by testing multiplex relations, such as the influence of Luther's letters and travel routes [3], and by extending the unit of analysis from cities to territorial states [10, 13]. Becker *et al.* [4] provide a comprehensive overview of explanatory factors of the cause of the Reformation.

Our analysis builds on this work and extends it in three important ways. First, we do not adopt a 'Luther-centric' view but also account for other drivers of the Reformation, such as Reformed and Calvinist movements. Specifically, we extend the selection of territories from [10] and also include territories in Switzerland (mainly Zwinglian-Reformed) and the Netherlands (mainly Calvinistic). We use the letters and whereabouts of several reformers, not only the ones of Luther or his students, extending the works of [3, 30]. We extend spatial relations beyond the distance to Wittenberg or Zurich, the places associated with Luther and Zwingli, extending the works of [37, 13, 42, 15, 30, 54].

Second, we account for the volatile nature of the HRE by tracking temporal changes in dependent and independent variables in a fine-grained manner. Since territories gained or lost land and titles due to wars, marriage, or the division of the estate, characteristics such as rule titles, dynastic relations, and alliances changed over time. Rather

[1] The HRE provides a useful research setting because it includes many territories corresponding to many observations of confessional decisions. In contrast, other sovereign states in Europe, such as France or England, only yield one observation, respectively, since the sovereign chose the confession for the whole state.

than treating temporal variables as static (e.g., logistic, Poisson, and OLS regressions) [15, 37, 36, 13, 42, 30] or only considering the previous time step (e.g., temporal lag model) [10], we account for the full history of a territory, including changes in the independent variables, if data are available. We also measure the dependent variable, whether and when a territory adopted Protestantism, on a year-specific basis, rather than merging several years into 'decisive phases' of the Reformation [10, 42]. This allows a more fine-grained view of adoption dynamics during the Reformation.

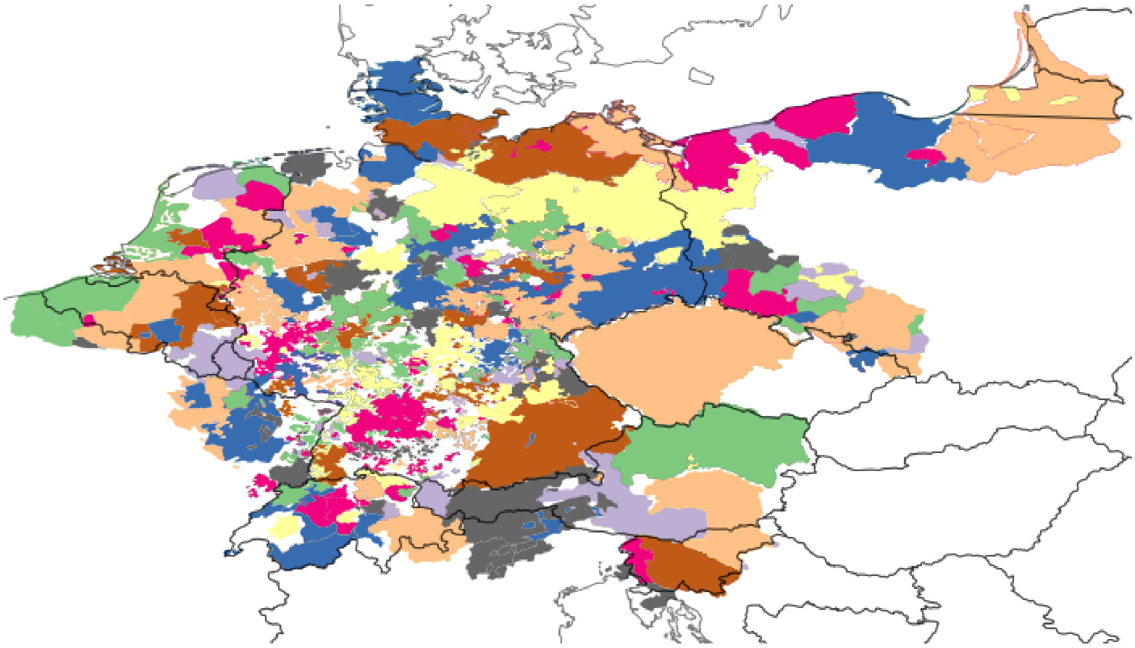

Figure 1: Territories of the Holy Roman Empire (HRE) in the data set. The map is aggregated over time, since territories changed their realm over time (e.g., losses during wars). Modern political borders are plotted to facilitate orientation. (Adapted from [41])

Third, we account for real-world spatial relations between territories by reconstructing their geopolitical borders. This enables us to compute real-world neighbourhood relations rather than relying on artificial measures based on direct distance [10, 37, 13, 42, 15, 30, 54], which fail to capture spatial relations adequately [48]. Figure 1 shows territories of the HRE in the geographic space, and illustrates that our data provide rich neigbourhood relations.

Historiographical research already exemplified that neighbourhood relations matter. For instance, the adoption of Protestantism in Strasbourg in 1523 quickly spilled over to neighbouring cities and territories, such as Ulm, Esslingen, and Constance [39, 18]. On the one hand, Strasbourg reformers, such as Martin Bucer, spread protestant ideas to neighbouring places via letters and personal travels [50]. On the other hand, the university of Strasbourg attracted students from neighbouring places who carried the new ideas back to their home towns. Moreover, territorial rulers were inspired by successful implementations of the Reformation in neighbouring territories. They hired the responsible reformers for their own services, such as duke Ulrich of Württemberg did with the reformers Martin Bucer (from Strasbourg) and Ambrosius Blarer (from Constance) [16]. These examples motivate our research to study the role of neighborhood relations in the adoption of Protestantism both in more detail and on a larger scale, using data from 262 territories of the HRE.

2 Methods

2.1 Aim and quantity of interest

The aim of this analysis is to estimate how characteristics of territories affected their chance to switch from Catholicism to Protestantism in the first place[2]. Unlike case studies which highlight the differences between territories to become protestant, we focus on similarities between territories. That is, we analyse *across* territories how their characteristics reveal patterns in becoming protestant. Our unit of analysis is a territory and our studied population comprises all territories which were considered to be relevant for the Reformation (based on an informed choice by [47]).

Our main quantity of interest is the chance of a territory to become protestant. This chance is estimated with a statistical model. It computes how characteristics of territories and their history, i.e., the time until territories become protestant, influence whether and when a territory becomes protestant.

Figure 2 provides a visual illustration of denominational switches of territories over time. Each subfigure captures one decade in the 16th century. Red and blue areas correspond to catholic and protestant territories, respectively. We see that more territories become protestant over time. However, from this visualisation alone, we cannot

[2] To keep the analysis tractable, we only consider the first switch from Catholicism to Protestantism of a territory. That is, a territory can experience one type of event only once, which is called a *single spell process*. In contrast, in reality, many territories changed confessions several times, such as Electoral Palatinate becoming Lutheran in 1556, Calvinist in 1563, Lutheran again in 1576, Calvinist again in 1583, and after some changes in the context of the Thirty Years' War, catholic again in 1622 and afterwards (only authorities) [46]. So territories could switch several times and could experience several types of switches (e.g., catholic → protestant, protestant → catholic, protestant → protestant).

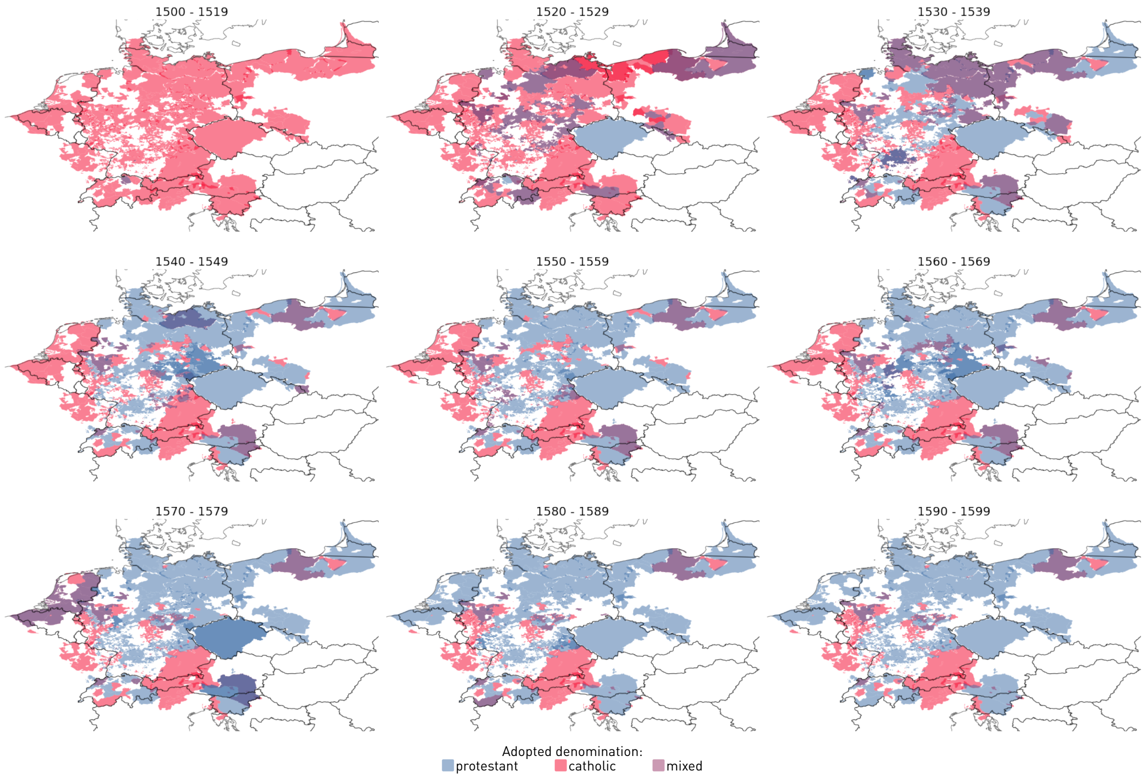

Figure 2: Adopted denomination of territories over time. By 1519, only Zurich had become protestant, whereas by 1599, 140 territories had become protestant. Dark shading (■, ■) indicates that a territory switched its state during the examined period, and different states are plotted ontop of each other. A change of state can be due to (1) territories changing their denomination within Protestantism (e.g., Bohemia), (2) territories uniting with other territories into larger ones (e.g. Liegnitz-Brieg and Wohlgau are united), or (3) territories splitting into smaller territories (e.g., Pommern splits into Pommern-Stettin and Pommern-Wolgast).

distill any overarching pattern of why some territories became protestant and others remained catholic. To discover these patterns, we use a statistical model.

2.2 Theory and hypotheses

We define characteristics of territories which are expected to affect the chance of territories to become protestant. We base our analysis on the seven characteristics defined by historiographical research because they were specifically developed to explain the adoption of Protestantism among territories [49]. In the following, we describe these seven characteristics in detail and formulate hypotheses on how we expect these characteristics to affect the chance of territories to become protestant. In addition, we extend the theory by an eighth characteristic: neighbourhood relations between territories.

Resistance of catholic forces from within the territory. The Catholic Church opposed the Reformation because it threatened the Church's powerful position in the lives of laypeople and politics. Whereas the Catholic Church claimed the monopoly on mediating between God and the laypeople, protestant reformers argued that this mediation was not necessary and laypeople could directly communicate with God. Whereas the Catholic Church had successfully restricted the power of territorial rulers to achieve its own interests, these rulers used the Reformation to gain greater political independence. Given this opposition of the Catholic Church against the Reformation, catholic forces, such as bishops and monasteries, also opposed territories becoming protestant. We formulate the following hypothesis:

Hypothesis 1 *The larger the resistance of catholic forces from within the territory, the smaller the chance of the territory to become protestant.*

Political power of territories. The adoption of Protestantism was not exclusively a question of faith but also a question of political power. Depending on how powerful a territory was, it could decide to become protestant (or to remain catholic) without considering the interests of other territories. Similar to geopolitics between modern countries, territories depended on each other in various ways. Territories shared the rule over parts of land (condominates). They provided patronage to other territories in return for duties. They conquered other territories in wars, sometimes annexing the conquered land, sometimes staying separate but installing a bailiff, sometimes allowing self-governance but demanding duties. Within these interdependencies, powerful territories had more leverage to put into practice their most preferred decision than weak territories. In the historiographical discussion of our proposed factors, power relations are examined for neighbouring territories [49]. This focus is reasonable because neighbours were probably the most important political and economic partners. Territories shared the same resources (e.g., rivers) and were close trading partners since transporting goods over long distances was expensive [19]. Assuming that a territory wants to become protestant, it has a larger probability of doing so the more powerful it is. We formulate the following hypothesis:

Hypothesis 2 *The larger the political power of a territory, the larger the chance of the territory to become protestant.*

Dynastic relations. Marriages and division of the estate created kin relations between rulers across territories. For example, Ernestine and Albertine Saxony originated from the division of the House of Wettin in 1485. Through these interdependencies, some dynasties could increase their range of influence, such as asking kin-related territories for support in a war or asking them to vote in the dynasty's favour at political diets. These kin relations may have also affected the adoption of Protestantism [49]. The decision of a territory to either become protestant or to remain catholic is influenced by the opinion of territories from the same dynasty on that matter. We formulate the following hypothesis:

Hypothesis 3 *The more territories of a dynasty have become protestant in the past, the larger the chance of a territory, belonging to the same dynasty, to become protestant.*

Influence of 'top' reformers. Reformers were members of the clergy, like Martin Luther and Huldrych Zwingli, who developed the theological aspects of the Reformation. These aspects considered how to interpret the Bible and how to practice faith. Reformers spread these ideas by travelling, preaching, printing, and exchanging letters. Often, reformers were explicitly invited by the territorial ruler and were offered employments as advisor or preacher. By these means, reformers could influence the acceptance of Protestantism in the population and of the ruler. We formulate the following hypothesis.

Hypothesis 4 *The more a territory is exposed to the ideas of top reformers, the larger its chance to become protestant.*

Closeness to the emperor. During the Reformation, the emperors of the Holy Roman Empire came from the catholic house of Habsburg in Spain. Charles V. ruled from 1519 to 1556 and his brother Ferdinand I. from 1556 to 1564. Especially Charles opposed the Reformation because when he ascended to the throne he was only 21 and therefore felt that he had to gain acceptance among the territorial princes and rule with a hard hand. Since the emperors during the Reformation were supporters of Catholicism, territories which were ideologically close to the emperors are assumed to have supported Catholicism, too. Since we lack data to measure the ideological or social closeness of territorial rulers towards the emperor, we will not operationalise this factor and exclude it from the analysis.

