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Inferring mechanisms for global constitutional progress

Alex Rutherford[1*], Yonatan Lupu[2], Manuel Cebrian[3], Iyad Rahwan[3], Brad L. LeVeck[4] and Manuel Garcia-Herranz[1*]

Constitutions help define domestic political orders, but are known to be influenced by international mechanisms that are normative, temporal and network based. Here we introduce the concept of the 'provision space'—the set of all legal provisions existing across the world's constitutions, which grows over time. We make use of techniques from network science and information retrieval to quantify and compare temporal and network effects on constitutional change, which have been the focus of previous work. Furthermore, we propose that hierarchical effects—a set of mechanisms by which the adoption of certain constitutional provisions leads to or facilitates the adoption of additional provisions—are also crucial. These hierarchical mechanisms appear to play an important role in the emergence of new political rights, and may therefore provide a useful roadmap for advocates of those rights.

National constitutions describe the fundamental principles by which the state will be governed, political and legal state institutions, the powers, procedures and duties of those institutions, and the rights and responsibilities of individuals. The constitution has several roles: to act as a 'rule book' for how the country should operate; reflect the values and character of the country; and provide a means for accountability through international law[1].

There is great diversity in the content of national constitutions[2]. While some constitutions, such as that of the United States, are relatively short and explicitly provide for a relatively small set of individual rights, many newer documents are much more detailed. Which mechanisms account for these differences? While historical accounts and legal theory have suggested several reasons for this variation, scholars have only recently begun to examine this type of question using systematic data[3–8].

The processes for constitutional creation and evolution take many forms, including executive action, constituent assembly, referendum, or some combination of these. In some cases, the same constitution is slowly refined over many decades or even centuries. In others, constitutions are dissolved and replaced with new documents, often as part of a broader political transition such as the installation of a new political regime. This diversity in origin persists in present-day constitutions; in a small number of countries, the constitution is partially unwritten, and legal rules and principles are derived in part from judicial precedent. The constitution writing process generally involves some degree of compromise and coordination between elected representatives, institutions and/or citizens, of which the case of Iceland's 2008 crowdsourced constitutional reform is an extreme example[9]. This complexity in how constitutions change poses a challenge for international organizations such as the United Nations Children's Fund (UNICEF) and other United Nations agencies that seek to advocate for certain groups. Typically, advocacy takes place on a country or regional level and is broken down into thematic clusters related to programmatic areas such as education or health. A clearer understanding of the mechanisms of influence between countries and particular legal provisions that lead to constitutional change can suggest useful synergies. These synergies could be between advocacy efforts in different countries, between different rights or between institutions with distinct causes, each synergy making advocacy more efficient and effective.

More concretely, our key research question is as follows: which mechanism(s) explain(s) the variation in national constitutions and the timing of constitutional amendment? Existing work suggests—but has not rigorously tested the relative impacts of—two key sets of mechanisms: (1) temporal effects that are likely to affect countries (and, in turn, their national constitutions) independently of their national characteristics; and (2) network effects that impact national constitutions depending on countries' histories and place in the world. In addition to examining the relative impacts of these two sets of mechanisms, we posit and analyse a third mechanism: hierarchical effects—a set of mechanisms by which the adoption of certain constitutional provisions leads to or facilitates the adoption of additional provisions. Provisions in related substantive areas are often adopted in certain orders, with more basic provisions paving the legal and normative road for subsequent provisions. As we demonstrate, there is a strong co-dependence in the adoption of individual constitutional provisions, in addition to temporal and network effects.

This paper uses a range of quantitative techniques from the field of computational social science to analyse the process of constitutional change. Computational social science is now a well-developed field in which computational methods (and particularly those of network science[10]) are applied to analyse social systems with numerous diverse applications[11]. The field of comparative law (the study of differing national legal systems) has historically used qualitative analysis to answer questions about national constitutions. The application of computational techniques to constitutional documents and the historical records of their changes provide an attractive alternative toolset with which to systematically analyse and measure the dynamics of global constitutionalism.

Although the use of computational tools is relatively new in this literature, it is growing. Law and Versteeg[3] analysed the presence or absence of social rights provisions over a 60-year period. They used this to classify countries on an ideological scale with a libertarian,

[1]UNICEF Office of Innovation, New York, NY, USA. [2]George Washington University, Washington DC, USA. [3]MIT Media Lab, Cambridge, MA, USA. [4]University of California Merced, Merced, CA, USA. *e-mail: alex@alexrutherford.org; mgarciaherranz@unicef.org

common law nature at one extreme and a more statist nature at the other. Later work[4] found evidence that the adoption of social rights is influenced by former colonizers, as well as other countries with the same legal system and the same dominant foreign aid donor. Ginsburg et al.[5] investigated the interpretability of national constitutions and found that textual features were more important than contextual factors, such as the geographical region and applicability of common law. More recent work has used topic modelling[6,7] to classify and assess formal constitutions, although this work has examined only the preambles (or introductions) to these documents rather than the full texts. Rockmore and colleagues[8] analysed the diffusion of legal concepts between constitutions over time using a biological framework in which some countries' constitutions inherit from one another. It was found that several distinct epochs of cultural evolution exist and, while most constitutions are only influential for a short period, several have a sustained influence. More broadly, the combination of interacting temporal and network influences on constitutions, along with a series of abrupt perturbations and trends acting at different time scales is typical of a complex system[12]. As others[13–17] show, studying law using the tools of network science can yield meaningful and novel results.

