Technological Forecasting & Social Change 157 (2020) 120099

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

Collaboration in innovation: An empirical test of Varieties of Capitalism

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ARTICLE INFO

Keywords:
Innovation
Invention
Varieties of Capitalism
Institutions
Comparative capitalisms
Collaboration
Patent

ABSTRACT

Do country-level institutions drive firm-level collaboration in invention? Hall and Soskice's (2001) Varieties of Capitalism (VoC) contends that the institutional configurations of modern capitalist economies push organizations towards country-specific behavioral patterns in terms of collaboration frequency and duration. In this article, we first extract these claims from the VoC literature and then test them in the empirical setting of collaboration in invention. Towards this end, we construct an original dataset of patents and employ a novel metric of historical collaboration stickiness. We find strong support in favor of Hall and Soskice's prediction that inter-firm collaboration will be more common within coordinated-market economies. However, the VoC claim that organizations within coordinated-market economies will form more durable collaborative relationships than those formed within liberal-market economies does not hold up to empirical scrutiny.

1. Introduction

Of the grand theories attempting to explain international variation in firm behavior, Hall and Soskice's (2001) Varieties of Capitalism (VoC) is unique in that it offers multiple testable hypotheses in regard to patterns of inter-firm collaboration. In particular, VoC makes explicit predictions regarding collaboration frequency and the longevity or stickiness of collaborative relationships. In coordinated-market economies (CMEs), legal tolerance for relational contracting, strong inter-firm deliberation institutions, and rigid labor markets are predicted to produce frequent collaboration and durable corporate relationships. In contrast, in liberal-market economies (LMEs) where relational contracting is less common, institutions of deliberation are less strong, and labor markets are more fluid, collaboration is hypothesized to be less common and more transitory. In this article, we evaluate these predictions empirically using an original patent dataset and a novel metric of historical collaboration stickiness.

Investigating the substantive claims of Hall and Soskice's thesis is warranted, in part, by VoC's significant scholarly influence. Indeed, if the merit of a theoretical contribution is determined by that contribution's capacity to stimulate subsequent scholarly inquiry, there is no doubt as to the success of VoC. Since they put forth the VoC framework in the Introduction to a 2001 edited volume, Hall and Soskice's theory of the institutional origins of comparative advantage has generated a steady stream of theoretical and empirical scholarship.[1] For example, the logic underlying VoC has been extended beyond the rich democracies considered in the original text to Asia (Carney et al. 2009), Latin America (Schneider 2009; Schrank 2009), South Africa (Nattrass 2014), and many of the post-communist states (Lane and Myant, 2016). The framework has also been applied to a wide range of research areas including wage inequality (Rueda and Pontusson, 2000), regional innovation systems (Asheim and Coenen 2006), labor migration (Devitt, 2011), and economic growth (Hall and Gingerich, 2009; Kenworthy, 2006).

However, the merit of a theoretical contribution does not depend solely on usage, but also the extent to which its propositions correspond to observation. The majority of empirical scholarship on VoC – and indeed, on the comparative capitalism literature more generally – has focused on Hall and Soskice's proposed typology. For example, one prominent strand of research has sought to test the stability of the proposed LME/CME dichotomy (Brewste et al. 2006; Kenworthy 2006; Hall and Gingerich, 2009; Schneider and Paunescu 2012). Illustrative of this approach, Schneider and Paunescu (2012) preform a clustering analysis using proxies for national institutions to evaluate Hall and Soskice's original categorization of countries.

This focus on the categorization of capitalist economies, however, raises what Witt and Jackson recently described as the 'so what' of variety of capitalisms' (Witt and Jackson, 2016: 779). Specifically, the authors lament that while a large literature exists documenting the existence and emergence of a diversity of national institutional

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[1] As of June 25, 2019 Hall and Soskice's book had received 12,942 citations on Google Scholar.

https://doi.org/10.1016/j.techfore.2020.120099
Received 13 February 2019; Received in revised form 23 March 2020; Accepted 2 May 2020

configurations, 'research linking institutional differences to specific economic outcomes has remained surprisingly underdeveloped' (Witt and Jackson, 2016: 780). Indeed, we are aware of no other studies that use statistical techniques to evaluate VoC's predictions regarding collaboration.[2] By testing the relationship between institutional environments and observed economic outcomes, our article aims to contribute to filling this gap. Specifically, we consider whether patterns of inter-firm collaboration on invention – a class of firm behavior central to Hall and Soskice's proposed mechanism for determining national comparative advantage[3] – vary according to the predictions of the VoC approach.