Characteristics of the ruler. In the 16th century, the choice of religion was made by the territorial ruler. He decided which religion his subjects should adopt and hence which official religion his territory should have. Due to this central role of the ruler, historiographical research assumes that the ruler's personal character traits influenced his decision to either remain catholic or become protestant [49]. Many character traits exist that may have contributed to the adoption of Protestantism, such as theological expertise, curiosity in new ideas and steadfastness. Since we lack data about character traits, we will not operationalise them and exclude them from the analysis. However, in a case study, we will examine the role of Philip of Hesse through the letters that he sent to other territories.

Characteristics of the subjects. Although the official religious decision-making power lay with the territorial ruler, his subjects could also influence this decision. By expressing their (dis-)content with current religious practices, subjects could signal to their ruler whether they preferred to adopt Protestantism or to remain catholic. Sometimes this signal was explicit with subjects rioting against a certain religious decision of their ruler (e.g., Reutlingen and Nuremberg [3]). Usually, the signal was implicit with the ruler being influenced by the cultural and economic developments in his territory which in turn influenced his decisions. We formulate the following hypothesis:

Hypothesis 5 *The more economically well-off the subjects, the larger the chance of the territory to become protestant.*

Neighbourhood relations. So far we have introduced historiographical factors that assume that territories adopt Protestantism independently of each other, i.e., without considering previous adoption choices of other territories[4]. However, in reality, religious choices of territories were likely to be interrelated over time. If a territory became protestant in the past it may exert pressure on catholic territories to also become protestant. This influence may especially take place for neighbouring territories because, as we saw earlier for power relations, neighbours are interrelated via geopolitical and economic relations. So the choice to become protestant (remain catholic) of neighbouring territories is assumed to have affected the choice of the focal territory.

[3] Urban elites were unhappy with the quality of the sermons and arranged for the employment of special preachers ("Prädikanten") alongside the catholic priests. For example, Andreas Osiander was hired in Nuremberg and Matthäus Alber in Reutlingen

[4] An exception are dynastic relations. Previous religious decisions of dynastic members are assumed to affect the religious decision of a territory of the same dynasty at present. However, only a few dynasties contain several territories in our data. So interrelations between choices of territories are not broadly captured.

However, this strong role of protestant neighbours does not become apparent when looking at the data alone. The average territory only had a small fraction of protestant neighbours ($mean = 11.42\%, SD = 0.18$)[5]. Our statistical model helps to solve the mismatch between theoretical considerations and data (see Fig. 5 in Results section).

The small fraction of protestant neighbours can only be realised in a fragmented geopolitical structure like the HRE, where many geographically small territories existed. This fragmentation leads to a large number of neighbours (independent of denomination) ($range = [0, 19], mean = 3.36, SD = 3.54$). Our theoretical consideration on the role of protestant neighbours represent a network effect where territories (nodes) are connected if they are geographic neighbours (edges) and influence each others religious decisions among their direct neighbours. We formulate the following hypothesis:

Hypothesis 6 *The more neighbouring territories have become protestant in the past, the larger the chance of the focal territory to become protestant.*

2.3 Operationalisation

To test our hypotheses, we translate the characteristics of territories from the theory into quantifiable measures that can later be used as independent variables in a statistical model. Appendix A provides a detailed description of our operationalisation procedure. The aim of operationalisation is not to capture the full complexity of a theoretical factor, but rather to reduce this complexity to aspects that are relevant for the analysis at hand. Thus, the measures resulting from operationalisation are always more simple than the original theoretical factors. As we will see, this simplification does not bias the representation of the Reformation, but rather enables us to interpret our results.

Resistance of catholic forces from within the territory. We use the number of monasteries in a territory to operationalise the resistance of catholic forces. Monasteries were a powerful arm of the Catholic Church because they held a large share of the church's wealth [35, p. 56]. Moreover, monasteries were mainly disliked by protestant princes who often expropriated and dissolved them [25, 11]. We proxy the number of monasteries during the Reformation by the number of monastery ruins that have survived until today. This is a good measure because it can be accessed on OpenStreetMap and is available for the majority of territories, which reduces selection bias. To get

[5]The mean fraction of protestant neighbours was computed per territory over the years of its history. These means were then averaged again across territories, which yielded the 11.42%.

an idea of this coverage, Figure 3 shows the location of monastery ruins in the Holy Roman Empire. The corresponding independent variable is called `monasteries` and is time-fixed.

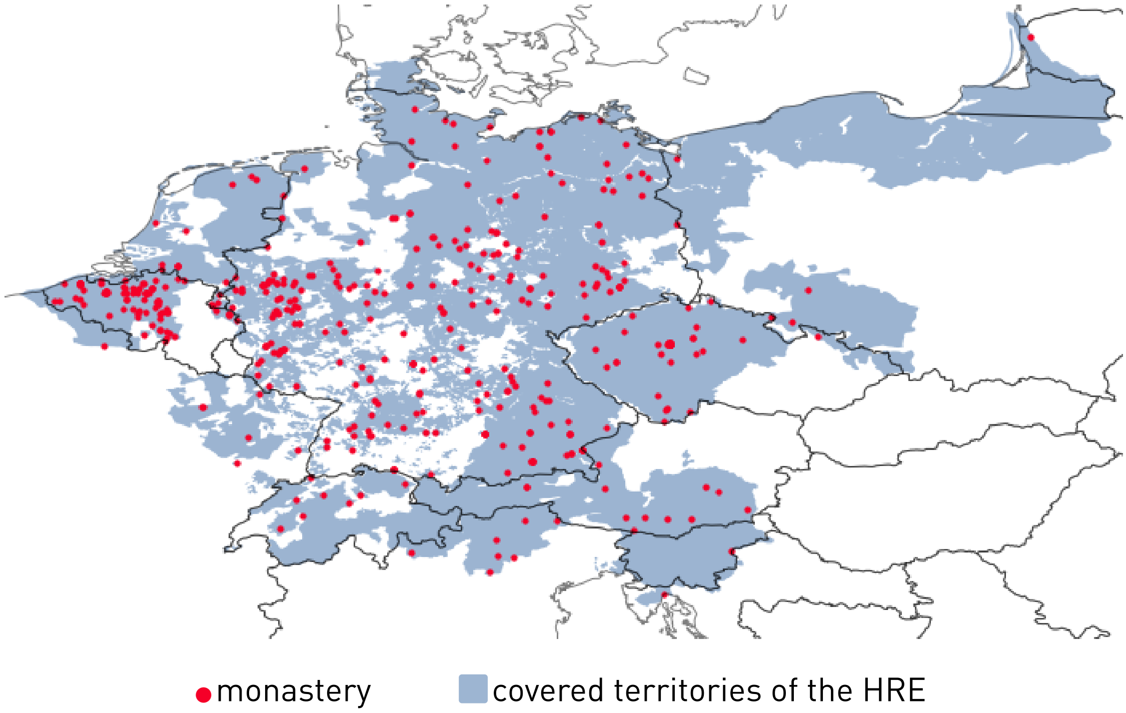

Figure 3: Ruins of monasteries in the Holy Roman Empire (HRE). Locations were extracted from OpenStreetMap. Source: own work.

Political power of territories. We use a ranking of rule titles to operationalise political power. For example, an electorate is more powerful than a duchy (see Appendix B for the complete ranking). We use two versions of political power. A territory's absolute power comparing its rule title to the titles of all other territories in the Holy Roman Empire, and a territory's relative power, only using its neighbours for the comparison. The corresponding independent variables are called `absPower` and `relPower` and are time-dependent.

Dynastic relations. We operationalise dynastic relations as group membership of the same family, weighted by the elapsed time since a dynastic member became protestant. The corresponding independent variable is called `dynasty` and is time-dependent.

Influence of 'top' reformers. We operationalise the influence of top reformers in two ways: the number of days they spent in a territory per year, and the number of letters they sent to a territory per year. Similar to the operationalisation of dynastic relations, we weigh the influences by time, meaning that the more time passes the smaller the weight of a visiting day or letter. The corresponding independent variables are called `visits` and `letters` and are time-dependent.

Closeness to the emperor. Since we do not have data about the ideological or social closeness of territorial rulers towards the emperor, we do not operationalise this factor. We reflect on ideas for potential measures in the discussion section.

Character of the ruler. Since we do not have data about the character traits of territorial rulers, let alone about their names, we do not operationalise this factor. However, we examine the role of rulers by looking at the visits and letters of Philip of Hesse.

Character of the subjects. We proxy the socio-economic situation in the population with three main concepts defined by Becker *et al.* [3]: literacy, economic potential and connectivity. Literacy denotes whether or not a territory had a university or printing press. The corresponding independent variables are called `uni` and `print`. Economic potential corresponds to the size of a territory's population in 1500 and the growth rate of that population in the 15th century. The corresponding independent variables are called `pop1500` and `growth15`. Connectivity denotes a territory's market potential in the year 1500 and whether or not a territory has access to water ways. The corresponding independent variables are called `market1500` and `water`. Since only 28 out of 262 territories have non-missing values for variables representing economic potential and connectivity, we exclude these variables from the main analysis and examine them in sensitivity and robustness checks in Appendix D.2

Neighbourhood relations. To operationalise neighbourhood relations, we compute the fraction of a territory's neighbours that have become protestant in the past. This fraction is time-weighted, meaning that the more time has elapsed between now and the time when a neighbour became protestant, the smaller the weight of the neighbouring switch.

2.4 Data

We used three datasets to operationalise our variables: Territories, socio-economic characteristics of cities, and letters.

Territories We use the dataset generated by Roller [41] to define characteristics of territories. This dataset contains the borders of territories as vectorised polygons and various non-spatial characteristics of territories such as denominational changes, which the authors crawled from Wikipedia. We extend this dataset with the locations of ruins of monasteries which we had crawled from OpenStreetMap. In total, the data comprise 262 territories.

Socio-economic characteristics We use the dataset generated by Rubin [42] on socio-economic characteristics of cities during the Reformation. To obtain territory-specific data, we averaged Rubin's city-values over all cities of the same territory.

Letters We use letter editions of nine notable reformers[6] to track whereabouts and letter correspondences of reformers. The data contain information on the sender, receiver, sending and receiving place, and sending date of a letter. In total, the data contain 3,370 individuals and 26,663 letters.

2.5 Stratified Cox Model with constant event times

To estimate the effect of the operationalised variables on the adoption of Protestantism in territories, we apply a Stratified Cox Model with constant event times (from now on: Stratified Cox Model) [2, 1] [6, p. 160]. This model checks how the estimand, the chance of a territory to become protestant, changes in response to the history of a territory. This history comprises temporal changes of characteristics of a territory, such as changes in power relations. The history of a territory is only examined for the time the territory remained catholic, i.e., the time before the territory became protestant. Through this model choice, we decrease the possibility of reverse causality, where the adoption of Protestantism would influence characteristics of the territory.

The Stratified Cox Model uses terms like 'risk', 'hazard', and 'survival' because it was originally developed for risk assessment in a medical context [6, p. 7]. The aim was

[6] Martin Luther [32], Philip Melanchthon [38], Huldrych Zwingli [58], Heinrich Bullinger [8], Martin Bucer [7], Andreas Karlstadt [29], Oswald Myconius [34], Johannes Oekolampad [9], Joachim Vadian [9]

to estimate the survival probability of patients after medical treatment. That is, assess the risk (hazard) of death (failure) posed by certain influencing factors over time. Translated to our example of the Reformation, a territory becoming protestant represents death or failure, whereas a territory remaining catholic represents survival. The chance that a territory becomes protestant at a certain moment represents its 'risk or hazard to become protestant'.

Besides the Stratified Cox Model, other models exist to estimate the risk of a territory to become protestant, such as logistic regression and linear regression [6, p. 19]. Whereas these models either estimate whether a territory became protestant (logistic regression) or how long the territory took to become protestant (linear regression), the Stratified Cox Model estimates both components together: the denominational switch and its timing. Even if logistic and linear regression were combined, they would not be as powerful as the Stratified Cox Model, because they do not distinguish between territories that 'failed' because they became protestant and those which always remained catholic but ceased to exist for other reasons, e.g., through mediation issued by Napoleon. Moreover, both, logistic and linear regression, do not account for time-dependent independent variables.

The Stratified Cox Model assumes that the risk to become protestant is influenced by two factors: a baseline hazard and the independent variables. The baseline hazard corresponds to the risk of a territory to become protestant if all tested characteristics of the territory are ignored. In practice, we set the values of these characteristics to zero, resulting in territories which had no ruler (and hence neither a rule title nor dynastic relations); no subjects; no universities, printing press, or monasteries; were not in contact with reformers; and had no neighbouring territories. By setting all variables to zero, the baseline hazard ignores differences between territories and assigns them the same risk to become protestant.

Another property of the baseline hazard is that it differs per year of the observation period. That is, for every year in our data, territories are assigned different baseline hazards. For the Reformation, this time-variant property is reasonable because political, economic, and natural events occurred at different points in time and are likely to have changed the risk to become protestant. For example, the defeat of the Schmalkaldic League in 1547 may have decreased the risk to become protestant compared to the official adoption of Lutheran faith by imperial cities at the Diet of Augsburg in 1530.

The second factor that influences the risk to become protestant are the independent variables. The Stratified Cox Model assumes that the effect of an independent variable

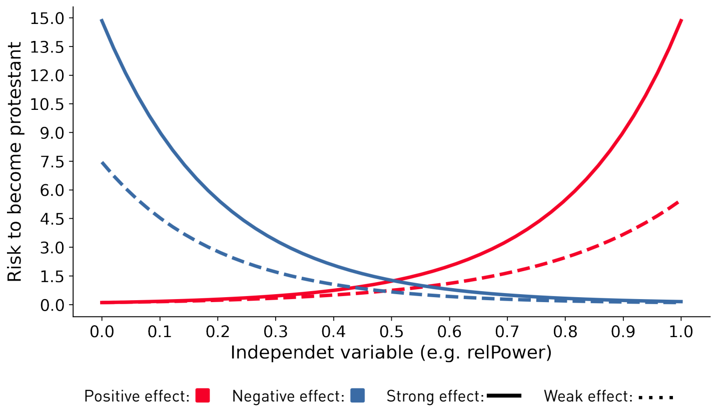

Figure 4: Schematic representation of differing strengths of independent variables on the adoption of Protestantism in the Stratified Cox Model. The model assumes that the risk to become protestant increases exponentially as the values of the independent variable increase or decrease. Independent variables can strengthen (red: steeper slope) or weaken (blue: flatter slope) this effect.

on the risk to become protestant is defined by an exponential function. The slope of this function indicates the strength of influence, i.e., how important the independent variable is for the adoption of Protestantism. It is this slope that the model estimates from the data.

Figure 4 illustrates examples of such exponential functions for the independent variable relative local power (`relPower`). The red curves illustrate a positive effect: the more powerful a territory is locally, the larger its risk to become protestant. The blue curves illustrate a negative effect: the more powerful a territory is locally, the smaller its risk to become protestant. Negative and positive effects can differ in strengths, i.e., be differently important for the adoption of Protestantism. Steep slopes (solid lines) correspond to strong effects, whereas flat slopes (dashed lines) to weak effects.