We use computational techniques to answer the question of how constitutions progress. In so doing, we make four contributions: (1) we introduce the concept of the provision space as an alternative representation of constitutional change; (2) we introduce the concept of hierarchical effects that affect constitutional change; (3) to analyse hierarchical effects, we define hierarchical dependencies between provisions that are consistent with normative descriptions of how rights emerge; and (4) we quantify the relative strengths of temporal and network effects on each provision. Previous work in this area has typically applied either natural language processing or classification to constitutional text and numerical representations of provisions. In this paper, we make use of a wide range of computational techniques that together allow us to more comprehensively infer the mechanisms underlying constitutional change. Specifically, we study temporal effects through clustering of high-dimensional time series, network effects through text similarity and community detection, and hierarchical effects through network analysis and numerical optimization.

We are particularly interested in how constitutions progress by adding new rights that protect vulnerable populations. We therefore measure progress by the addition of legal clauses that protect minority populations. We focus on rights protecting children and young people not only as this is a relatively under-studied set of rights, but in order to inform the advocacy undertaken by international organizations such as UNICEF to further these rights. Our intention is both to complement theoretical accounts of constitutional change with empirical analysis, and to advance previous empirical analyses by uncovering powerful, generalizable mechanisms that have strong explanatory power across all countries and time periods.

To address our research question, our research design proceeds in four steps. We analyse hierarchical effects first, as these analyses represent the core contribution of this paper, followed by a quantitative comparison of temporal and network effects. First, we measure changes in the size of the provision space; that is, the cardinality of the provisions included across all national constitutions over time. Next, we analyse how new provisions are added to each country's constitution to uncover hierarchical dependencies between them. Then, we analyse similarity across the network of constitutions in terms of provisions and the language used. Doing so allows us to computationally define clusters of similar constitutions and, in turn, model the membership in those clusters on national characteristics. While we find that network effects play a role in these clusters, much of the variance is attributable to other factors. Finally, we analyse the rates of constitutional provision co-adoption in these clusters. Doing so allows us to disentangle temporal and network mechanisms with respect to each provision, resulting in a scoring of the importance of both of these mechanisms.

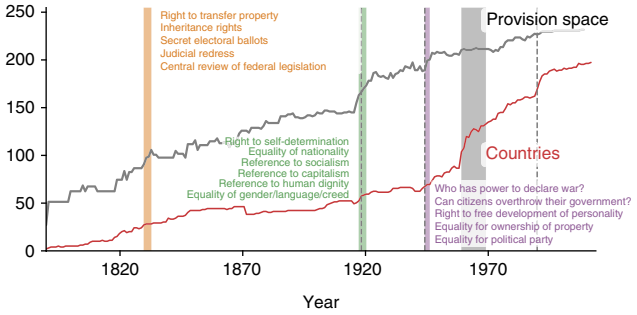

Fig. 1 | Provision space. Size of the provision space over time (grey line) compared with growth in the number of countries (red line). Introductions of specific provisions are highlighted. Dashed lines (from left to right) refer to the end of World War I and World War II, and collapse of the Soviet Union. The grey shaded area represents African decolonization between 1960 and 1970.

Hierarchical effects

In this section, we quantify hierarchical dependencies within provisions.

Specifying the provision space. We begin to uncover hierarchical effects by characterizing the temporal dynamics of constitutional development with a view to measuring the influence of time on which provisions are included in a constitution. We introduce the concept of a provision space—the set of provisions included across all national constitutions in a given year. This is analogous to the product space[18], by which a country may only produce complex goods by first producing other related goods of incrementally increasing complexity. In terms of constitutions, countries may be more likely to adopt certain provisions under certain conditions. Formally, the provision space at time t, $\rho(t)$ is determined by the provisions of each of the $n^c(t)$ countries in existence in year t, each of which is given by $\rho^c(t)$ as

$$\rho(t) = \{\rho^1(t) \bigcup \rho^2(t) \cdots \bigcup \rho^{n^c(t)}(t)\} \quad (1)$$