However, investigation into the sources of international variation in patterns of inter-firm collaboration has relevance beyond the comparative capitalisms literature. Indeed, inter-firm collaboration is linked to a wide range of practical economic outcomes. For example, a large literature has found inter-firm collaboration to be associated with enhanced firm-level innovative capacity.[4] This relationship has been found to hold for a large number of sectors including, biotechnology (Baum et al. 2000; Kang and Park 2012), pharmaceuticals (Gemser et al. 1996), chemical (Ahuja 2000; Streb, 2003), high technology (Romijn and Albu 2002; Patrakosol and Olson, 2007), services (Elg and Johansson, 1997), unmanned aerial vehicles (Best et al., 2020) and various manufacturing sectors (Tsai 2009; Nieto and Santamaria 2007). Because national performance in technological innovation is central to the so-called new economic growth theories (e.g. Romer 1990, 1994; Grossman and Helpman 1994), understanding the factors that drive inter-firm collaboration should matter for scholars of national economic competitiveness.

Further, the configuration of inter-firm collaboration has been shown to be associated with the character of the innovation produced within the collaboration. For example, Balachandran and Hernandez (2018) find that collaborative triads involving international partners tend to be associated with more radical innovation whereas domestic triads are associated with increased innovation volume. Because collaboration has been linked to the character of firm-level innovation, specifying the factors that drive collaboration should matter for management scholars interested in innovation.

To preview our results, we find strong support for Hall and Soskice's prediction that inter-firm collaboration will be more prevalent in CMEs. This finding is insensitive to outlier countries and model specification. However, we fail to find support for VoC's contention that collaboration within CMEs will be more durable over time. In sum, while collaboration on invention is found to be more common within CME, there is no evidence showing that the duration of these collaborations is different from the collaborations formed in LMEs.

The primary contributions of this article are three-fold. First, by documenting the association between VoC classification and rates of inter-firm collaboration on invention, we contribute to the literature linking the institutional variation described in VoC to concrete economic outcomes (Witt and Jackson, 2016). Second, we contribute to the literature on inter-firm collaboration by identifying an important determinant of collaboration propensity. While research on collaboration within the management literature often implicitly acknowledges country-level institutional differences by controlling for country effects, the literature rarely discusses the particular institutions that drive variation in collaboration propensity (Aristei et al., 2016). Our study suggests that the mechanisms proposed by Hall and Soskice are plausible explanations of this variation. Finally, we make a methodological contribution. Our proposed metric for collaborative stickiness offers a means to gauge persistence of inter-firm collaboration using readily available patent data.

The remainder of this article proceeds as follows. In the section that follows, we apply the reasoning proposed by VoC to extract two testable hypotheses regarding country-level variation in inter-organization collaboration behavior. Section 3 describes the data and methods used to test these hypotheses. In Section 3, we also propose a new method for calculating the durability or stickiness of collaboration in invention.[5] Section 4 presents the results of our study. Section 5 concludes.

2. Literature review and hypotheses

Of concern here are national differences in patterns of inter-organization collaboration. While VoC speaks directly to this topic, before turning to Hall and Soskice's substantive claims regarding collaboration, the section that follows provides a brief overview of the primary precepts of VoC as a general theory of firm behavior and identifies the mechanisms proposed to promote institutional persistence.[6]

2.1. Varieties of Capitalism: A brief review

At its essence, VoC proposes a theory of economic organization in which a given economy at a given moment is situated along a spectrum defined by the manner in which firms solve coordination problems with the other entities with which they interact. At one (theoretical) pole, sit economies in which firms' interactions are coordinated by corporate hierarchies or the market. In these liberal-market economies (LMEs), transactions that are not internalized into the hierarchy of a firm tend to take place on an arms-length basis. At the opposite end of the spectrum are coordinated-market economies (CMEs), in which dense and durable networks of relationships replace the arms-length transactions of the market as the preferred means of coordination.[7]