Appendix C provides a detailed description of how the slope of the exponential function is estimated.

To estimate the importance of independent variables for the adoption of Protestantism (i.e., the slope of the exponential function), the Stratified Cox Model compares two groups of territories on a yearly basis: the event set and the risk set. The event set comprises all territories which became protestant in a specific year. The risk set comprises all territories that are still catholic in that year. That is, territories were at risk of becoming protestant in that year but in reality did not become protestant. The risk set does not distinguish between territories which always remained catholic and those which became protestant at a later point in time. To estimate the effect of a variable on the risk to become protestant, the Stratified Cox Model compares territories of the event set with those of the risk set along the variable of interest. For example, for the variable `monasteries`, the model checks how many monasteries territories in the event set have compared to territories in the risk set. The larger this difference, the larger the inferred effect of the variable on the risk to become protestant. That is, the steeper the estimated slope of the exponential function.

To compute the final risk of a territory to become protestant, the Stratified Cox Model combines the baseline hazard and the effect of the independent variables by multiplying the baseline hazard values with the estimated exponential functions. Appendix C provides a detailed description of the Stratified Cox Model, compares it to related models, and formally defines our tested model (see equation 3).

One may object that a statistical model, like the Stratified Cox Model, is too simplistic to capture the driving factors behind the adoption of Protestantism. And yes, it is highly likely that more than the proposed independent variables were important for that adoption. However, a statistical model does not claim to capture all driving factors. It rather focuses on the important ones, defined by hypotheses, in order to find coarse patterns among the territories that explain their denominational choice. These coarse patterns enable us to reduce the complexity of denominational choices to a level were essential elements are kept, while inessential ones are discarded. In this way, we can interpret complex issues, like the adoption of Protestantism, across many territories.

3 Results

Our contribution is twofold: First, we operationalised qualitative factors for the adoption of Protestantism in the Holy Roman Empire of the 16th century, which allows us to test them as independent variables in a quantitative setting. Second, we run such a test by estimating a Stratified Cox Model. In such a model, characteristics of territories (e.g., power) are only considered for the time the territory remained catholic, i.e., before the switch to Protestantism. Through this modeling choice, we decrease the possibility of reverse causality.

We compare two models: The 'historiographical model' estimates the effect of the theoretical factors proposed by historiographical research on the risk of territories to become protestant, and the 'neighboorhood model' additionally estimates the effect of geographic neighbourhood relations.

Table 1: Cox estimates for first switch of territories from Catholicism to Protestantism. Comparison of histographical theory without and with network effects

	Without neighbourhood	With neighbourhood
Catholic resistance		
monasteries	−2.74% (0.0153)*	−2.42% (0.0157)
Power relations		
absPower	−4.23% (0.0460)	−3.37% (0.0479)
relPower	2.53 (0.3821)**	6.40 (0.4442)***
Dynastic relations		
dynasty	2.29 (0.7655)	13.67% (0.7890)
Top reformers		
visits	0% (0.0001)	0% (0.0001)
letters	0.95% (0.0022)***	0.74% (0.0022)***
Character of subjects		
uni	65.20% (0.2930)*	44.72% (0.2950)
print	−12.34% (0.2304)	1.92% (0.2289)
Controls		
lifetime	0.03% (0.0004)	0% (0.0004)
Neighbourhood		
switchedNeighbours		29.85 (0.5468)***
switchedNeighbours:relPower		−94.95% (0.8148)***
McFadden pseudo-R^2	0.014	0.043
Num. events	192	192
Num. obs.	22666	22666
Missings	0	0

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

Table 1 shows the results of both models. The numbers quantify the size and direction of each independent variable on the risk to become protestant. Small effects are presented as percentage changes of the hazard rate. A positive (negative) percentage indicates that a unit change in the independent variable increases (decreases) the hazard rate (risk to become protestant) by that percentage. Large effects are presented as hazard ratios, which is the risk to become protestant divided by the risk to remain catholic. We read the hazard ratios as: 'A one unit change in the independent variable makes territories X times more likely to become protestant.', where X is the hazard ratio.

The numbers in brackets correspond to the standard errors of the estimated effects, which are used to infer the significance level of the effect, which is indicated by the number of stars. The more stars an effect has, the smaller the probability to make a type I error, i.e., to falsely infer that the corresponding independent variable has an effect on the risk to become protestant, when in reality it does not have an effect. The smaller this probability, the more certain we are that our observed effect is likely to be real rather than random.

3.1 Historiographical model

The first column in Table 1 shows the results for the historiographical model, i.e., the model without neighbourhood effects which tests the originally proposed historiographical factors.

Four out of the eight tested independent variables are significant at the 0.05 or 0.01 level, which means that we infer that their effect is different from random. We see that `monasteries` has a negative effect on the chance of a territory to become protestant. Precisely, every additional monastery in a territory decreases the territory's chance to become protestant by 2.74%. This finding supports hypothesis 1.

Looking at `relPower`, we see that if a territory increases its power in its neighbourhood by one rank, it is on average 2.53 times more likely to become protestant than to remain catholic. This indicates that territories, which are powerful relative to their neighbours, have a higher chance to become protestant than weak territories. This finding supports hypothesis 2. Interestingly, more power drives the adoption of Protestantism only locally in the neighbourhood of the territory, but not globally in the whole Holy Roman Empire. As the non-significant effect of `absPower` shows, the model does not provide sufficient evidence to claim that the global power rank of a territory affects its adoption of Protestantism.

Next, we look at the influence of top reformers. Each letter that a reformer sends to a territory increases the territory's risk to become protestant by 0.95% on average. This effect scales up as the number of letters increases: For every 10, 20, and 50 additional sent letters, the hazard increases by 9.97%, 20.92%, and 60.80%, respectively. In contrast, visits of reformers do not seem to affect the adoption of Protestantism, since the corresponding coefficient is close to zero. These results indicate that letters were a more powerful tool than physical visits to convince the territorial ruler and his subjects to adopt Protestantism. This may be because letters could be passed on, especially with the printing press, so ideas of reformers could spread faster than if reformers visited one place at a time.

Last, `uni` has a positive effect on the adoption of Protestantism. For every additional university in a territory, the chance of that territory to become protestant increases by 65.20%. This finding supports hypothesis 5. The result indicates that universities acted as places of idea exchange, which encouraged the spread of new protestant thoughts.

We now consider the remaining non-significant effects. The sign of the effects of `dynasty` supports the corresponding hypothesis 3: the more members of a dynasty have become protestant, the more likely remaining members are to become protestant. However, since this effect is non-significant, we lack evidence to distinguish it from random. The negative coefficient of `print` indicates that additional printing presses in a territory decrease its risk to become protestant. However, since the effect is non-significant, we have no evidence to distinguish the effect from a random pattern. Hence, we will not interpret the effect further. Since the negative sign of the `print` effect contradicts our hypothesis 5, we conclude that the effect points to gaps in the data set which could be addressed in future work.

In summary, testing the historiographical factors alone without neighbourhood effect revealed that the historiographical theory is supported to some extent. Each of the five tested theoretical factors included at least one independent variable where the sign of the coefficient supported the proposed hypothesis. However, four out of the eight tested independent variables could not be distinguished from random (`absPower`, `dynasty`, `visits`, `print`).

3.2 Neighbourhood model

Results change once we combine the historiographical factors with neighbourhood relations, as shown in the second column of Table 1. First, we notice that the effect size of four out of the previously tested eight independent variables decreases in comparison with the ones from the historiographical model in column one. Second, the added variable `switchedNeighbours` has a large positive significant effect, which supports hypothesis 6. This indicates that territories are more likely to become protestant the more of their neighbours have already become protestant *and* the more recent these neighbouring switches occurred. The effect size means that if all neighbours of a territory have become protestant in the previous year, that territory is on average 29.85 times more likely to become protestant than if none of its neighbours had become protestant.

The two changes between the historiographical and the neighbourhood model indicate that the added `switchedNeighbours` effect accounts for most of the explained variance in the dependent variable that was previously explained by the historiographic variables. That is, the `switchedNeighbours` effect 'steals' explanatory power from the other variables, because it explains the risk to become protestant better than the other variables. This finding is crucial because it indicates how important geopolitical relations and the accompanying information transfer between territories were during the Reformation. This finding implies that understanding why territories became protestant requires us to study territories together rather than in isolation.

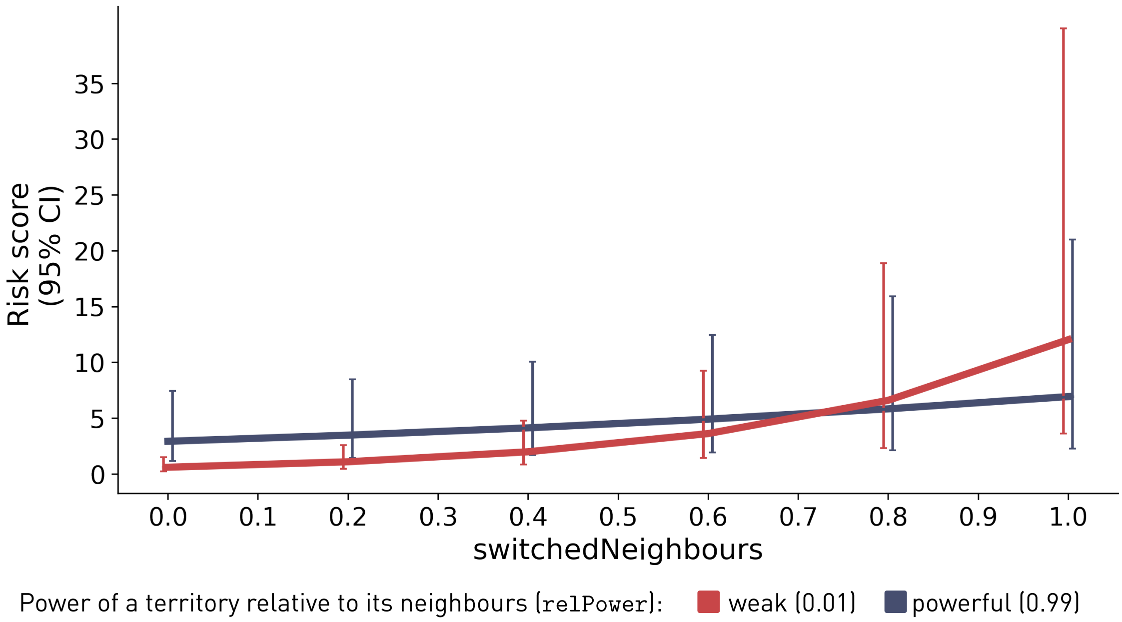

Figure 5: Interaction effect of the fraction of switched neighbours (x-axis) and local power (colours) on the adoption of Protestantism (y-axis). Weak territories (red) are more likely to become protestant than powerful territories (blue) if a large fraction of their neighbours has already switched in the past. The overlapping confidence intervals indicate that the effect between representatives of weak (`relPower` = 0.01) and powerful (`relPower` = 0.99) territories is not as large as the average interaction effect in Table 1 may suggest. For this plot only territories with neighbours were included in the model (see Appendix D.1 Table 3 column 3).

We can further differentiate the explanation behind the neighbourhood effect (`switchedNeighbours`) by building on the effect of local power relations (`relPower`). In the historiographical model, we saw that locally powerful territories are more likely to become protestant than locally weak territories. In the neighbourhood model this effect is even stronger.

How do these local power relations relate to the neighbourhood effect? To answer this question, we examine the interaction effect `switchedNeighbours:relPower`. This effect captures how the adoption of Protestantism is affected by neighbouring switches and local power relations together. We remind ourselves that the independent variable `switchedNeighbours` captures the fraction of neighbours of a territory that have become protestant in the past. This variable is time-weighted, meaning that recent neighbour switches count more than switches in the distant past. `relPower` captures how powerful a territory's rule title is relative to its neighbours. Appendix A provides a detailed description on the operationalisation of independent variables.

The coefficient for `switchedNeighbours:relPower` in Table 1 shows that if all neighbours of a territory became protestant in the previous year, and the territory increased from the lowest to the largest power rank relative to its neighbours (i.e., became more powerful), the risk of the territory to become protestant decreases by 94.95% on average. This means that locally powerful territories benefit less from neighbouring switches than weak territories.

Figure 5 examines this effect in detail. It shows the effect of `switchedNeighbours` (x-axis) on the risk score (y-axis) for different levels of `relPower` corresponding to weak and powerful territories (colour). Large x-values indicate that a large fraction of neighbours has switched to Protestantism and that these switches occurred recently. Large y-values indicate that the probability of a territory to become protestant increases sharply. The red and blue lines corresponds to specific groups of weak and strong territories, respectively, namely those with `relPower`= 0.01 and `relPower`= 0.99.

We see that the red line is steeper than the blue line, which is almost flat. This finding matches the interaction effect in Table **??**: Weak territories are more likely to become protestant once many of their neighbours have switched, whereas powerful territories become protestant independent of the number of switched neighbours.

However, it is important to remember that the interaction effect in Table 1 is an average effect. That is, the effect on the adoption of Protestantism is averaged over all increases of `switchedNeighbours` and `relPower` in the data. In contrast the effect in Figure 5 only compares one increase in `relPower`: the one from 0.01 to 0.99. We find that the confidence intervals (errorbars) of both `relPower` values overlap. This indicates that these specific groups of weak and powerful territories do not differ as much in their switch pattern as the significant average effect might suggest. We conclude that there is a tendency for difference, rather than a clear separation, between weak and powerful territories in how they are affected by switched neighbours.

Table 2: Cox estimates for first switch of territories from Catholicism to Protestantism. Comparison of histographical theory without and with network effects

	Luther	Philip of Hesse
Catholic resistance		
monasteries	−1.70% (0.0151)	−0.69% (0.0133)
Power relations		
absPower	−3.22% (0.0477)	−3.27% (0.0480)
relPower	6.24 (0.4435)***	6.38 (0.4460)***
Dynastic relations		
dynasty	11.94% (0.7895)	20.17% (0.7885)
Character of subjects		
uni	37.15% (0.2905)	19.33% (0.2932)
print	4.45% (0.2248)	15.30% (0.2201)
Neighbourhood		
switchedNeighbours	30.26 (0.5435)***	27.26 (0.5477)***
switchedNeighbours:relPower	−94.76% (0.8082)***	−93.30% (0.8002)***
Controls		
lifetime	0.01% (0.0004)	0% (0.0004)
Top reformers		
visits Luther	−0.01% (0.0004)	
letters Luther	2.30% (0.0102)**	
visits Philipp of Hesse		0.32% (0.0022)
letters Philipp of Hesse		12.89% (0.0668)*
McFadden pseudo-R^2	0.040	0.040
Num. events	192	192
Num. obs.	22666	22666
Missings	0	0

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

3.3 The example of Philip of Hesse

So far, we have examined the influence of top reformers as combined measures aggregated over all reformers in our data. Since we expect reformers to differ in their influence they exert on territories, we now differentiate `visits` and `letters` between individuals. We are specifically interested in the differences between members of the clergy and princes because these groups can be used to respectively account for the 'bottom-up' and 'top-down' perspectives of the Reformation in our model, a dichotomy that was originally developed to explain the Reformation in England [33]. The bottom-up Reformation corresponds to the perspective that the adoption of Protestantism was driven by the subjects and laypeople [14]. They saw the Reformation as an opportunity to become more independent from their territorial ruler and gain more self-determination in practicing their faith. In contrast, the perspective of the top-down Reformation states that princes drove the adoption of Protestantism as political strategy to become more independent from Imperial and Church rule [22].