We use data on 234 constitutional provisions, representing legal concepts and rights, from the survey undertaken by http://comparativeconstitutionsproject.org/ with a binary 'yes or no' coding (see Supplementary Table 14 for a full list). In Fig. 1, we plot the growth of the size of the provision space over time as new provisions are first adopted. We also plot the number of constitutions in force. In both trends, there is an increasing, although not strictly monotonic, trend. Using vertical lines, we also plot key world events that have been argued to affect constitutionalism, including the 1830 revolutions, world wars, decolonization and end of the Cold War. The results are worth noting. First, some periods of growth in the provision space coincide with important events, such as the world wars. This is suggestive evidence of global trends in constitutional change in response to major changes in the balance of power and rise of new ideologies. Second, some periods of growth in the number of constitutions do not witness a corresponding growth in the provision space, including the decolonization period and end of the Cold War. This suggests that newly independent countries during those periods did not adopt new types of constitutional provisions, but rather created their new constitutions based on the set of constitutional provisions in place around the globe at that time. The gradual expansion of the provision space is consistent with a 'rights creep'[3] under which rights are increasingly likely to be adopted, and

Table 1 | Provisions relating to children and young people, and their most commonly co-occurring provision

Child provision	Top co-occurring provision
Access to higher education	Right to join trade unions
Privileges for juveniles in criminal process	Protection from ex-post facto laws
Compulsory education	Free education
Free education	Protection from the environment
Limits in the employment of children	Right to join trade unions
Equality regardless of parentage	General guarantee of equality
Right to found a family	General guarantee of equality
State support for children	State support for the disabled
Rights of children guaranteed	General guarantee of equality

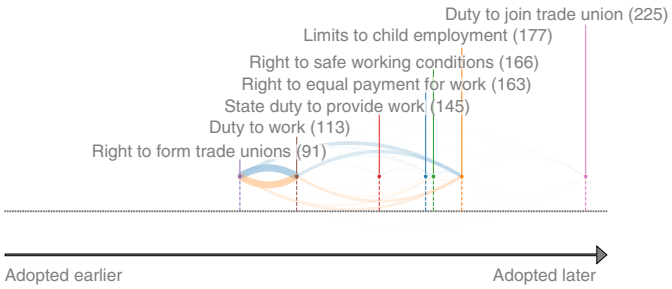

Fig. 2 | Representation of the hierarchical dependencies of provisions based on the sequential adoption by all countries over time. Provisions on the left are adopted before provisions to the right. Provisions related to work are labelled with their numerical position in the hierarchy (out of 234) and connections to provisions below them (blue) and above them (red) in the hierarchy. Provisions at the top of the hierarchy will have more blue edges than red, and vice versa for those at the bottom of the hierarchy.

in the case of younger states, increasingly likely to be adopted at their inception. This is supported by the increasing mutual similarity over time in provisions adopted (see Supplementary Fig. 17) and the fact that provisions are nearly three times more likely to be adopted when a country's constitution is first written than to be inserted by amendment.

Provision co-occurrence. We continue our analysis by focusing on temporal dependence among a set of related rights. We specifically consider nine provisions targeted at children and young people, and the corresponding provision that most frequently co-occurs with each (Table 1). Our intention here is to uncover potentially non-obvious relationships between provisions that would motivate advocacy on one issue as an indirect means to support another. While most existing work on human rights and constitutional law focuses on issues such as protections for civil rights and physical integrity rights, significantly less attention has been paid to the rights of vulnerable populations such as children. In addition, while almost all constitutions provide some civil rights protections for the general population, children's rights protections are less common, allowing us greater leverage in assessing where and in what order they have been adopted. Finally, the principal interest of UNICEF, as the United Nations agency for the protection of vulnerable children, is the legal rights affecting children and young people.

We note that some of these co-occurrences are unsurprising; for example, free education and compulsory education. In addition, the ubiquity of the broad-reaching general guarantee of equality is not, in itself, conclusive. Yet the co-occurrence of limits in the employment of children and right to join trade unions hints at a richer process. This demonstrates that the protection of adults at work typically precedes consideration of protecting children at work by potentially providing a legal precedent. This is consistent with adjacency claims[19], when new rights are claimed to follow tautologically from related rights that are already adopted and norm grafting[20] when changing legal norms.

Next, we consider the time-dependencies between all provisions adopted by a country in order to explicitly reconstruct the path dependence of new legal provisions. We measure this hierarchical structure by constructing a directed network between provisions, such that an edge from i to j is weighted by the number of countries for which i has been adopted before j. From this, we identify the minimal violation ranking; that is, the ranking most consistent with this network, as in Clauset et al.[21]. We find strong evidence that the provisions represent a hierarchical structure with only 24% of edges being violated (50% represents 'no better than random'). The ranking is robust over 10 epochs with pairwise Spearman's correlations no lower than 0.95 (see Supplementary Fig. 29).