However, VoC does not merely create a typology of firm behavior; rather it contends that the prevalence of a given type of firm behavior will depend on the domestic institutional setting in which firms operate. Such institutional configurations are posited to be quite stable over time. Indeed, institutional persistence is a central component of Hall and Soskice's thesis.[8] That is, VoC predicts not convergence towards a set of optimal institutions, but rather multiple institutional equilibria, each of which affords particular advantages to the firms

[2] Case studies have used the logic of VoC to explain inter-firm collaboration. For example, DeVore and Weiss (2014) employ the VoC framework to explain collaboration in the development and production of military aircraft

[3] Within VoC, a country's comparative advantage is defined in terms of the type (incremental or radical) of innovation in which it specializes (Hall and Soskice, 2001: 32). Thus, the process by which firms produce innovations is a particularly important class of firm behavior within the VoC approach.

[4] While the preponderance of the evidence supports a link between inter-firm collaboration and innovation the literature is not unanimous. Bougrain and Haudeville (2002) examine technological cooperation amongst French SMEs and fail to find a link between innovative success and cooperation.

[5] Throughout this article we follow president in the innovation literature and use the term "invention" to refer to novel *patented* intellectual property.

[6] VoC's claim of institutional stability permits empirical tests such as ours to utilize Hall and Soskice's original categorization of countries.

[7] Often a third, hybrid, 'variety' of capitalism is postulated. These mixed-market economies (MMEs) are said to possess traits from both LMEs and CMEs. The classification of countries within the VoC framework proceeds by precisely articulating the ideal type economies (CME and LME) that occupy the ends of the coordinated-liberal spectrum. The political and economic institutions characterizing these categories are thoroughly defined and the mechanisms by which they affect firm behavior are explicitly specified. It is thus straightforward to extract the predictions of VoC in regard to firm behavior in CMEs and LMEs. However, because MMEs receive scant treatment by Hall and Soskice, we limit our empirical tests to CMEs and LMEs.

[8] It should be noted that Hall and Soskice do not argue that national institutional configurations will remain completely static. National political economies will, for example, be forced to adjust to external factors such as globalization. Rather, the VoC framework suggests that change will be moderated by the existence of institutional complementarities and firms' acquired comparative institutional advantages and thus that the persistence of institutional diversity will likely persist.

operating therein. Or in the words of the authors, 'nations often prosper, not by becoming more similar, but by building on their institutional differences' (Hall and Soskice 2001: 60). Two mechanisms drive the persistence of national institutional configurations and thus the persistence of the LME/CME distinction: institutional complementary and comparative institutional advantage.

Hall and Soskice define two institutions to be complementary when the returns to one institution are positively correlated with the presence or efficiency of the other.[9] Complementary institutions are thus incentivized to limit the change undergone by other complimentary institutions. This moderating process limits system-wide change. For example, the authors cite the presence of such complementarities between financial and labor institutions. A financial system, such as those in LMEs, that uses short time-horizons to evaluate investments will benefit from flexible labor markets. Within such economies, firms that use rigid or long-term employment practices will likely have reduced access to financing. On the other hand, the 'patient capital' typical of lending in CMEs is argued to be well suited for the long-term employment that is typical in such economies.

The stability of institutional configurations is also maintained by the vital role that such arrangements play in determining firm behavior and firm success. As firms adapt their coordinating behavior to their institutional setting, they develop associated comparative advantages. Hall and Soskice describe this process of adaption succinctly stating, 'the institutional structure of a particular political economy provides firms with advantages for engaging in specific types of activities there' (Hall and Soskice 2001: 37). Because firms' operations are carefully calibrated to their institutional setting, they will tend to resist significant changes to a given institution.

2.2. Varieties of Capitalism's hypotheses regarding collaboration

As institutions constitute the underlying causal force behind firms' preferred coordination strategy and institutions primarily vary on a country-specific basis, VoC predicts country-specific variation in the prevalence of a chosen coordination strategy. It is these country-specific predictions that are exploited here to test VoC claims regarding collaboration. In particular, in the sections that follow, we identify two areas in which VoC makes predictions regarding collaboration in the development and production of new technologies: collaboration frequency and collaborative network stickiness.