To represent the bottom-up perspective in our model, we include the visits and letters of the reformer Martin Luther. For the top-down perspective, we include these measures for Philip of Hesse, the prince ruling over the landgraviate Hesse. We chose Luther because, as university lecturer, he had a lot of contact to students who could then spread the Reformation in a bottom-up manner. Luther recruited students as messengers who would spread reformist ideas among the population [30]. We chose Philip of Hesse because he was one of the most dedicated rulers in terms of pushing for the Reformation. He was one of the founders of the Schmalkaldic League and became one of its most important leaders.

Table 2 shows the models for Luther and Philip of Hesse in columns one and two, respectively. Like the combined `letters` of the historiographical and neighbourhood models, the individual `letters` of Luther and Philip of Hessen are also positive significant. This indicates that the letters, the two individuals sent to territories, increased the chance that these territories would become protestant. Especially, the effect of the letters of Philip of Hesse is large. Whereas every letter Luther wrote increases the hazard rate by only 2.30%, every letter of Philip of Hesse increases the hazard rate by 12.89%. Similar to the historiographical and neighbourhood models, `visits` does not affect the adoption of Protestantism, as the non-significant and small coefficients show. In summary, these findings indicate that Philip of Hesse contributed more to the adoption of Protestantism in territories than Luther. This gently points towards the top-down perspective of the Reformation. However, to draw stronger conclusions more than two individuals would have to be examined.

4 Discussion

4.1 Links to hypotheses

In this paper, we examined why territories of the HRE adopted Protestantism. The starting point of our analysis was a set of theoretical factors proposed by historiographical research that are assumed to be relevant for the adoption of Protestantism [49]. We translated each of these factors into quantifiable measures and statistically tested to what extent they influence whether and when territories became protestant.

If we restrict ourselves only to the proposed historiographical factors, our model shows that local power relations and reformers were the main factors affecting the adoption of Protestantism. However, when we additionally include geographic neighborhood relations in our model, we find that these neighborhood relations accounted for the largest effect, whereas the effect of many other driving factors became smaller. The finding that neighborhood relations are most important in explaining the adoption of Protestantism supports our hypothesis 6. Succinctly, to understand the adoption of Protestantism, interdependencies between territories should be taken into account rather than analysing territories in isolation.

We further find from our model a positive effect of local power relations. This indicates that territories, that were locally powerful relative to their direct geographic neighbours, were more likely to become protestant than locally weak territories. In contrast, global power relations did not show an effect in our model. This outcome highlights the importance of local structures for the spread of ideas in 16th century Europe, a finding which has also been discussed for trade relations [19]. This supports our hypothesis 2.

Looking at the effect of reformers, our analysis suggests that reformers mainly promoted the adoption of Protestantism via the letters they sent to territories and not via their physical visits. This supports our hypothesis 4. Since letters can be reprinted and passed on, using them to spread ideas is more scalable compared to personal visits, where an individual can only transmit ideas at a specific location and time.

4.2 Reflections of impact of reformers and rulers

When distinguishing between the letters of Martin Luther, as an exemplary reformer, and landgrave Philip of Hesse, an exemplary prince, we find that the letters of Philip had a larger effect on the adoption of Protestantism. This finding may point to a prominent role of territorial rulers for the Reformation. It is in line with historiographical research claiming that 'characteristics of the ruler' affected the adoption of Protestantism [49], a theoretical factor we did not explicitly operationalise due to a lack of data.

We can explain the strong role of the ruler in two ways. On the one hand, it may be due to the ruler's personal conviction about reformist ideas. For example, John Frederik I of Saxony was known for being deeply convinced about the ideological truth of the Reformation. On the other hand, rulers may have supported the Reformation for personal convenience. For example, Philip of Hesse turned to theologians when the Catholic Church forbid him to marry a second wife. Capturing the role of the ruler, let alone disentangling conviction from convenience, is difficult with the current setup of the analysis [10].

Importantly, our results do not suggest that Philip's letters were per se more influential than the ones of Luther. The difference between Philip and Luther, in terms of their letters, rather reflects the different societal positions of the two men. Philip, as ruler, had access to key societal figures and, with the help of personal secretaries, could increase the reach of his messages. Luther, in contrast, did not have these amenities. So the effect of letters rather illustrates the influence of a position in society or a life situation than the ability to write persuasively. Moreover, influence is of course a multifaceted concept not only captured by letters. Personal conversations were probably the most common way to convey messages in the 16th century, and rulers like Philip had additional means to exert influence, such as allowing himself mounted messengers or attending imperial diets. Due to a lack of data, these aspects of influence were not operationalised.

To consolidate our result of the strong role of the rulers, a more systematic comparison between reformers and rulers should be conducted in the future that compares several representatives of reformers and princes.

4.3 Reflections on neighbourhood relations

Our analysis reveals that geographic neighbourhood relations between territories are the most important variable to explain the adoption of Protestantism. The more neighbours had become protestant in the recent past, the more likely is a territory to become protestant at present. This supports our hypothesis 6. In combination with relative local power, the results showed that mainly weak territories profited from neighbourhood effects. Once strong neighbours had become protestant, weak territories were more likely to adopt Protestantism.

Adopting Protestantism was especially risky for weak territories because they were not prepared to offer resistance against a potential military intervention of imperial troops. This risk was reduced once powerful neighbours of these weak territories had already adopted Protestantism. Our geographic neighbourhood effect therefore captures a strategic neighbourhood alliance between strong and weak neighbours. This finding may be caused by the vague legal setting in the HRE about the adoption of Protestantism. The stance of the emperor towards Protestantism was often ambiguous making it difficult for rulers to assess how adoptions of Protestantism would be handled in practice. [7] The legal situation was only clarified in 1555, when the Peace of Augsburg permitted rulers to choose the confession for their subjects.

Our finding is in line with Cantoni [10], although he operationalised neighbourhood effects differently, namely as the direct distance between each territory and Wittenberg. This resulted in a Luther-focused view of the Reformation where Protestantism spread in concentric circles around Ernestine Saxony. In contrast, our analysis provides an alternative explanation showing that local neighbourhood relations rather than central dependencies to Wittenberg affect the adoption of Protestantism. Since our analysis also includes Calvinist territories (e.g. Dutch provinces) and Reformed ones (e.g., Swiss kantons), and those which adopted Protestantism before Ernestine Saxony (e.g., Zürich (1519), Reutlingen (1519), Basel bishopric (1521)[8]), we loosen the Lutheran-focus and provide a more holistic view of the Reformation.

As Cantoni [10] already noted, the neighbourhood effect could also be explained by spill-overs where protestant ideas diffuse to neighbouring territories via trade routes. However, if spill-overs were the true underlying mechanism, weaker and stronger ter-

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[7] In 1521, emperor Charles V. had condemned Luther and Protestantism in the Edict of Worms. However, at the Imperial Diet of Speyer in 1526, Charles temporarily granted princes greater confessional freedom until an official church council would settle the confessional conflict. Princes were given the vague recommendation to behave in religious matters ‘as they may hope and trust to answer before God and his Majesty’. Since the promised council did not come about, uncertainty increased. At the Peace of Frankfurt in 1533, Charles suspended the Edict of Worms and stopped all trials against protestants at the Imperial Chamber Court (Reichskammergericht). However, in 1546 and 1547, Charles suppressed protestants again. He defeated their troops in the Schmalkaldic war and tried to force them to sign the Augsburg Interim in 1549, a compromise creed aiming to reunify the churches.

[8] In these years, the sermon included protestant elements. However, many catholic elements continued to exist. For example, mass had not been abolished, the cult of saints was still practiced, and a protestant church ordinance had not been adopted. These ambiguities show that nailing down the adoption of Protestantism to one date is difficult.

ritories would adopt Protestantism to the same extent, provided that they have the same amount of trade connections with their neighbours. But this is not supported in the analysis. Therefore, because Cantoni and we find that weaker territories profit more from neighbourhood effects, there is evidence that strategic alliances rather than spill-overs account for the underlying mechanism of the adoption of Protestantism.

4.4 Reflections on our operationalisation

Statistical models require concrete measures. Therefore, we have to operationalise abstract concepts, such as political power or neighbourhood relations. We do not claim that our operationalisation is the only or even the *optimal* one. Instead, we demonstrate in our paper that it is a *possible* one, leading to interpretable results. Other ways to measure influences on the adoption of Protestantism may exist or will be developed in the future as more data become available.

One criticism may regard the way we have *selected* our independent variables. Our operationalisation is restricted by available theories and data, and indeed we have taken the relevant driving factors for our analysis from historiographical research [49]. There is neither a need nor a justification to spoil this analysis with unfounded factors, because including them in statistical analyses can bias the results [24]. Once theories about the adoption of Protestantisms change, our selection of operationalised concepts will, too.

Another criticism may point out that our measures are *incomplete*. For example, bad harvests may have affected the adoption of Protestantism but are not part of our analysis. A third criticism may find that our measures are *insufficient*, because they are only rough proxies rather than adequate representations of the underlying abstract concepts. For instance, catholic resistance was more complex than the number of monastery ruins that have survived until today suggests. Some monasteries may have been dissolved even before the Reformation or have been instrumental in starting the Reformation, as was Martin Luther's Wittenberg Augustinian monastery.

Further, subjective factors, such as the characteristics of the ruler, are difficult to measure and therefore had to be left out from our quantitative analysis. Measuring political power by means of a ranking of titles also poses a problem. The Elector of Trier was not as powerful as Landgrave Philip of Hesse, even if the title suggests a greater importance in the empire. Further, territories in the 16th century were not a homogenous dominion, as proxied by polygons, but a heterogenous one.

Criticism of this kind applies to all forms of operationalisation, because all of them have to select a subset of abstract concepts and to simplify them. Data availability always biases the analysis. We can imagine better ways to proxy our variables, but putting these ideas into practice is often thwarted because of the amount and quality of available data. We propose to turn this discussion around, pointing to the fact how much was achieved *despite* these obvious limitations.

4.5 Reflections on our modeling approach

A famous aphorism in statistics says: "All models are wrong, but some are useful." The usefulness of our model lies in the disclosure of large adoption patterns of Protestantism across 262 territories of the HRE. Only their simultaneous study could reveal the impact of their political and spatial relations on their denominational choice.

In summary, our analysis supports, in a quantitative manner, arguments *why* these territories adopted Protestantism. We showed that strategic alliances between neighbouring territories explain this adoption best. Weaker neighbors are more likely to adopt Protestantism once more powerful neighbors have done so. Our model has not only shown, but *quantified* the great influence of geographical proximity on the introduction of the Reformation. Our findings suggest that territories were *inter*dependent in their decision to adopt Protestantism. Therefore, to better capture these interdependencies, territories should not be studied in isolation but together.

Our paper makes a methodological contribution to identify, quantify and weight some of the causing factors behind the adoption of Protestantism. We do not claim that our analysis reflects all historical details of the Reformation. We claim quite the opposite: We can achieve reasonable insights about the importance of certain factors without accounting for all of these details. Taking the example of our novel, yet simplified, spatial representation of territories, our results demonstrate that essential characteristics of spatial dependencies are still captured and insightful interpretations are possible. Our most important result remains largely unaffected by such methodological issues.

The Reformation is among the best studied subjects in historical and theological sciences. It is not only the widespread and long lasting impact of the reformatory ideas that transformed whole societies, which makes the Reformation a prime research target. Also its intertwined theological, religious, political, social and economic causes have to be investigated and possibly disentangled, to better understand the Reformation. Our study elucidates possibilities and problems of quantitative methods for researching the history of the Reformation. As demonstrated, statistical models make abstract concepts behind the adoption of Protestantism quantifiable. Rather than decreasing the quality of the analysis, the statistical perspective allows us to capture the *systemic* aspects of the Reformation. To do justice to our approach, we frame the methodological discussion more generally. Social, political or economic phenomena can be studied under different perspectives, regarding their *causes* and regarding their *dynamics*. The *Why?* and the *How?* question are not mutually exclusive - in fact they can enlighten each other, as long as we understand that they serve *different* purposes and give *different* answers. Thus, knowing why some developments happened by no means already explains how they occurred, and the other way round. It is completely legitimate to address these two questions separately, with different methodologies.

Our contribution in this paper regards the *causes* that lead some territories to adopt protestantism and others not. As we pointed out in detail above, these causes have been discussed in the literature for long. The aim of our paper was not to extent the list of such driving factors, but to operationalise them and to quantify their impact in a statistical model. We are not arguing about evidence, but about importance. We do not theorise, but assign weights to existing arguments. This is a necessary step forward in building new models that shall capture the systemic *dynamics* in a quantitative manner. Such models have to use our weighted driving factors as an *input*, to further develop the process perspective on the Reformation, discussed in the Introduction.

We see our analysis as a next step towards better understanding the adoption of Protestantism. Future studies are encouraged to extend our methods and test them in other settings, possibly accounting for more complex spatial relations between territories and their impact on political decisions. Our findings can provide an impetus for further research. It pleas for a greater role of spatial factors and, in particular, neighborhood relations during the Reformation, which should be explored in more detail.

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Appendices

A Operationalisation of theoretical characteristics of territories

To test our hypotheses, we translate selected qualitative characteristics of territories into quantifiable measures that can later be used as independent variables in a statistical model.

Resistance of catholic forces from within the territory. We use the number of monasteries in a territory to operationalise the resistance of catholic forces. Since monasteries in the HRE were all founded by devout catholics and often had political influence, they predominantly rejected the Reformation and offered resistance. We assume that cases where monasteries converted to Protestantism or were incorporated into secular possessions represent exceptions from the norm. The number of monasteries is a time-fixed variable. We crawl the number of monasteries from OpenStrettMap.

Operationalising catholic resistance with the number of monastery ruins does not capture the historical complexity of that concept. Catholic forces acted through multiple means and monasteries were just one of them. However, since data is restricted we cannot capture catholic resistance in its full complexity.