The provision space is, by definition, a set of rights and concepts that grows over time as the result of many societal and global-level processes. These include new evidence bases, technological advances and continued advocacy on behalf of marginalized groups. Therefore, by definition, the provision space contains both structural provisions that are accepted as building blocks of a constitution and novel concepts that challenge current legal norms. Thus, the position of a provision in the hierarchy is somewhat determined by the year in which the provision first entered the provision space ($n=234$, Spearman's $\rho=0.69$ ($P<10^{-32}$)). As expected, the provisions found in the lower positions of the hierarchy are fundamental, structural provisions such as reference to the branches of government, the military and religion.

A specific example of provisions related to work is visualized in Fig. 2 (see Supplementary Fig. 30 for an example of provisions related to education). We see that the right to form trade unions is a foundational provision that precedes more specific labour rights, such as equal pay for equal work and the right to a safe working environment. Although advocates of new legal rights or 'norm entrepreneurs'[19] have been seen to leverage existing laws in order to introduce new ones, we are able to construct an empirically driven ranking of provisions that suggests exactly which established provisions have been able to support others.

Network effects

In this section, we define a network of relations between constitutions and define associated communities.

Constitutional text and provision similarity. In addition to hierarchical effects, constitutions are affected by another set of mechanisms that affect countries based on their relationships with specific other states. We refer to these mechanisms as 'network effects'. Many constitutions belonging to former colonies were based on or influenced by the laws and constitutions of former colonial powers[22,23]. For example, the United Kingdom drafted some provisions of the constitutions of its newly independent colonies[23]. The colonial relationship may also continue to exert influence after independence. Related to colonial history is the country's legal system, often inherited from a former colonizer, which can have tremendous effects on the form of the national constitution. Scholars have yielded several classifications of legal systems, such as Arminjon et al.[24], La Porta et al.[25] and Zweigert et al.[26], based largely on qualitative assessments focusing on religion, national history and differing applications of common law and civil law.

Globalization is also likely to provide pressure on countries to adopt the legal norms of influential and powerful states. The United States' constitution has been especially influential on those of other countries, with some countries copying portions of it word for word[27,28], although Law and Versteeg[3,29] found that this influence has waned in recent years. Finally, while powerful states can exert effects on constitutions, these effects may instead be greater on states within its sphere of influence. For example, Billias[27] found that the effect of the US constitution was greatest on Latin-American states.

To better understand inter-country network effects, we analysed the ways in which constitutions are and are not similar. We began by considering the similarity values between the language dedicated to the same provision in different constitutions using the Jaccard index such that larger values indicate greater similarity. Surprisingly, we found low text similarity values (see Supplementary Section 3). That is, countries that include provisions covering similar substantive issues use differing words to address those issues. Furthermore, we found only an intermediate correlation between the similarity matrices based on full constitutional text (including non-provisional content such as preambles) on the one hand and the concatenation of all provisions on the other ($n = 194$, Pearson's $\rho = 0.39$, $P < 10^{-12}$). This suggests that any similarity in constitutional texts is driven by both similarity within non-provisional content and similar wording between different provisions.

To get a better sense of the relationship between constitutional and provision similarity, we defined a constitutional provision fingerprint for each constitution. This is a binary-valued vector of length $n_{\text{provisions}} = 234$, indicating the presence or absence of a provision. The provision similarity between two countries is computed as the cosine distance between their provision fingerprints; the text similarity is defined as above. For each country, we measure the text and provision similarity of the remaining countries. That is, for each country i we have a set of textual similarities and provision similarities of length $n_{\text{countries}} - 1 = 193$. From these two measures of similarity, we construct two country rankings—from most similar to least similar. Using the Spearman's rank correlation coefficient, we derive a value in the range −1 to 1 that describes how similar these rankings are. Values close to 1 suggest that the constitutions that have the most similar text content also have similar provisions (and vice versa), as would be expected if constitutions were perfectly inherited or copied with no new provisions inserted or deleted. We find low correlations between these 2 rankings; $<\rho_s> = 0.227$ ($\sigma = 0.146$). Considering the raw numerical values rather than ranks using a Pearson's correlation yields similar results with $<\rho> = 0.257$ ($\sigma = 0.149$).

These findings suggest that network effects lead to imitation of constitutions but not perfect inheritance in terms of text and substantive content. Instead, these findings suggest that states make changes to individual provisions despite similarity of wording.

Constitutional similarity clusters. Next, we focused on the entire constitutional text, including text that may not be attributable to a specific subject; for example, a preamble. To the extent that newly independent countries adopt their former colonizer's (or another state's) constitution, we should find that these documents are similar both in terms of language and choice of provisions.