2.2.1. Collaboration frequency

VoC contends that inter-firm cooperation in general and collaborative R&D schemes in particular will be more common in CMEs than LMEs (Hall and Soskice, 2001: 6-12). In the words of Hall and Soskice, modes of inter-firm coordination within CME's are characterized by 'more reliance of collaborative, as opposed to competitive, relationships' (Hall and Soskice 2001: 8). As with each of the primary claims about firm behavior that are made by VoC, the underlying mechanism driving firms' propensity to collaborate are the prevailing domestic economic institutions within the economy in question. In the case of collaboration frequency, the primary operative institutions are legal and regulatory systems that promote relational contracting, institutions such as business organizations that facilitate deliberation, and labor markets.

Relational contracting, or relationship-governed exchange, refers to inter-organization agreements in which the means of enforcement is located in the prevailing social norms (especially trust and 'good faith') in which the contracting parties are embedded. Researchers have found that legal and regulatory systems that allow relational contracting facilitate complex long-term inter-firm relationships such as collaborative research agreements (Casper, 2001; Hill, 1995; Teubner, 2001). Because relational contracting is more common in CMEs than in LMEs, VoC predicts that firms within CMEs will more frequently engage in the kind of uncertain, long-term, collaborative relationships that it facilitates (Hall and Soskice, 2001). Teubner summarizes the contracting practices and inter-firm relations in the archetypical CME (Germany) stating, 'inter-company relations tend to be cooperative networks with relational long-term contracting, horizontally within markets as well as vertically between different suppliers, producers, and distributors' (Teubner, 2001: 434). Conversely, in institutional environments in which relational contracting is uncommon, the requirement to stipulate, within formal contracts, the large number of contingencies inherent to such relationships discourages the creation of cooperative research and development agreements. Hall and Soskice summarize the absence of this contracting option in the archetypical LME (the US), noting that, 'companies wishing to engage in relational contracts with other firms get little assistance from the American legal system' (Hall and Soskice, 2011: 31).

According to VoC, collaboration within CMEs is also promoted by means of institutions of inter-organization deliberation. Hall and Soskice (2001) argue that institutions that enable deliberation promote collaboration primarily by means of increasing parties' shared knowledge. For example, the authors argue that institutions of deliberation increase investment in co-specific assets (assets for which the expected return is dependent on the behavior of other parties) in two ways. First, deliberation provides parties with a fuller understanding of the risks and returns associated with the investment. Second, deliberation allows parties to manage concerns regarding opportunism and the eventual distribution of the endeavor's expected returns. Both processes increase the likelihood of collaboration by increasing the value of co-specific assets by means of increasing shared knowledge and reducing uncertainty regarding the actions of other parties.[10] In LMEs where deliberation institutions play a more muted role, VoC predicts that rather than investing in co-specific assets, firms will tend to invest in assets that can be inexpensively diverted to other ends.

Finally, according to VoC, differences in the structure of labor markets affect a firm's decision to include collaboration as part of its innovation or technology acquisition strategy. Within CMEs, inter-firm knowledge transfer by means of poaching employees is limited by long-term labor contracts and approximate parity in salaries across firms. Prevented from acquiring technological and scientific knowhow through poaching, firms within CMEs tend to augment their innovative capacity through inter-firm R&D collaboration (Hall and Soskice, 2001; Wood, 2001). In contrast, in LMEs where labor markets are more fluid and there is less like-job parity in salaries, knowledge transfer by means of movement of scientific personnel across firms is more common. Wood (2001) observes that skills poaching is further limited in CMEs by network monitoring and industry associations. In particular, Wood observes that poaching is limited, 'through the circulation of information between companies, between business and banks, and particularly between companies and 'monitors' such as employers associations and chambers of commerce' (Wood, 2001: 257).

The above discussion demonstrates that VoC makes a clear prediction regarding the relative prevalence of collaboration in CMEs and

[9] Douglas North (1994, 2005) is the prominent scholar to observe the quality of institutional complementarity and note its role is limiting rapid institutional change. North describes the process succinctly, stating, "The reason is that the economies of scope, the complementarities, and the network externalities that arise from a given institutional matrix of formal rules, informal constraints, and enforcement characteristics will typically bias costs and benefits in favor of choices consistent with the existent framework" (North 1994: 6).