Political power of territories. We use the official rule titles of the territories to operationalise political power. Examples for rule titles are duchy, principality, and county. The rule titles in the 16th century were hierarchically ordered. Each title was associated with specific rights and duties. For example, territorial rulers of electorates were allowed to elect the emperor. Imperial cities were allowed to have their own judiciary rather than being subject to the one of the emperor, but they still had to pay him taxes. Free cities were in the reversed position: dependent on the judiciary of the emperor but free from imperial taxes[9]. Since rule titles changed frequently as

[9] Free cities still had to pay taxes to their territorial lords, especially to bishops.

a result of wars, marriage, and the division of the estate, we use political power as a time-dependent variable. Moreover, since precise hierarchical differences between rule titles are case-specific and often unknown, we capture hierarchical relations between rule titles by ranks and use political power as an ordinary variable. Appendix B shows our mapping from rule titles to ranks. Higher ranks indicate more power.

We use two versions of political power: absolute and relative local power. Absolute power corresponds to the rank of the rule title among all possible rule titles in the Holy Roman Empire. This ranking corresponds to the one in Appendix B. For example, an electorate has an absolute power of 11 whereas a county has an absolute power of 5. Relative local power corresponds to the relative rank of the rule title among the rule titles of a territory's neighbours. For example, if a duchy is surrounded by a bishoric, a free city, and a bailwick, the corresponding local ranks are: 4 (bishopric), 3 (free city), 2 (duchy), and 1 (bailwick). We normalise the local rank of the duchy by the number of its neighbours (4, including the duchy itself), which results in the relative local rank of the duchy 2/4 = 0.5. This number indicates how powerful the duchy is in its neighbourhood. The relative rank is called the relative local power. It is a time-dependent variable because rule titles and neighbourhoods changed over time.

Operationalising power by rule titles is not without issues, since titles not always reflect the power relations between rulers. For example, the Elector of Trier was not as powerful as Landgrave Philip of Hesse, even if the title suggests a greater importance in the empire. Due to a lack of data, we cannot opertaionalise power relations in a more complex way. We assume that for the majority of rulers, their titles are indicative of their power.

Dynastic relations. We group territories if they are members of the same dynasty. For example, the territories Anhalt-Bernburg, Anhalt-Dessau, Anhalt-Köthen, and Anhalt-Zerbst all belong to the dynasty of Anhalt. To operationalise dynastic relations of a focal territory, we aggregate past switches to Protestantism of members from the same dynasty and track them over time. Specifically, we compute a time-weighted proportion of switched dynastic members, because members that remained catholic also influenced others in their dynasty.

We compute the proportion of

We time-weigh this variable, meaning that the more time passes the smaller the weight of a switch of a dynastic member.

Figure 6 illustrates this operationalisation with the example of the focal territory Anhalt-Zerbst. Anhalt-Zerbst switched in 1537 and we start to track its history in 1500 (as we do for all territories). For every year of this history, we check whether other territories of the Anhalt dynasty have switched. This is the case for Anhalt-Bernburg in 1521 and Anhalt-Dessau in 1534. The weight of these switches over time is represented by the green bars. Dark shading indicates that the switch has a large weight, whereas bright shading indicates a weak weight.

As the transition from dark to bright shading indicates, we assume that, as more time passes after the switches, their weight decreases. Specifically, we use an exponential decay function with a half-life of 15 years to weigh previous switches over time. A half-life of 15 years corresponds to the time of a generation indicating that the effect of a switch halves every 15 years. The initial value of the weight of the switch is set to one, i.e., in the year of the switch. The sum of the effects of the switches of Anhalt-Bernburg and Anhalt-Dessau corresponds to the operationalised dynastic relation of Anhalt-Zerbst, which is represented by the red bar. The last member of the Anhalt dynasty, Anhalt-Köthen always remained catholic and ceased to exist in 1509. It does not contribute to the red bar of Anhalt-Zerbst.

In summary, the dynastic relation of a focal territory measures the weight of past switches of territories from the same dynasty as the focal territory. It represents a time-dependent variable.

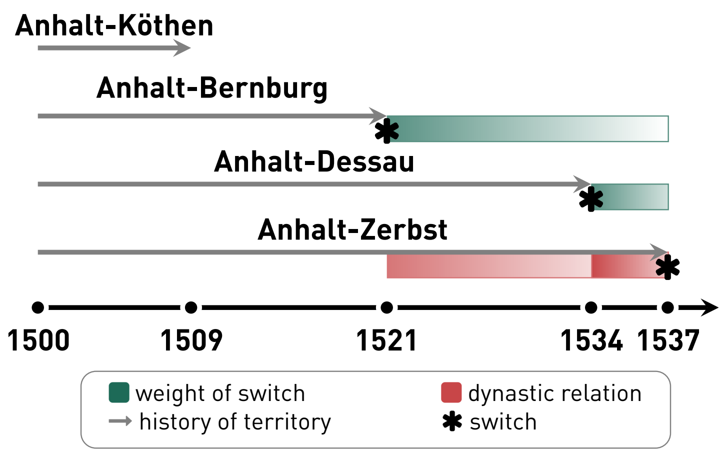


Figure 6: Operationalising dynastic relations of the territory Anhalt-Zerbst.

Influence of 'top' reformers. We operationalise the influence of top reformers in two ways: The time-weighted number of days reformers spent in a territory, and the time-weighted number of letters reformers sent to a territory. Like for the dynasty variable, time-weighting is done with an exponential decay function. The more time passes the smaller the weight of a visit or a letter.

Figure 7 illustrates the operationalisation for the `visits` variable in the territory Ernestine Saxony. For space reasons, only some physical visits of Martin Luther are shown. We start to track the history of Ernestine Saxony in 1500. In 1525, Ernestine Saxony became protestant, so we end to track its history in that year. For every year in this period, we track the number of days reformers spent in Ernestine Saxony. For example, we see that Luther spent 250 days in 1516, 343 days in 1522, and 365 days in 1524. These numbers are computed from the sending and receiving locations and sending dates of Luther's letters in our data. These numbers only approximate Luther's real stays, because of unobserved letters and flawed meta-data.

We assign each of Luther's visited days a weight of one in the year the visit occurred. As time passes, this weight decreases according to an exponential decay function with a half-life of 15 years. So depending on the number of days a visit comprises and the time when the visit started, visits can exert different strengths on the risk of Ernestine Saxony to become protestant. In Figure 7, the weights of the three exemplary visits of Luther are indicated by the shading of the green bars.

By combining the colour bars of all visits of all reformers over time, we compute the `visits` variable of all reformers on Ernestine Saxony. If we combine the exemplary visits of Luther in Figure 7, we see that `visits` is largest in 1524, because the weight of three visits of Luther is combined. The weight in 1521 is weak because no new visits are conducted and the strength of the previous visit, which happened in 1516, has already weakened.

This example can easily be mapped to `letters` by replacing days spent in a territory per year with the number of letters sent to a territory per year. Like before, weighting by time was achieved with an exponential decay function using a half-life of 15 years. The independent variables `visits` and `letters` are time-dependent.

In reality, the influence of a person is more complex than captured by the number of sent letters and the number of days spent at a place. The content of personal conversations, societal standing, and other factors may have also contributed to the person's influence. However, since we lack data to operationalise these factors, we rely on letters and the duration of visits.

Closeness to the emperor. Since we lack data to measure a territorial ruler's closeness to the emperor, we do not operationalise this factor and exclude it from the ana-

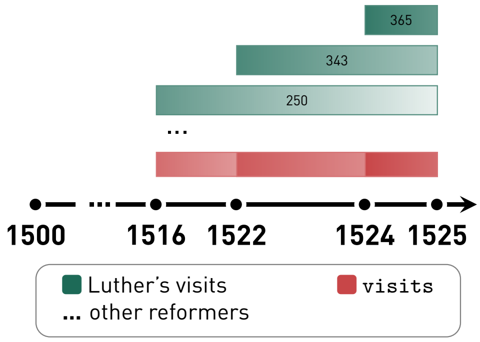


Figure 7: Operationalising physical influence of reformers for Ernestine Saxony.

lysis. A first idea may have been to capture it via the membership of rulers in protestant and catholic alliances. For example, the Schmalkaldic League was an alliances of protestant princes whereas the Catholic League (also called League of Dessau) was one of catholic princes, including the emperor himself. Since the emperor Charles V. strongly opposed the Schmalkaldic League and defeated it in the Schmalkaldic war in 1547, one may assume these alliances to represent ideological closeness to the emperor.

However, since membership in the Schmalkaldic League required the acceptance of the protestant Confessio Augustana, all Schmalkaldic members were in fact supporting Protestantism before joining the League. So the adoption of Protestantism drove membership of the Schmalkaldic League, rather than the other way round. Thus, including membership in the Schmalkaldic League as independent variable would lead to reverse causality in our model, which is why we dropped this operationalisation and excluded the factor 'closeness to the emperor' from the analysis.

Characteristics of the ruler. Since we do not have data about the character traits of territorial rulers, let alone about their names, we do not operationalise this factor. However, we examine the role of rulers by looking at the example of the letters landgrave Philip of Hesse sent to territories.

Characteristics of the subjects. Since we do not have data on individual subjects, we proxy their character traits with population-specific measures. We focus on socio-economic measures because reformist ideas partially originated from discontent with the socio-economic situation and affected it in turn. For example, Luther criticized the trade of indulgences of the Catholic Church which he accused of squeezing money out of the laypeople. He encouraged laypeople to read the Bible themselves for which literacy had to increase in turn [5].

We proxy the socio-economic situation in the population with three main concepts proposed by Becker *et al.* [3], who studied the adoption of Protestantism in cities: literacy, economic potential and connectivity. We operationalise literacy by noting whether a territory had a university and whether it had a printing press. Universities were places where educated circles met to develop and discuss ideas and have been shown to contribute to the spread of the Reformation [21, 30]. Printing presses did not only facilitate the spread of ideas but also required people to be able to read the prints.

We operationalise the economic potential of a territory by the size of its population in 1500 and the growth rate of that population in the 15th century. A large population size and growth rate indicate that individuals were able to focus on aspects of life beyond feeding and shelter, such as questioning existing social hierarchies.

We operationalise the connectivity of a territory by its access to water ways and its market potential in the year 1500. The market potential of a city is its population size divided by the distance to the closest of the following cities: Mainz, Wittenberg, Zurich [42]. These variables indicate how well ideas could be exchanged which is an important factor for the spread of the Reformation. All of the described variables are time-fixed and are measured before the onset of the Reformation in 1517.

Neighbourhood relations. To operationalise neighbourhood relations, we aggregate the past switches of neighbouring territories. The corresponding independent variable is called `switchedNeighbours`. We track the neighbours of a focal territory from 1500 until it switched, or in case it never switched, until it ceased to exist. Once a neighbour switches, this switch gets a weight of one, which decreases over time, i.e., we time-weigh `switchedNeighbours`. Similar to `dynasty`, `visits`, and `letters`, this time-weighing is modeled with an exponential decay function with a half-life of 15 years. To measure the effect of all switched neighbours, we sum the individual weighted effects and divide this sum by the total number of neighbours. That is, the effect of neighbouring switches is operationalised as the time-weighted fraction of neighbours who have switched in the past. By using the fraction instead of the count of switched neighbours, we assume that catholic neighbours also influenced the decision of a territory to become protestant.

Figure 8 illustrates this operationalisation with the example of the focal territory Albertine Saxony. Albertine Saxony became protestant in 1546 and we start to track its history in 1500 (as for all territories). For every year of this period, we check whether some of its neighbours have switched (Fig. 9 shows the neighbourhood of Albertine Saxony on a map). Bohemia switched in 1520, Mansfeld and Ernestine Saxony in 1525, Schwar-

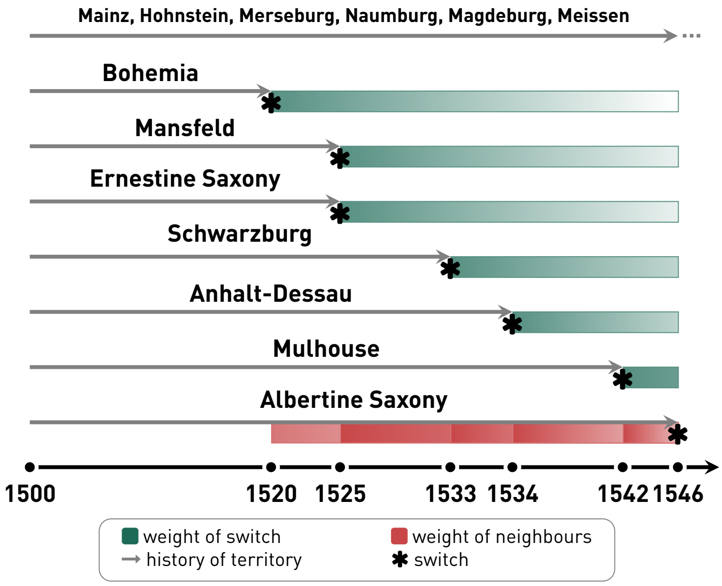


Figure 8: Operationalising fraction of switched neighbours of Albertine Saxony.

zburg in 1533, Anhalt-Dessau in 1534, and Mühlhausen in 1542. Moreover, there are two neighbours who always remained catholic (Mainz and Hohnstein), and four neighbours who became protestant after Albertine Saxony switched (Merseburg, Naumburg, Magdeburg, Meissen). The neighbour Anhalt-Köthen ceased to exist in 1509, i.e., before Albertine Saxony became protestant. So the total number of neighbours is 13 until 1509, and 12 for the time afterwards.

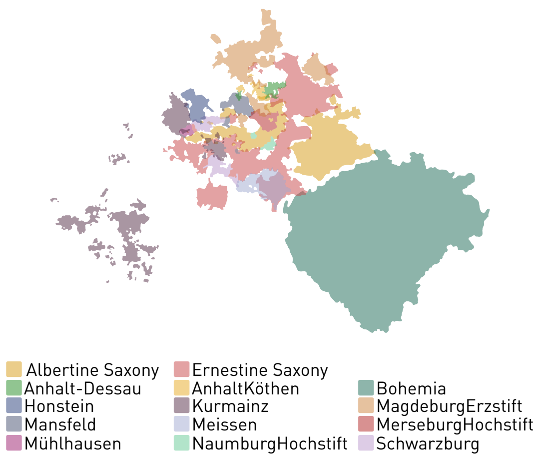


Figure 9: Albertine Saxony and its neighbours

Each of the neighbouring switches can potentially affect the risk of Albertine Saxony to become protestant with its weight. This weight is represented by the green bars below the neighbours' names. The transition from dark to bright shading indicates that the weight of a neighbouring switch becomes weaker over time. The red colorbar at the bottom combines the individual weights of the neighbours, including the catholic neighbours. The red colourbar represents the weight of all neighbouring switches on Albertine Saxony to become protestant. Its values are computed per year.