We find strong structure within the text similarity values, with the hierarchical clustering in Fig. 3 demonstrating a cophenetic correlation coefficient of $\rho = 0.65$ ($P < 10^{-5}$). In particular, there is strong structure between the constitutions of countries with shared colonial histories (see Fig. 3), despite considerable diversity in terms of word length, time of writing and other characteristics. In some cases, new colonies adopt portions of a former colonizer's constitution word for word, but the finding of similarity persisting over time also suggests an influence that persists after independence, perhaps attributable to academic and immigrant links between countries and

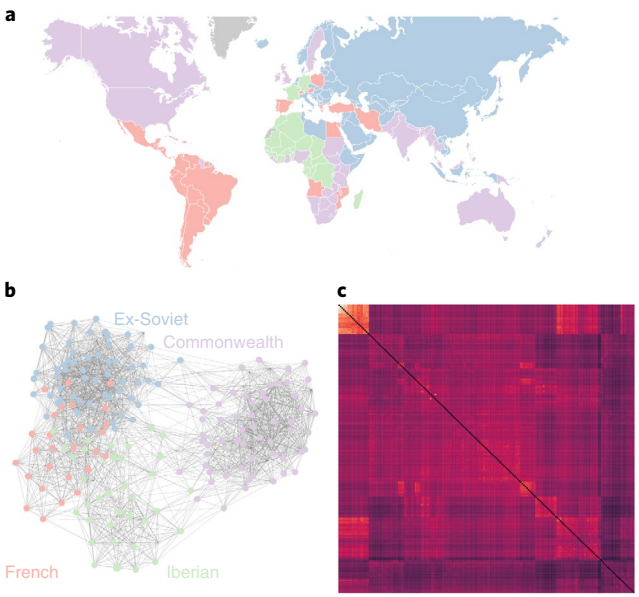

Fig. 3 | Constitutional document similarity. a–c, Clusters derived from the constitutional similarity network as a geographical map (**a**), network (**b**) and hierarchically clustered heat map of the text similarity matrix (**c**).

their former colonial powers. These results are all the more remarkable given that the constitutions are English translations of documents from other languages. Previous studies on cross-language plagiarism have found that the distributions of similarity scores and word lengths of translations can be sensitive to the language pair[30].

Next, we used network analysis to systematically assess how well network effects predict constitutional similarity. We used the text similarity scores derived above to construct a network, such that the more similar the two countries' constitutions, the greater the weight of the edge. We then applied a community detection algorithm to discover clusters of mutually similar national constitutions. The number of clusters was arrived at endogenously to optimize the partition of the network into communities. Four clusters emerged, reflecting typical classifications of legal systems, the membership of which is shown in Fig. 3 and listed in full in Supplementary Section 3. While there are many algorithms to partition a network, we consider the spinglass method as it better complements the pairwise similarities between the countries we wish to uncover. Nevertheless, we also compare several alternative methods in the Supplementary Information.

We note that the clusters reveal some consistency with qualitative characterizations of legal systems and the network effects of former colonial rule. One cluster contains the majority of former French colonial countries along with France itself. The former British and Spanish empires along with the UK and Spain themselves separate into two distinct clusters. The final cluster includes members of the former Soviet Union and Eastern Bloc, but also a mix of Middle Eastern and Asian countries. Nonetheless, the results of this analysis and colonial history are not perfectly correlated, with examples being Greece and Germany in the Iberian cluster. Interestingly, while provisions themselves strongly cluster together, we find no significant correspondence between provisions and country clusters (see Supplementary Fig. 16). One possible explanation is that constitutional texts in some languages confer relatively large text similarity scores despite provisions that are very different. An alternative explanation is that constitutional documents as a whole may use similar language, yet that similarity is not reflected in individual provisions.

To assess how well network effects predict network structure of the data (and, in turn, constitutional similarity), we analyse the

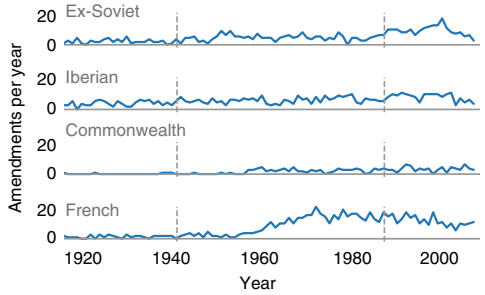

Fig. 4 | Constitutional amendment activity. Timeline of constitutional amendment activity over time, broken down by language-based cluster. Dashed lines indicate 1945 (the end of World War II) and 1991 (the collapse of the Soviet Union), respectively.