[10] Within CMEs, institutions of deliberation also compliment legal systems in promoting inter-organization cooperation by means of relational contracting. For example, Hall and Soskice (2001: 26) observe that the German legal system's acquiescence to open-ended contracting is contingent on contractual gaps being filled by standards developed by the pertinent industry association.

LMEs. Applying the claims of VoC to our object of analysis produces our first testable claim.

Hypothesis 1. *Collaboration will be more common in CMEs than in LMEs.*

2.2. Collaborative durability

In addition to making predictions related to the frequency with which organizations will engage in collaboration, Varieties of Capitalism makes clear predictions regarding the character of collaborative networks. In particular, VoC predicts that collaborative networks within CMEs will demonstrate high historical stickiness. Conversely, the institutions within LMEs will create collaborative networks characterized by low historical stickiness.

The establishment of enduring collaborative relationships is central to VoC's conceptualization of firm behavior within CMEs. While the institutions proposed to explain the LME-CME collaboration frequency gap also drive the durability of collaborative relationships, Hall and Soskice underscore the particular contribution of financing practices in encouraging long-term inter-firm relationships within CMEs. Whereas the provision and terms of financing within LMEs are argued to be contingent on short-term criteria such as recent stock prices or quarterly earnings, Hall and Soskice contend that lenders within CME use longer time horizons to evaluate investments. Such 'patient capital' allows firms to establish durable collaborative ties such as those necessary to co-fund research and development projects. In describing the effect of long-term financing on inter-firm collaboration, Hall and Soskice contend that patient capital (along with the associated system of corporate governance), 'allows credible commitment to long-run relations between companies' (Hall and Soskice, 2001: 28). In LMEs on the other hand, where time-horizons are shorter, the contribution of finance is to make 'credible commitments difficult for LR [long-run] relational sunk investments between companies' (Hall and Soskice, 2001: 32).

Hall and Soskice also argue that the process by which financial institutions gather information about borrowers within CMEs encourages long-term collaboration. Hall and Soskice explain that whereas financial markets are cleared in LMEs through borrowers' near-complete disclosure of their internal financial condition to potential lenders, receiving financing within CMEs 'is not entirely dependent on publicly available financial data or current returns' (Hall and Soskice, 2001: 22). Instead, within CMEs, lenders' due diligence is dependent on the intra-network exchange of private information. These relationships extend beyond bilateral ties between lender and borrower; they are instead, 'dense networks linking the managers and technical personnel inside a company to their counterparts in other firms on terms that provide for the sharing of reliable information about the progress of the firm' (Hall and Soskice, 2001: 23). Such 'network monitoring' is facilitated by the repeated interactions, familiarity, and trust associated with durable relationships.

In sum, by means of the prolonged investment time horizons facilitated by 'patient capital' and the importance of durable ties to effective network monitoring, VoC predicts that collaborative relationships within CMEs will be relatively stable, or sticky, over time.

Hypothesis 2. *Organizations within CMEs will exhibit greater historical stickiness in their collaborative relationships than those within LMEs.*

Table 1
VoC classification, patenting by country.

Country	Type	Patents	% of Patents
United States of America	LME	3569	42.7%
Japan	CME	2550	30.5%
Germany	CME	1214	14.5%
United Kingdom	LME	226	2.7%
Canada	LME	168	2.0%
Switzerland	CME	211	2.5%
Netherlands	CME	178	2.1%
Sweden	CME	137	1.6%
Austria	CME	77	0.9%
Australia	LME	74	0.9%
Belgium	CME	64	0.8%
Finland	CME	77	0.9%
Denmark	CME	54	0.6%
New Zealand	LME	11	0.1%
Ireland	LME	16	0.2%
Norway	CME	16	0.2%

3. Data and methods

To test VoC's predictions regarding collaboration in the context of technological invention requires information on international technological invention, collaboration networks, and the country of residence of patent applicants. Towards this end we compile a novel dataset comprised of, randomly selected, patents and patent applicant residence information from 2005-2009 (inclusive, publication year basis).

To construct the dataset, we first extract a randomly selected set of granted patents from the EPO Worldwide Patent Statistical Database (PATSTAT).