For example, consider the year 1525 by which three neighbours had become protestant: Bohemia, Mansfeld, and Ernestine Saxony. Since Bohemia had already switched in 1520, the weight of its switch has already decreased by 1525 and has a value of 0.79. Since Mansfeld and Ernestine Saxony switched in 1525, their weights have not decreased yet and have a value of one, respectively. To combine these three individual effects, they are added and divided by the total number of neighbours Albertine Saxony had in 1525, which is 12. This yields a combined effect of $(0.79 + 1 + 1)/12 = 0.232$ for the year 1525.

Since the number of neighbours of a territory changes over time and neighbours switch at different points in time, the effect of neighbouring switches is computed as a time-dependent variable.

Operationalising territories as polygons to identify neighbourhood relations, is of course a simplification of the historical situation. A territory was not a homogenous dominion, as proxied by polygons, but a heterogenous one. However, data on these heterogeneities is not available, which is why we simplify dominions to polygons.

B Ranking of rule titles

Based on an informed decision, we rank rule titles according to their power. Higher ranks indicate more power.

- Electorate: 11
- Imperial city: 10
- Free city: 10
- Free imperial city: 10
- Imperial castle: 10
- County of the empire: 10
- Imperial county: 10
- Reichsunmittelbarkeit: 10
- Archduchy: 9
- Kingdom: 9

- Duchy: 8
- Titular duchy: 8
- Principality: 7
- Bishopric: 7
- Imperial knights: 7
- Margraviate: 6
- Landgraviate: 6
- County: 5
- City: 5
- Lordship: 4
- Vest: 4
- Gemeine Herrschaft: 4
- Zugewandter Ort: 3
- Kanton: 3
- Bailiwick: 2
- French: 1

C Statistical model

To estimate the effect of the operationalised variables on the adoption of Protestantism in territories, we apply an Event History Model. These models check how the variable of interest, the risk of a territory to become protestant, changes in response to the characteristics of territories, and the time it takes territories to switch.

A widely used Event History Model is the Cox Proportional Hazards model [6, p. 47-68] [12]. It assumes that each independent variable has a constant effect over time. For example, a higher rule title will always increase the risk of a territory to become protestant. Since the Reformation was an especially volatile period, these constant time effects do not hold. We therefore modify the Cox Proportional Hazards Model by allowing the risk to become protestant to differ per year. That is, we stratify per year, leading to a Stratified Cox Model with constant event times. In the following, we discuss the terminology of Event History Models in detail, compare the Cox Proportional Hazards Model and the Stratified Cox Model with constant event times, and explain why we have to use the stratified model in our case.

Terminology. An Event History Model explains why territories became protestant in the first place. Becoming protestant is the *event* that a territory may or may not experience. The territories that experienced the event, i.e., became protestant, are called switch territories. Those that did not, i.e., always remained catholic, are called remained territories.

To keep the model tractable, we only consider the first switch from Catholicism to Protestantism of a territory. That is, a territory can experience one type of event only once, which is called a *single spell process*. However, in reality, many territories changed denominations several times, such as Electoral Palatinate becoming Lutheran in 1556, Calvinist in 1563, Lutheran again in 1576, Calvinist again in 1583, and after some changes in the context of the Thirty Years' War, catholic again in 1622 and afterwards (only authorities). So territories can switch several times and experience several types of switches (catholic-protestant, protestant-protestant, protestant-catholic). This results in a process of multiple events with multiple event types. Since no established event history model exists for this process, yet, we model the simpler single spell process [6].

The time between the founding year of a territory and the year in which it became protestant is called the *history* or *duration time*. For remained territories the duration time runs from their founding year until the year where they ceased to exist. The duration time represents the period in which the territories are at risk of becoming protestant. For each year of the duration time, the model splits territories into two groups: the event and the risk set. The *event set* contains territories which became protestant after that duration time. The *risk set* contains territories which are still catholic after that duration time, i.e., they are at risk of becoming protestant, but did not become protestant.

By comparing territories in the event and risk sets along the independent variables, the model computes the effect of these independent variables on the dependent variable, the risk of a territory to become protestant. This risk to experience the event is called the *hazard rate*. The hazard rate depends on the effect of the independent variables and the baseline hazard, which we explain below. If an independent variable has a positive effect on the hazard rate, territories are more likely to become protestant if they have large values of that independent variable. If an independent variable has a negative effect on the hazard rate, territories are less likely to become protestant if they have large values of that independent variable. The *baseline hazard* corresponds to the risk of a territory to become protestant given that all imaginable variables that may influence the hazard rate are set to zero. In our analysis, this may correspond to a territory without any ruler, subjects, monasteries, alliances, dynasty, reformers, and neighbours.

Cox Proportional Hazards Model. The Cox Proportional Hazards Model is one of the most widely used Event History Models. In this model, the precise nature of the baseline hazard is assumed to be unknown. That is, we only know *that* the baseline hazard changes over duration times but not *how* this function looks like. For example, a territory that has existed for ten years has a different baseline hazard than a territory that has existed for years years. But we do not know which function describes the increase/decrease of the baseline hazard from the ten years to the twenty years. Since the baseline hazard is unknown but the hazard rate depends on it, the Cox Proportional Hazards Model uses an additional assumption to infer the hazard rate: the *proportional hazards assumption*. It states that the hazard rate of territories to become protestant ($h(t)$) is proportional to their baseline hazard ($h_0(t)$), where t corresponds to the duration time. The proportionality factor is the effect size (β) of the tested independent variables ($\mathbf{x}$).

$$h(t) = h_0(t) exp(\beta \mathbf{x}) \tag{1}$$

where *exp* is an exponential function. As a consequence of this assumption, the effect of each independent variable on the hazard rate is constant over duration times.

The Cox Proportional Hazard Mode starts by grouping territories by duration times. The duration times run from 0, corresponding to the founding year of territories, to the maximum number of years a territory has existed. For each duration time, those territories are selected that have not become protestant at an earlier duration time. Figure 10 provides a detailed example for a duration time of 62 years. We see that the territories East Frisia and Holstein have become protestant after 62 years. They comprise the event set. Territories that are still catholic after 62 years comprise the risk set. For instance, Beuthen, Fribourg, and Lorrain are part of the risk set. We see that the risk set does not distinguish between territories which become protestant at a later point, i.e., after more than 62 years (e.g., Beuthen), and territories that always remain catholic (e.g., Fribourg, Lothringen). Moreover, we see that the model does not distinguish between years of the observation period. That is, although East Frisia (founding year: 1464) was founded in a different year than Beuthen (founding year: 1459) both territories are included for a duration time of 62 years because they had not become protestant beforehand.

By comparing territories of the event set with those from the risk set, the model infers the baseline hazard and the effect of the independent variables on the risk to become protestant. Figure 11 shows the result of these comparisons. For the baseline hazard, the values of all independent variables are set to zero across territories. As a

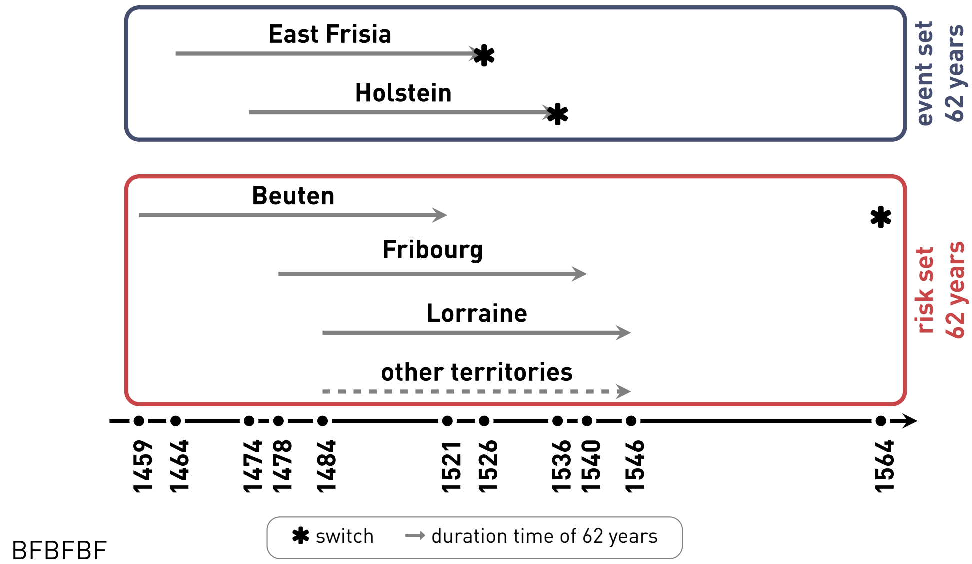


Figure 10: Schematic representation of the the Cox Proportional Hazard Model by means of selection of territories. The model computes the effect of the independent variables and the effect of the duration time on the risk to become protestant. The duration time covers the number of years a territory has existed until a certain point. For each duration time, an event set and a risk set of territories are constructed. The Figure shows the sets for a duration time of 62 years. The event set comprises all territories that became protestant after that duration time. The risk set comprises all territories that are still catholic after that duration time.

consequence, territories are only distinguishable by their denominational choice, but not by their values of absolute power, number of monasteries, and the other independent variables. For each duration time, the model compares the numbers of territories that became protestant after that time with those that still remained catholic. By aggregating the results of these comparisons across duration times, the model infers the baseline hazard. As Figure 11 shows, the baseline hazard varies across duration times. However, its precise functional form is unknown, as is illustrated by the dashed line.

To infer the effect of the independent variables, the model compares territories of the event set with those from the risk set along their values of the independent variables. This comparison is again conducted for each duration time. For example, for the independent variable absPower and scenario in Figure 10, the model would compare the ranks of the rule titles the territories have after 62 years. This results in a comparison of county (East Frisia) and duchy (Holstein) vs. duchy (Beuthen), free imperial city (Fribourg), and duchy (Lorraine). The model conducts this comparison across all duration times. The model then continues by comapring absPower of events and risk sets

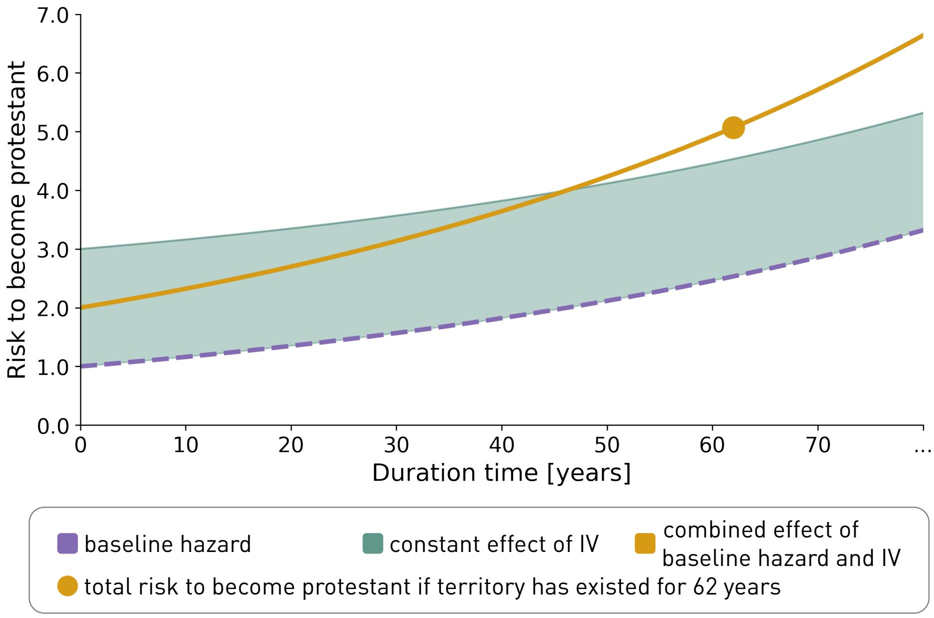


Figure 11: Schematic representation of the computations of a Cox Proportional Hazard Model. By comparing territories of the event set with those in the risk set, the model infers the baseline hazard, which is a function of the duration time, and the effect of the independent variables, which are independent of the duration time. By combining the two effects, the risk of a territory to become protestant is computed.

of other duration times and averages the results to yield the effect absPower has on the risk of a territory to become protestant. Due to the proportional hazard assumption, the effect of the independent variable is constant over duration times, which is why the green band in Figure 11 has the same height across duration times. Thus, differences in the hazard rate across duration times are not due to the independent variable but due to the baseline hazard.

As a final step, the model combines the baseline hazard and the effects of the independent variables to yield the total risk of a territory to become protestant, given the specific values of the duration time and the independent variables. This total risk corresponds to the yellow line in Figure 11. The yellow dot indicates the total risk for a duration time of 62 years.

Figure 11 shows that the Cox Proportional Hazards Model can make two types of inferences: estimate the effect of independent variables and the effect of duration times on the hazard rate. Mapped to the Reformation, this implies that we can for example infer how the number of monasteries affected the risk of territories to become protestant, and how the lifetime of a territory affected that risk.

However, the proportional hazards assumption poses problems in our data. Consider the independent variable `letters` as an example, which measures the effect of letters that reformers sent to a territory. The proportional hazards assumption would imply that for every N letters that Luther sends to a territory, the risk of that territory to become protestant increases by the same percentage across duration times. So whether a territory had existed for ten or twenty years: Luther's letters would always have the same effect on the hazard rate. This is unlikely to be the case since some territories were only founded shortly before or after Luther's death (1546) so his letters cannot have influenced the hazard equally across duration times. The intuition that our data violate the proportional hazards assumption is confirmed by statistically testing the assumption with a global test for the whole model [20, 23] and for each independent variable separately [23]. Because of this violation, applying a Cox Proportional Hazards Model to our data would yield invalid results and we have to look for an alternative solution.

Stratified Cox model with constant event times. To address the problem of the violated proportional hazards assumption, we modify the Cox Proportional Hazards Model by stratifying over time [2, 1] [6, p. 160]. This means that we separate our data points by year of the observation period, where each year is called a *stratum*. For each stratum j, we compute a separate baseline hazard, i.e., the risk to become protestant differs per year. To compute strata per year of the observation period rather than per year of the duration time (as we did in the Cox Proportional Hazard Model), we set the starting date of the duration time to 1500 for all territories.

$$h_j(t) = h_{0j}(t) exp(\beta \mathbf{x}) \tag{2}$$

For the Reformation, this modification is reasonable because political, economic, and natural events occurred at different points in time and are likely to have changed the risk to become protestant. For example, the defeat of the Schmalkaldic League in 1547 may have decreased the risk to become protestant compared to the official adoption of Lutheran faith by imperial cities at the Diet of Augsburg in 1530.