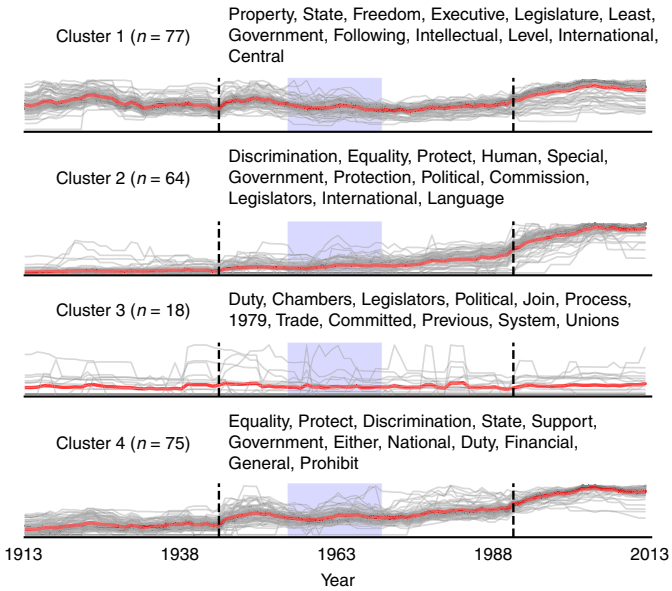

Fig. 5 | Clustering of time series of provisional adoption. The number of provisions in each cluster is indicated, along with the most common terms in the labels of the cluster members. The mean of each cluster is marked in red. The blue shaded region refers to the period of decolonization 1960–1970. Dashed lines indicate 1945 (the end of World War II) and 1991 (the collapse of the Soviet Union), respectively.

clusters using a series of multinomial logit models in which the cluster identification is the dependent variable. The clusters appear to correlate well with the legal system types identified in a study by La Porta et al.[25], which divides the legal system into five categories: UK (correlated with our Commonwealth cluster), French (our Francophone cluster), Spanish (our Iberian cluster), former Socialist (our Soviet cluster) and Scandinavian (our Soviet cluster). A multinomial logit model that includes only the La Porta et al.[25] classifications yields an expected percent correctly predicted (ePCP) of 58.48%, so the qualitative characterizations incorrectly predict many of our results. Considering instead only indicators[28] of former colonial powers as features, and using data from ref. [31], has an improved ePCP of 65.01%. A model that includes both sets of variables yields an ePCP of 76.24%. This suggests that while the similarities in wording are consistent in terms with colonial history and geography to an extent, other factors, potentially including country-specific and global effects, may play important roles in influencing such texts.

In addition, we note that when countries first create a constitution there is a strong tendency to add provisions across all colonial-based clusters (see Supplementary Fig. 20). This suggests that the adoption of provisions in new constitutions is encouraged by other contextual factors (such as the temporal effects discussed in previous sections; for example, concerted policy efforts) that are unrelated to the precedent or influence of other countries with a shared history or legal system.

Temporal effects

Here we uncover temporal relations between constitutional amendment and provisional adoption and quantify these effects relative to network mediated effects.

Constitutional amendments over time. A third set of mechanisms for constitutional change consists of events and trends that affect constitutions independent of network effects. We refer to these mechanisms as 'temporal effects' that tend to be mediated globally. These effects include the influence of both new rights and provisions that have been recently introduced elsewhere in the world, as well as the disruptive influence of key historical events. Historical events can have especially strong, and often lasting, influence. Wartime turbulence and post-war occupation and reconstruction can result in dramatic changes to formal constitutions[32]. The end of World War II led to a wave of constitution making that signalled a new, universalist approach that embraced international law[7]. Likewise, the period of decolonization, particularly during the 1960s and 1970s, witnessed a proliferation in new constitutions that differed greatly in the extent to which they reflected the legal systems and values of former colonizers. As Pargendler[33] notes, some former colonies rejected their colonizers' legal framework: "*wholesale legal transplants from one legal system seemed more dangerous to one's identity and autonomy than a combination of numerous foreign sources.*" New constitutions tend to be created in historical waves that follow critical historical events[34]. Seven distinct 'waves' of constitutional activity have been identified[2]: the aftermaths of the world wars, decolonization period, fall of Southern European dictatorships in the 1970s and fall of the Soviet Union.

In addition to specific events, temporal effects on constitutions can include broader trends. The present-day versions of formal constitutions also represent the result of long-term and complex international interdependencies. Ongoing international trends can influence the content and style of constitutions being drafted or modified at a given time. Extant constitutions also influence new constitutions by forming a baseline relative to which changes are made or new provisions added. Changing social and legal norms, cultural trends and new empirical evidence bases probably yield profound and enduring influences on constitution drafting. For example, Beck et al.[35] found that new constitutions tend to reflect global human rights norms at the time they are adopted, especially in new and less powerful states.

We compared network and temporal effects by analysing constitutional amendments across clusters over time in order to compare the relative importance in the proliferation of each provision. Network effects would predict a low correlation between constitutional amendments in one cluster and constitutional amendments in another cluster at a given time. Yet, if global shocks and trends have worldwide effects, we should see countries in multiple clusters amending their constitutions at similar times.

Figure 4 shows rates of constitutional amendment over time in each of the clusters identified above. Some common features are shared across clusters, such as spikes in activity following world wars and the collapse of the Soviet Union. Remarkably, significant coordination is observed between clusters despite limited geographic proximity or obvious political similarity. A simple pairwise correlation over time confirms this, with statistically significant correlation values in the range 0.50–0.71 (additional details in Supplementary Table 1).