Patents are drawn such that 2,000 patents are selected for each publication year.[11] We exclude patents with incomplete information. For instance, if two applicants jointly file a patent but country information is available for only one of the applicants, we drop the patent from our sample. We also exclude patents filed by applicants from countries that are neither LME nor CME. Finally, we remove collaborative patents that are VoC 'mixed' (i.e. patents co-filed by applicants from both CME and LME countries). This leaves us with 8,358 patents.

Using the obtained applicant residence information, we code the patents according to the two VoC categories: CME and LME. In the final dataset of 8,358 patents, 917 patents (11% of the total) have multiple applicants (collaborative patents), 3,939 patents (47%) were filed by applicants from an LME country, and 4,419 (53%) were filed by applicants from a CME country. For each country considered here, Table 1 summarizes the VoC classification, the number of patents contributed, and the proportion that these patents represent in the full sample.

The means by which we calculate collaboration ensures that our data is unlikely to be distorted by merger and acquisition (M&A) activity. Following a merger or acquisition, the resultant firm will be listed a single assignee on patents. Because we measure collaboration as the occurrence of more than one assignee on a given patent, combined firms will appear as a single organization following the merger or acquisition event.

3.1. Variables

3.1.1. Dependent variables

To test the two VoC hypotheses, we utilize two dependent variables: collaboration and collaboration network stickiness. To test whether

[11] When feasible, the use of population data is preferable to the use of a random sample. We employ a sampling approach for two primary reasons. First, we are concerned with testing hypotheses, rather than attaining estimates of population-level differences. Second, the calculation of the collaboration stickiness (STICK) metric requires considerable computational resources. The use of a sampling strategy becomes problematic for hypothesis testing when the sample introduces systematic bias (e.g. selection bias) into the analysis. For example, if the sample contains an over-representation of certain groups within the population, the estimated parameter may not reflect the true population parameter. We have dealt with this possibility by using a computerized random sampling function. Further, the proportion of patents represented by US and Japanese patents in our sample is consistent with global rates of patenting. That is, within the countries considered in our study, the majority of global of patents are filed by the US or Japanese applicants as reported in WIPO 2019 data (World Intellectual Property Indicators, 2019).

collaboration is more common in CMEs than LMEs (Hypothesis 1), we operationalize collaboration (CLB) as patents with multiple applicants.[12]

Collaboration network stickiness (STICK) measures the persistence of collaborative relationships over time. To calculate this measure, we extract all possible variations of applicant pairs for each collaboration patent. We then search for patents that were jointly filed by the same pair of applicants within five-years prior to the filing year of the patent in question. When matches are found, the applicant pair is assigned a 1 and a 0 otherwise. The ratio of the number of applicant pairs that had previously collaborated to the total number of possible applicant pairs for the patent in question gives our measurement for network sickness. The indicator takes the following formula.

$$STICK_p = \frac{\sum_{i=1,i<j}^{n} \delta_{i,j}}{{}_nC_2}$$

Where n is the number of applicants for patent p, i and j are indices for the applicants, ${}_nC_2$ is the number of possible pair combinations created from the patents applicants, and $\delta_{i,j}$ takes 1 if there are other patents that were jointly filed by applicants (i,j) within the previous five years and 0 otherwise.

3.1.2. Independent variables

VoC contends that the primary determinant of firm level collaboration behavior is the set of political and economic institutions in which firms operate. Because these institutions vary on a national level, firm behavior is predicted to vary on a national level. Finally, VoC posits that national political and economic institutions can be classified into one of two groups: CME or LME. Thus testing the validity of the VoC claim that a country's classification determines the collaboration behavior of its domestic firms, begins by simply assigning a dummy variable to patents based on economy type (either LME or CME) of the country of residence of the applicants. For example, if a patent has an applicant from an LME country, the LME variable takes a value of 1. These variables are mutually exclusive in our dataset. We set the reference group equal to patents that have applicants from LMEs.

3.1.3. Control variables

To isolate the effect of the VoC categories on our metrics of collaborative behavior, we control for seven factors. First, we control for the breadth of the technological coverage of the patented invention using the number of International Patent Classification (IPC) subclasses (4-digit) assigned to a given patent. Patents assigned a large number of IPC subclasses will likely have greater technological coverage than those assigned a small number of subclasses (Harhoff et al., 2003). Because greater technological coverage is likely to be associated with differences in collaboration behavior, we include number of IPC subclasses as a control in our model.