In contrast to the Cox Proportional Hazards Model, where we obtained one baseline hazard function defined over duration times, stratifying over time yields several baseline hazard functions, one per year. Like in the Cox Proportional Hazards Model, the effect of an independent variable is still constant, but now this effect is constant over the observation time and not over the duration time. Stratifying by year yields a *Stratified Cox model with constant event times*. For the remainder of this Appendix, we will refer to this model as Stratified Cox Model.

Since the baseline hazards in the Stratified Cox Model are no longer dependent on duration time, this model does not require the proportional hazard assumption to yield valid results. On the one hand, this is advantageous since our data violate the proportional hazards assumption, so the Stratified Cox Model allows us to compute valid estimates without this assumption. On the other hand, we lose inferential power on the timing of the switch to Protestantism. That is, we can no longer draw conclusions on how the risk to become protestant changes depending on how long a territory had already existed. For example, we cannot infer whether old territories, like the prince-bishopric Basel which was founded in 400, are more likely to become protestant than younger ones, like Pommern-Stettin which was founded in 1523. Since our theoretical factors do not make claims about the effect of territories' period of existence, the loss of inference of duration times does not negatively restrict our analysis. Our focus is on estimating the effect of independent variables on the risk to become protestant, which the Stratified Cox Model is able to do. To account for the lifetime of territories, we add it as control variable. As we saw in the results section, this variable does not have an effect on the risk to become protestant.

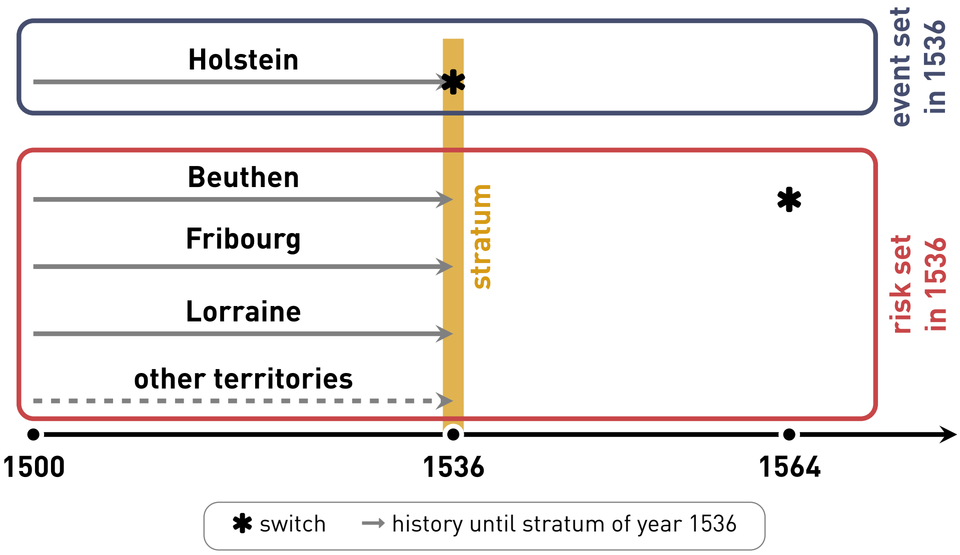


Figure 12: Schematic representation of the Stratified Cox Model by means of a selection of territories. The model computes the effect of the independent variables and the effect of the observation time on the risk to become protestant. For each year, an event set and a risk set of territories is constructed. The event set comprises all territories that became protestant in that year. The risk set comprises all territories that are still catholic in that year.

Figure 12 illustrates the Stratified Cox Model. It maps the example from Figure 10, where a Cox Proportional Hazards Model was used, to the time-stratified case. Rather than computing the hazard rate per duration time, we now compute it for each year of the observation period. Panel A shows this for the year 1536, which represents one stratum. The event set includes all territories that became protestant in 1536, which is only Holstein. The risk set includes all territories that are still catholic in 1536, such as Beuthen, Fribourg, Lorraine, and many more. Like in the Cox Proportional Hazard Model, the risk set does not distinguish between territories that never became protestant (e.g., Fribourg and Lorraine) and those that became protestant in a lter stratum (e.g., Beuthen). In contrast to Figure 10, East Frisia is excluded from this example because it already became protestant in 1521. So it can neither be part of the event set nor of the risk set of 1536. However, East Frisia was part of the event set for the stratum 1521 and part of the risk set in all strata earlier than 1521.

As for the Cox Proportional Hazards Model, the Stratified Cox Model compares territories in the event set with those in the risk set along their denominational decision and their values of an independent variable. These comparision yield the baseline hazard and the effect of the independent variables on the risk of the territories to become protestant.

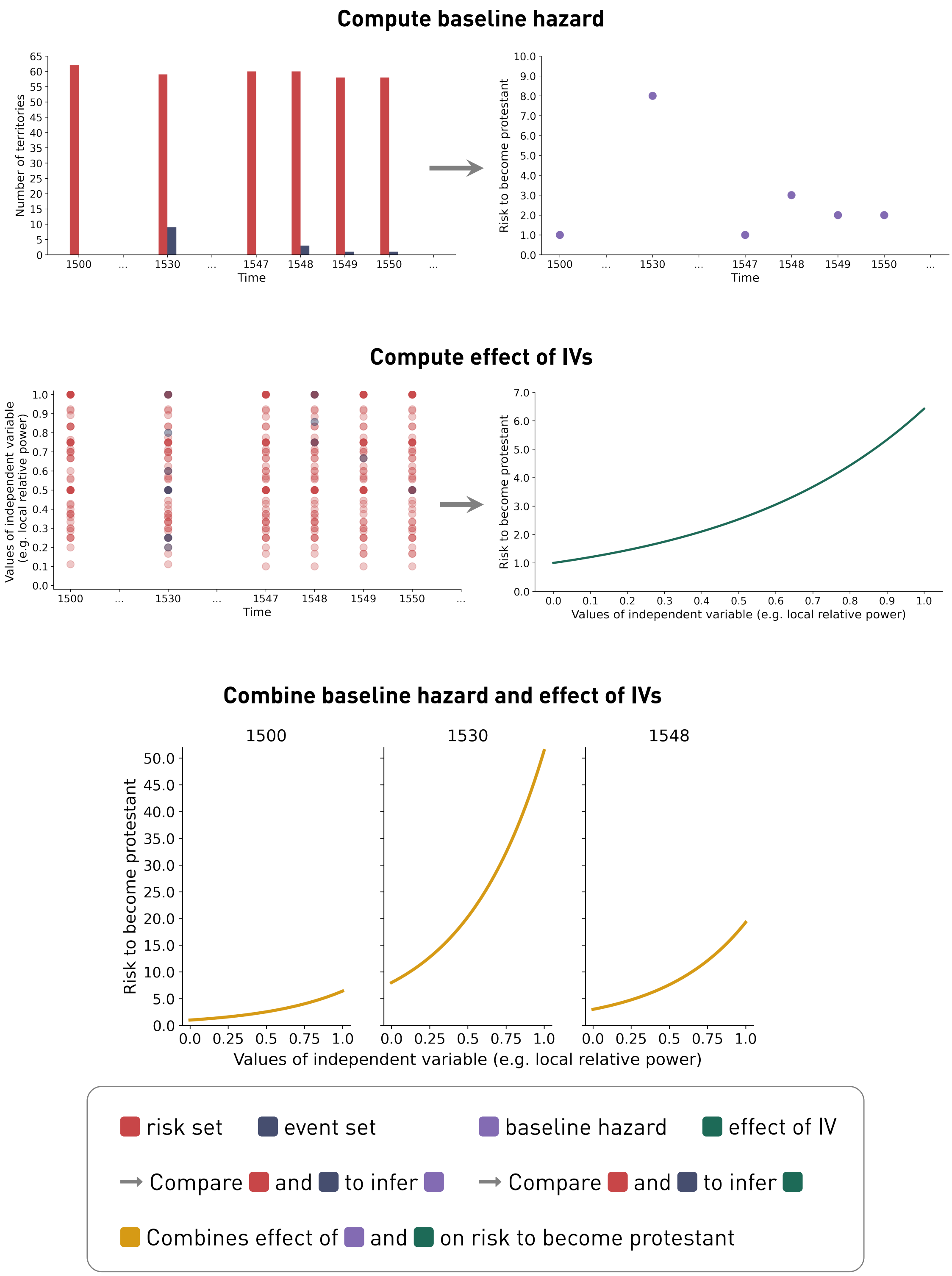


Figure 13: Schematic representation of the computations in the Stratified Cox Model The model computes the effect of the independent variables and the effect of the observation time on the risk to become protestant. By comparing territories of the event set with those in the risk set the model infers the baseline hazard, which depends on the observation time, and the effect of the independent variables, which is independent of the observation time. By combining the two effects, the risk of a territory to become protestant is computed.

Figure 13 shows how these comparisons are computed, using values from our data set. The bar chart in the top row plots the number of territories in the event and risk sets over the observation time. Using the ratios of these numbers per year, while ignoring the values of all independent variables, the model estimated the risk of territories to become protestant in a specific year, all other factors being zero. This is the baseline hazard shown by the purple dots in the graph on the right. For example, we see that the baseline hazard is higher in 1530 than in 1547. This makes sense because in 1530 Protestantism found wide support and was encouraged. For example, the Confessio Augustana was adopted in 1530, a rulebook on how to practice the protestant faith. Given the official character of this rule book, Protestantism was seen as a standard, and a standard is considered normal and therefore supported. However, in 1547 catholic troops defeated the Schmalkaldic League, an alliance of protestant princes, which discouraged the adoption of Protestantism.

The two graphs in the second row of Figure 13 show the computation of the effect of the independent variables by the example of the relative local power of territories (`relPower`). The scatter plot shows the values of `relPower` of each territory per year of the observation period. Blue dots correspond to territories in the event set, red ones to those in the risk set. By comparing territories in the event set with those in the risk set along their values of `relPower`, the model infers the slop of an exponential function, shown on the right. This slope is the estimated effect size of an independent variable. It indicates how important this variable is for the adoption of Protestantism. In the graph, the slope is positive, meaning that if a territory is powerful relative to its neighbours its risk to become protestant increases. This is the result which we found in the results section. In contrast to the baseline hazard, the effect of an independent variable is independent of the observation time.

In a final step, the model combines the baseline hazard and the effect of the independent variables to yield the total risk of a territory to become protestant. This total risk is computed per year of the observation period, as the graphs in the bottom row of Figure 13 show. For each year, the model takes the corresponding year-specific baseline hazard and multiplies it with the constant effect of the independent variables. This weakens or strengthens the total risk to become protestant, as the varying slopes in the bottom graphs show.

Whereas the Cox Proportional Hazard Model could do two types of inferences, one for the effect of duration time and one for the effect of independent variables, the Stratified Cox Model can only do the inference based on independent variables because the hazard rate is no longer defined across duration times. In our analysis, we estimate the following Stratified Cox Model, which we call neighbourhood model:

$$\begin{aligned} h_j(t) = h_{0j}(t)exp(\beta_1 & \texttt{monasteries} \\ +\beta_2 & \texttt{absPower} \\ +\beta_3 & \texttt{relPower} \\ +\beta_4 & \texttt{dynasty} \\ +\beta_5 & \texttt{visits} \\ +\beta_6 & \texttt{letters} \\ +\beta_7 & \texttt{uni} \\ +\beta_8 & \texttt{print} \\ +\beta_9 & \texttt{lifetime} \\ +\beta_{10} & \texttt{switchedNeighbours} \\ +\beta_{11} & \texttt{relPower} \times \texttt{switchedNeighbours}) \end{aligned} \tag{3}$$

$h_j(t)$ corresponds to the hazard rate of territories to become protestant in a stratum j. In our model, we stratify per year of the observation period, so each j corresponds to a year. $h_j(t)$ is the dependent variable we try to estimate. $h_{0j}(t)$ is the baseline hazard. `monasteries` corresponds to the number of monasteries located in the territory. `absPower` is an ordinal variable indicating the rank of a territory's rule title among all rule titles in the Holy Roman Empire. `relPower` indicates the rank of a territory's rule title among its direct (local) geographic neighbours relative to its total number of neighbours. `dynasty` corresponds to the fraction of territories belonging to the same dynasty as the focal territory that have switched before the current point in time. This variable is weighted by time, where the effect of previous switches decreases as time increases. `visits` corresponds to the number of days reformers spent in a territory in a certain year. `letters` corresponds to the number of letters reformers sent to a territory in a certain year. Similar to `dynasty`, `visits` and `letters` are time-weighted, where effect of previous visits and letters decreases as time increases. `uni` and `print` are dummy variables indicating whether a territory has a university or a printing press, respectively. `lifetime` is a control variable which measures the elapsed period between the current year and the foundation year of a territory. We included the variable to check whether older territories which could have been exposed to failed reformist attempts in the 12th-15th centuries, are more likely to adopt Protestantism. `switchedNeighbours` corresponds to the fraction of neighbouring territories that have switched to Protestantism in the past. The longer these switches lie in the past, the smaller is their weight (time-weighted). `switchedNeighbours:relPower` is an interaction effect to examine whether the effect of neighbours on the adoption of Protestantism is influenced by local power relations.

D Sensitivity and robustness checks

To strengthen the evidence for our results, we run sensitivity and robustness checks. Sensitivity checks use the same data as the original model but vary the included independent variables. Robustness checks use the same independent variables as the original model but compute them from different data. If sensitivity and robustness analyses reveal similar results as the original model, we have more evidence to believe that these results are likely to represent real patterns.

D.1 Inspection of neighbourhoods

In the Holy Roman Empire, every piece of land belonged to a ruler in the form of a territory. Hence, every territory had neighbouring territories. However, in our data set, some territories do not have neighbours, because of a pre-selection of 'Reformation-relevant' territories. The selected territories may not necessarily form a coherent geographical space.

If a territory does not have neighbours in our data, it is automatically the most powerful territory in its neighbourhood. So we assign it the maximum relative local power value of 1. This means that `relPower`= 1 has two meanings: a territory which won out over its neighbours and a territory with missing neighbourhood information. Since it is unlikely that all territories with missing neighbourhood information were the most powerful in their real-world neighbourhoods, `relPower` is biased upwards.

To quantify this bias, we run a robustness check by only including territories in the original neighbourhood model which had neighbours in our data. We construct the corresponding data in two ways: First, we select those territories which had neighbours at all times of their histories. This approach only includes complete histories but drastically reduces the number of territories[10]. We call this model 'complete history model'. Second, we select those points in time where a territory had neighbours.

[10]For instance, if a territory had existed for 500 years, but the data lack neighbourhood information for one of these 500 years, the complete history of the territory is discarded from the analysis.