Having found coordination between clusters, we investigated correlated temporal behaviours between provisions (Fig. 5). Our dataset of provisional adoption of countries suffers from a changing denominator. New constitutions enter when a country achieves independence, and may leave for several reasons—the country may simply no longer exist due to annexation or unification, or the constitution may be suspended; for example, during a temporary period of military rule. With this variability in mind, henceforth we consider the proportion of constitutions in existence that include each provision over time. We performed a clustering of provisions based on a dimensionality reduction on the yearly time series of proportional adoption of each provision (see Supplementary Figs. 21–26 for more details) and found strong evidence of coordinated behaviour.

Although these provisions are not arranged in topics or a hierarchy, we can extract some themes by inspection of the provision labels (Fig. 5). Cluster 2 mostly describes social rights of citizens and increases steadily over time. Cluster 1 also describes social rights, as well as religion and privacy, and is distinguished from the other clusters by a relatively high and constant adoption from the early twentieth century. Cluster 4 describes legal obligations of the state and enjoys a peak around 1945. All clusters are characterized by an increase and convergence over time with the exception of cluster 3, which contains a few obscure and sparsely adopted provisions, including the right to bear arms and same-sex marriage (the full list is found in Supplementary Tables 10–13). Each component is distinguished by behaviour in specific periods corresponding to World War II and the collapse of the Soviet Union. The trend for convergence and increasing adoption is observed not only across the components found above, but across the set of constitutions as a whole (see Supplementary Fig. 17).

Disentangling temporal and network effects. The results above have shown both strong and nuanced temporal and network effects on constitutions. Next, we quantified the effects of both temporal and network mechanisms on the adoption of individual provisions in order to determine the mechanism dominating each provisions' adoption. We considered each provision and compared: (1) the probability of two countries co-adopting each provision under the condition that they belong to the same cluster based on text similarity identified above (that is, network effects); and (2) the probability of co-adoption in the same year (that is, temporal effects). If the adoption of a provision is largely determined by colonial history and the legal system, the probability of co-adoption conditioned on the cluster is relatively high. Conversely, if the adoption of a provision is influenced by global shocks and temporal trends, the probability of co-adoption by year is higher.

These two effects are intuitively not always independent; countries sharing colonial history may well undergo constitutional amendment at the same time; for example, a coordinated period of decolonization. This correlation is confirmed by the scatter plot of these quantities per provision (Fig. 6) and a linear fit ($n=234$, $\rho=0.936$ ($P<10^{-12}$)) showing that the probabilities of temporal co-adoption and network co-adoption increase together.

Nonetheless, our results allow us to produce a rank ordering of provisions that have tended to be adopted due to temporal effects versus network effects, which can be classified by the residual difference from the regression line and associated z score. In Fig. 6, the adoption of provisions above the dashed linear regression line is driven by temporal effects, with several examples noted in the figure. Those below the line tend to be adopted in correlation with network effects.

We note several outlying provisions. For example, reference to God ($z=-0.89$) is more strongly co-adopted within clusters compared with the average. This suggests that the role of religion varies significantly with differing legal systems. In contrast, co-adoption of a duty to protect the environment ($z=6.00$) happened in similar years across clusters, suggesting that this provision is more dependent on changing global norms. A full list of provisions and associated z scores is provided in Supplementary Tables 15 and 16.

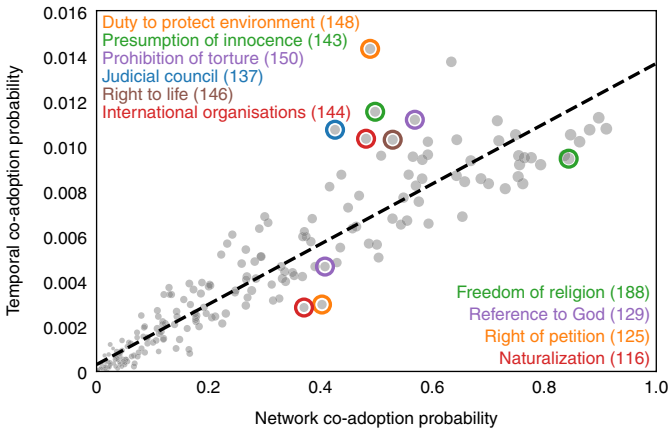

Fig. 6 | Network versus temporal adoption. Scatter plot of conditional probability of co-adoption of a provision given a common year of writing and a common network cluster. The dashed line indicates the linear regression. The size of the points indicates the number of countries adopting in the final year of the dataset (also indicated by the number in brackets).

Discussion

In this work, we have demonstrated that computational techniques can help us to uncover, understand and quantify competing mechanisms of constitutional change. Previous work posited temporal and network mechanisms for constitutional change. We analysed these mechanisms and uncovered a third set of mechanisms: the hierarchy and co-dependence of constitutional provisions.