Second, we control for the number of inventors on a patent. The technical complexity or scientific coverage of an invention is likely to relate positively to the number of individuals listed as inventors. Because the probability of collaboration is likely to increase in relation to complexity and scientific coverage, we add inventor counts to the regressions that follow.

Third, we control for the extent to which a patented invention is linked to the scientific literature. Patents that are closely linked to scientific research are likely to involve collaboration with universities or public research institutes (Meyer 2000; Schmoch 1993; Verbeek et al. 2002). We use the non-patent literature (NPL) that is cited in the patent application documents as a proxy for the linkage between a given invention and the scientific literature. We control for this effect using NPL counts for each patent.

Fourth, we control for patent quality. Research suggests that forward citation counts (i.e. the number citations that a patent receives from subsequent patents) are positively associated with patent quality (Lanjouw and Schankerman, 2004; Schmid and Wang, 2017; Schmid, 2018; Schmid and Fajebe, 2019). Because low quality inventions are less likely to require collaboration than high quality ones (Briggs and Wade, 2014), we introduce forward citation counts into the regression models. To address the truncation problem in counting forward citations, we limit the citation window to the three years following a patent's issuance.

Fifth, we control for the jurisdictional coverage of the patented invention for two reasons. First, patents filed in multiple jurisdictions have been found to be of higher quality than those filed in a single jurisdiction (Sampat et al. 2005; Thomson Reuters, 2011). Second, filing in multiple jurisdictions is likely to relate positively to applicant resources. Because patterns of collaboration are likely to be dependent on both patent quality and applicant resources, we control for jurisdictional coverage using each patent's jurisdiction count. We control for a time trend by introducing a set of dummy variables for the patent publication year. We also take into account each patent's associated technological field by introducing dummy variables for the primary IPC class code (3-digit) that is assigned to the patent in question.

In our sample, about 73% of patents were originated from either US or Japan (see Table 1). Hence, there is a possibility that our results are driven by different collaboration patterns or differences in patent law between US and Japan.[13] To address this concern, we introduce a binary variable that takes the value of 1 for patent assigned to patents and 0 otherwise (*US or Japan*) as a control variable in the main regression. Table 2 defines the variables used in our models. Table 3 provides the summary statistics for the variables used to test Hypothesis 1 and Table 4 provides summary statistics for the variables used to test Hypothesis 2. Table 5 and 6 illustrate the correlation between the variables used to test Hypotheses 1 and 2 respectively. Overall, the variables are not significantly correlated with each other. To check for multicollinearity, we conduct the Variation Inflation Factor (VIF) test. In all specifications, VIF values are below two.

3.2. Modeling collaboration

As the dependent variable used to test Hypothesis 1 is binary, we employ a standard logit regression model of the following form.

$$ln\left(\frac{\pi}{1-\pi}\right) = \beta_0 + \beta_1 \times LME + \sum \beta_j \times C_j + \varepsilon$$

Where π is the probability of a given patent involving collaboration, β_0 is a constant term, C_j are the control variables, and ε an error term.

By construction, collaboration network stickiness (STICK) takes a proportional value between 0 and 1. Therefore, to test Hypothesis 2, we employ a generalized linear model with a logit link function.

Taylor (2004) finds that the predictions of VoC are largely dependent on whether the US is included amongst LMEs. Furthermore, given the exceptional nature of the US in terms of technology productivity in our data, it is worthwhile to consider whether the inclusion of the US distorts the analysis. Thus we run our hypothesis tests with and without the US patents.

[12] Co-filing is a commonly used measure of collaboration (Ma and Lee, 2008; Stolpe, 2002). Because being listed as a patent applicant affords a party with economic rights to an invention, it is unlikely that a co-listed applicant did not contribute to a given invention.

[13] There are several notable differences between the Japanese and United States' patent systems. For example, Japan is a first-to-file system whereas the United States is a first-to-invent system. Japan also tends to have a high patent grant rate (roughly 70 percent) relative to the U.S. (roughly 30 percent). Finally, Japanese patent law has a lower requirement for the size of the "inventive step" necessary to patent an invention. This results in smaller inventions surpassing the patentability threshold.