Table 3: Cox estimates for first switch of territories from Catholicism to Protestantism. Comparison of histographical theory without and with network effects

	With and without neighbours	Complete history	Gaps in history
Catholic resistance			
monasteries	−2.42% (0.02)	−1.71% (0.02)	−1.61% (0.02)
Power relations			
absPower	−3.37% (0.05)	−4.50% (0.06)	−5.77% (0.06)
relPower	6.40 (0.44)***	4.65 (0.65)**	5.08 (0.65)**
Dynastic relations			
dynasty	13.67% (0.79)	−16.31% (0.93)	−11.49% (0.93)
Top reformers			
visits	0% (0.00)	0% (0.00)	0% (0.00)
letters	0.74% (0.00)***	0.58% (0.00)**	0.58% (0.00)**
Character of subjects			
uni	44.72% (0.30)	35.46% (0.31)	40.05% (0.31)
print	1.92% (0.23)	9.49% (0.26)	5.57% (0.26)
Controls			
lifetime	0% (0.00)	0.01% (0.00)	0.02% (0.00)
Neighbourhood			
switchedNeighbours	29.85 (0.55)***	21.01 (0.60)***	20.70 (0.60)***
switchedNeighbours:relPower	−94.95% (0.81)***	−89.07% (0.97)**	−88.79% (0.98)**
McFadden pseudo-R^2	0.043	0.053	0.053
Num. events	192	143	145
Num. obs.	22666	17738	18593
Missings	0	0	0

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

This approach only minimally reduces the number of territories but leaves gaps in the histories[11]. We call this model ‘gaps in history model’.

Table 3 shows the original neighbourhood model in column one where territories with and without neighbours were included. Column two shows the results of the ‘complete history model’ and column three the results of the ‘gaps in history model’. Cor-

[11] For instance, if a territory had existed for 500 years, and the data lack neighbourhood information for 499 years, the one remaining year is included in the analysis.

responding to the bias of the relative local power variable, we see that the coefficients for `relPower` and `switchedNeighbours:relPower` decrease in size in columns two and three compared to column one. However, the sign of the coefficients remains the same and the significance level only drops from < 0.01 to < 0.05. This indicates that the bias introduced by the operationalisation of local power relations slightly overestimates but does not distort the underlying effects revealed by the model. Since the size of the coefficients decreases more heavily in the 'gaps in history model' than in the 'complete history model', we infer that the 'gaps in history model' is more conservative and use it to analyse marginal effects of `switchedNeighbours:relPower` in Figure 5.

D.2 Inspection of economic variables

The economic variables market potential in 1500 (`marketpot1500`), access to waterways (`water`), the growth of the city population in the 15th century (`logcitygrowth15`), and the size of the population in 1500 (`pop1500`) have often been used in previous studies to examine the driving factors of the Reformation. In this analysis we intended to use these economic variables to operationalise characteristics of the subjects in a territory. Since in our data only 28 out of 262 territories had non-missing values for the economic variables, we excluded them from the analysis (historiographical and neighbourhood models).

To examine the impact of this variable omission, we run a combined sensitivity-robustness check. We extend the neighbourhood model from equation 3 by the economic variables and run this model on the 28 territories which have non-missing values for the economic variables. We call this extended model 'economic model' and formalise it as:

$$
\begin{aligned}
h_j(t) = h_{0j}(t)exp(\beta_1 &\texttt{monasteries} \\
+\beta_2 &\texttt{absPower} \\
+\beta_3 &\texttt{relPower} \\
+\beta_4 &\texttt{dynasty} \\
+\beta_5 &\texttt{visits} \\
+\beta_6 &\texttt{letters} \\
+\beta_7 &\texttt{uni} \\
+\beta_8 &\texttt{print} \\
+\beta_9 &\texttt{lifetime} \\
+\beta_{10} &\texttt{switchedNeighbours} \\
+\beta_{11} &\texttt{relPower} \times \texttt{switchedNeighbours} \\
+\beta_{12} &\texttt{marketpot1500} \\
+\beta_{13} &\texttt{water} \\
+\beta_{14} &\texttt{logcitygrowth15} \\
+\beta_{15} &\texttt{pop1500})
\end{aligned} \tag{4}
$$

Table 4 shows the results of the neighbourhood and economic model in columns one and two, respectively. In column 2, we notice that all but one of the economic variables have large p-values from which we conclude that we cannot distinguish their effect from random ($p_{\texttt{water}} = 0.84$, $p_{\texttt{logcitygrowth15}} = 0.36$, $p_{\texttt{pop1500}} = 0.23$). These variables do not contribute to the explanatory power of the model. In contrast, `marketpot1500` shows a negative significant effect: The larger a territory's market potential, the less likely that territory is to become protestant.[12]

By adding the economic variables results change. First, the effect of the independent variables from the neighbourhood model changes in size, direction, and significance in the economic model. Second, the economic model has higher explanatory power than the neighbourhood model, as the larger pseudo-R^2 value shows.

[12]The sign of the effect can be attributed to the vicinity of catholic cities, as Rubin [42] already noted.

Table 4: Cox estimates for first switch of territories from Catholicism to Protestantism. Comparison of histographical theory without and with network effects

	Neighbourhood	Economic	Neighbourhood with territories from economic
Catholic resistance			
monasteries	−2.42% (0.02)	2.13% (0.04)	0.85% (0.03)
Power relations			
absPower	−3.37% (0.05)	44.57% (0.43)	36.15% (0.31)
relPower	6.40 (0.44)***	2.36 (2.20)	−71.21% (1.77)
Dynastic relations			
dynasty	13.67% (0.79)		
Top reformers			
visits	0% (0.00)	0.03% (0.00)	0% (0.00)
letters	0.74% (0.00)***	0.61% (0.01)	1.18% (0.01)
Character of subjects			
uni	44.72% (0.30)	3.60 (0.85)	97.47% (0.73)
print	1.92% (0.23)	2.28 (0.77)	21.02% (0.61)
Controls			
lifetime	0% (0.00)	0.31% (0.00)	0.09% (0.00)
Neighbourhood			
switchedNeighbours	29.85 (0.55)***	14.19 (2.31)	10.74 (2.07)
switchedNeighbours:relPower	−94.95% (0.81)***	−63.30% (4.15)	72.48% (3.83)
Economic vars			
marketpot1500		−20.64% (0.09)**	
water		−19.68% (1.11)	
logcitygrowth15		2.41 (0.96)	
pop1500		7.33% (0.06)	
McFadden pseudo-R^2	0.043	0.275	0.204
Num. events	192	22	22
Num. obs.	22666	2430	2430
Missings	0	0	0

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

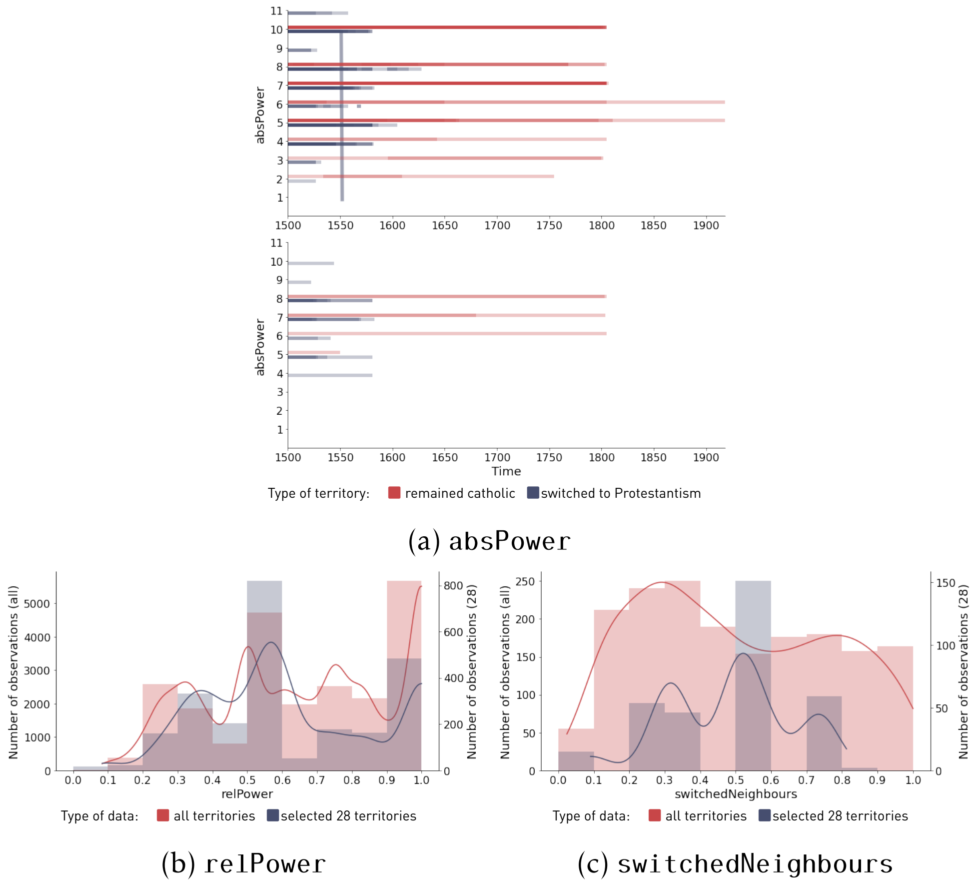
There are two possible reasons for these changes: First, the economic variables may be crucial to explain the adoption of Protestantism and their omission distorts model results. Second, the selected 28 territories, on which the economic model was run, may be different from the territories in the full data set and therefore cause the different model outcomes.

To provide support for one of these explanations, we run the original neighbourhood model on the selected 28 territories (Table 4 column 3). We see that coefficients and pseudo-R^2 are similar to the ones in the economic model. This result indicates that the 28 territories have special characteristics that distinguish them from the remaining territories. To investigate these differences in detail, we inspect those independent variables which were subject to a change in sign between columns 1 and 3 in Table 4. Changes in sign show that the basic direction of the effect is not preserved in the new data set, so the 28 territories are expected to differ a lot from all territories on these variables. Other independent variables, which only changed in size and significance but not in sign, can be attributed to the small sample size: 28 territories are too few to find significant and stable effects.

Figure 14 shows the inspection of the sign-changing variables `absPower`, `relPower`, and `switcheNeighbours:relPower`. To explain the change of sign of the interaction effect, `switchedNeighbours` is also examined, although its sign did not change.

Figure 14a shows the histories of global power ranks as coloured bands for all territories (top) and the selected 28 (bottom). Each territory is represented by one band. The length of a band corresponds to the period in which the territory held a power rank. The colour of a band distinguishes between territories that became protestant (blue) and those that remained catholic (red). The darker the shading of a band, the more territories held that power rank in a year. For example, `absPower` = 11 only has blue bands. This indicates that only switch territories have the highest global power rank in the data. The longest of the blue bands ends in around 1560. This marks the time when the corresponding territory became protestant.

When comparing the top and bottom figures, we note that histories are similar: red and blue bands are distributed evenly over the different power ranks, with large ranks being slightly dominated by switch territories. However, the full data set and the 28 territories differ in terms of temporal changes of the power ranks, as the vertical line in the top plot shows. Whereas the 28 territories keep their ranks over their histories, two territories in the full data set drop in rank from 10 to 1. These are the imperial cities Metz and Verdun, which lost their title after having been conquered by the French. Since Metz and Verdun became protestant, the model associates the drop in power rank



(a) absPower

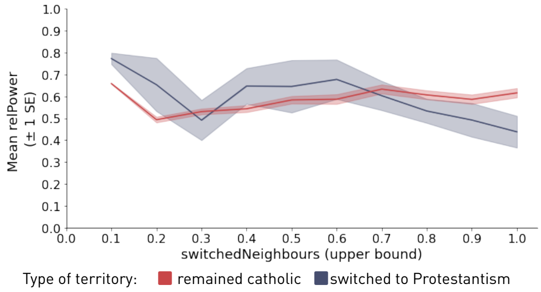
(b) relPower

(c) switchedNeighbours

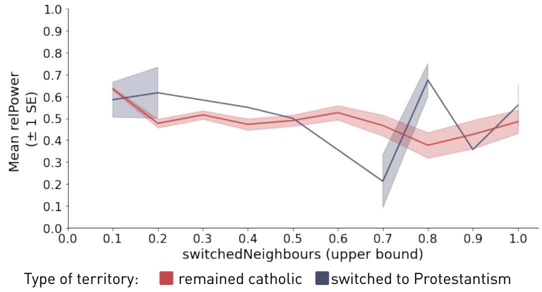
Figure 14: Comparing territories from neighbourhood model (all territories) and from economic model (28 territories) along independent variables that changed sign between neighbourhood and economic model. (a) Histories of global power ranks for all territories (top) and selected 28 (bottom). Only in full data set switch territories become weaker. (b) Histograms of local power values for all territories (red) and selected 28 territories (blue). The 28 territories contain fewer powerful teritories than the full data set. (c) Histograms of fraction of switched neighbours for all territories (red) and selected 28 territories (blue). The 28 territories contain fewer extreme values of `switchedNeighbours` than the full data set.

with the adoption of Protestantism and allocates a negative effect to `absPower` in the neighbourhood model. Since the 28 territories do not display such a drop, a positive effect is allocated to `absPower` in the economic model. Since only two territories display the drop pattern in the full data set, the effect is small and not significant.

Figure 14b shows the histograms and kernel density lines of relative local power values over the complete histories of territories. Territories from the full data set are displayed in red, the selected 28 territories are shown in blue. We see that the red and blue



(d) Interaction effect: all territories



(e) Interaction effect: 28 territories

Figure 14: (d) Mean local power of remained and switch territories of the full data set. Remained and switch territories only distinguish in `relPower` for large values of `switchedNeighbours`. (e) Mean local power of remained and switch territories of the selected 28 territories. Differences between remained and switch territories are due to outliers.

curves are similar except for the values between 0.65 and 0.9. In this range, the 28 territories have fewer observations than the territories in the full data set. This means that there is a smaller number of locally powerful territories among the 28 territories than among those in the full data set. Since locally weak territories dominate among the 28 territories, the effect of `relPower` becomes negative.

Figures 14d and 14e examine the interaction effect `switchedNeighbours:relPower` for territories in the full data set (14d) and for the 28 territories (14e). The red lines correspond to remained territories and the blue lines to switch territories. For territories of the full data set in Figure 14d, we see that the blue and the red lines are similar until `switchedNeighs`$\approx$ 0.7. This means that switch and remained territories are similarly locally powerful when a small to medium fraction of their neighbours has switched. Once more neighbours become protestant, switch territories become weaker than remained territories. This difference corresponds to the negative interaction effect in the neighbourhood model. For the 28 territories the interaction effect is positive for two reasons: First, none of the 28 territories has extreme values for the fraction of switched neighbours (Figure 14c), so remained and switch territories cannot distinguish themselves for large values of `switchedneighbours`. Second, outliers drive the positive effect. The peak of the blue line at `switchedNeighbours`= 0.8 in Figure 14e lets the model associate switch territories with a large fraction of switched neighbours and large local power values, although only two territories are responsible for this peak (St Gallen and Mühlhausen).