To understand the emergence of new legal provisions, we introduced the concept of provision space as the set of provisions that are included among all constitutions at a given time. The provision space grew almost monotonically over the past two centuries as new constitutional legal rights and concepts were introduced. We found evidence of hierarchical dependencies between legal provisions, such that one provision was typically preceded by adoption of another complementary and foundational provision. This effectively quantifies the phenomenon of adjacency claims. The fact that global adoption of rights to date has demonstrated this hierarchical structure supports an incremental approach to advocacy rather than imposing emerging rights on young states. However, further work through experimental policy tools would be required to verify this.

We also used a computational linguistic measure to quantify the similarity between pairs of constitutions from which clusters of mutually similar constitutions emerge. While these clusters align reasonably well with theoretically derived legal families, we also show that this similarity is not only due to perfect replication of the provisions of the parent constitution. Rather, states have a tendency to adopt similar provisions using different wording of existing provisions. They also insert new provisions at independence that are not present in parent constitutions.

While both network and temporal effects affect the nature of constitutions, the relative importance of these mechanisms varies between provisions. Here, we identify which provisions appear to be adopted in conjunction as a result of temporal effects versus network effects.

More generally, our work has not only quantified processes that have, until now, been only intuitively understood, but we have uncovered non-obvious dependencies within legal rights and countries. These findings can streamline advocacy by international

organizations that is often nationally or regionally focused as well as thematically stratified. In addition, non-intuitive relations between different legal provisions can suggest novel partnerships between organizations focused on ostensibly different themes. Stated more simply, to promote provision X, collaboration with organizations committed to provision Y may be more effective than directly advocating for provision X if strong dependencies exist between X and Y. Future work should resolve these dependencies to more clearly uncover causal relationships within hierarchical dependencies of provisions to provide a predictive model of adoption.

We acknowledge that this study is constrained by the nature of constitutional law. Laws that are conferred by judicial precedent or legislature are not included here. Future work should consider the texts of other appropriate legal documents. We are further limited by the lack of availability of historical versions of constitutions. This is due to copyright issues. Such an historical corpus containing each version of a constitution would provide a time-varying snapshot of the structure of constitutional similarities, allowing for a rich dynamical study of contagion and influence. Since constitutional and other legal documents tend to use more formal and strict language, these texts will probably be amenable to more complex semantic-level natural language-processing approaches. This will allow us to measure similarity between the content and meaning of different countries' specific provisions, beyond noting only that a pair of countries both refer to the same topic.

A natural extension to the question of which constitutional provisions are adopted and how is the question of their efficacy. Evidence exists[28] suggesting that rights that are supported by organizations (that is, the right to join a political party or the right to join a trade union) lead to increased protection of social rights when compared with intrinsically individual rights (for example, freedom of movement or freedom of expression). Further evidence exists of a 'rights creep', by which the signature of the United Nations International Convention on Human Rights becomes de rigueur for United Nations member states, yet does not necessarily lead to statistically significant improvements in the treatment of human rights[36]. The validity of such a 'top-down' approach to development is part of a larger discussion on the efficacy and causality of international development processes and metrics of evaluation[37].

Nevertheless, this work indicates that interdisciplinary quantitative techniques can provide rich insight into constitution making in young states, including by allowing us to assess the competing mechanisms underlying these legal and political processes. The findings presented here can be particularly informative in light of discussions of self-determination through the partition of extant states into new states.

Reporting Summary. Further information on experimental design is available in the Nature Research Reporting Summary linked to this article.

Data availability. All data are freely available at https://www.constituteproject.org/ and http://comparativeconstitutionsproject.org/.

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Author contributions

A.R. and Y.L. analysed the data. All authors contributed to writing the manuscript.

Competing interests

Two of the authors (A.R. and M.G.-H.) were employees of UNICEF when this work was completed.

Additional information

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Correspondence and requests for materials should be addressed to A.R. or M.G.

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Corresponding author(s): Alex Rutherford, Manuel Garcia-Herranz

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Software and code

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Data collection	All data is publicly available. Historical constitutional data can be downloaded from http://comparativeconstitutionsproject.org/ and the current constitutions are available at https://www.constituteproject.org/ and through the associated API.
Data analysis	Python 2.7

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Study description	This study is quantitative, analysing historical data about constitutions.
Research sample	Current and historical constitutions and meta-data from the Constitute Project and the Comparative Constitutions Project.
Sampling strategy	Our sample size is constrained to the number of extant national constitutions in a given year.
Data collection	The data was downloaded through the web pages for the Constitute Project and the Comparative Constitutions Project.
Timing	January 2015 - December 2015
Data exclusions	No data was excluded
Non-participation	NA
Randomization	NA

Reporting for specific materials, systems and methods

Materials & experimental systems

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☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
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☒	☐ Animals and other organisms
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Methods

n/a	Involved in the study
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☒	☐ MRI-based neuroimaging