Table 2
Variables and descriptions.

Variable	Description
Dependent variables	
Collaboration (CLB)	A binary variable that takes 1 if the patent was produced by collaboration
Collaboration stickiness (STICK)	Measures the persistence of collaborative relationships over time
Independent variables	
LME (reference group)	A binary variable that takes 1 if any of a patent's applicants resides in a LME country
CME	A binary variable that takes 1 if any of a patent's applicants resides in a CME country
Control variables	
Number of IPC subclasses	Measures a patent's technological breadth
Forward citations	Measures patent quality/diffusion
Count of cited non-patent literature (NPL)	Measures a patent's linkage to the scientific literature
No. of jurisdictions of the patent family	Measures patent quality and applicant resources
Number of inventors	Measures a patent's complexity or scientific coverage
Patent publication year	Set of dummy variables to control for a time trend
IPC Section Code	Set of dummy variables for IPC section codes
US or Japan	A binary variable that takes the value of 1 if the patent was originated from either US or Japan

Table 3
Summary statistics (For test of hypothesis 1).

Variable	Obs.	Mean	Std. Dev.	Min	Max
LME	8,358	0.471285	0.499205	0	1
CME	8,358	0.528715	0.499205	0	1
CLB	8,358	0.109715	0.312553	0	1
No. IPC subclasses	8,358	2.030749	1.301369	1	23
Forward citations	8,358	2.240369	4.496899	0	62
No. of cited NPL	8,358	3.211534	10.97883	0	106
No. of patent family	8,358	6.469371	10.92563	1	470
No. of inventors	8,358	2.652548	1.843299	1	20
US or Japan	8,358	0.731754	0.443073	0	1

Table 4
Summary statistics (For test of hypothesis 2).

Variable	Obs.	Mean	Std. Dev.	Min	Max
LME	917	0.401309	0.490431	0	1
CME	917	0.598691	0.490431	0	1
No. IPC subclasses	917	2.163577	1.396136	1	12
Forward citations	917	2.119956	3.774889	0	56
No. of cited NPL	917	4.321701	13.81949	0	104
No. of patent family	917	6.498364	14.59464	1	392
No. of inventors	917	3.244275	2.147224	1	14
US or Japan	917	0.822247	0.382514	0	1

Table 5
Correlation matrix, full sample, hypothesis 1 ($N = 8358$).

	LME	CME	No. IPC subclasses	Forward citation	No. of NPL	No. of pat. family	No. of inventors	US or Japan
LME	1.00							
CME	-1.00	1.00						
No. IPC Subcl	-0.02	0.02	1.00					
Forward citation	0.17	-0.17	0.00	1.00				
No. of NPL	0.18	-0.18	0.10	0.20	1.00			
No. of Pat. fam	0.01	-0.01	0.21	-0.04	0.12	1.00		
No. of inventors	0.00	0.00	0.09	0.08	0.10	0.09	1.00	
US or Japan	0.37	-0.37	0.03	0.15	0.08	-0.09	0.07	1.00

4. Results

Table 7 summarizes the results of the two VoC hypothesis tests. Overall, the data support Hypothesis 1; collaboration in patenting is more common in CMEs than in LMEs. However, we fail to find empirical support for Hypothesis 2; there is no statistically significant difference in the historical stickiness of collaborations based on VoC category.

The first column of Table 7 shows the test results for Hypothesis 1 excluding most of the control variables. The second column shows the results for the test once controls have been added. Both tests show Hypothesis 1 to be supported at the 0.01 significance level. That is, both tests indicate that patents field by entities within CMEs are more likely than those filed in LMEs to be collaborative patents.

The third and fourth columns of Table 7 provide the results for the tests of Hypothesis 2. Column three excludes the majority of the controls, while column four shows the full model. Both tests indicate that Hypothesis 2 is not supported by the data. That is, we fail to reject the null hypothesis that entities within CMEs and LMEs have no difference in the extent to collaborate with their historical collaborators when they collaborate on invention.

As a robustness check, we run the models using a sample from which US patents have been excluded. In this analysis, the variable *US or Japan*takes the value of 1 for the patents from Japan. Table 8 provides the result of the test for Hypothesis 1 and 2 in the US-excluded sample. Overall, the regression results are consistent with the regression result with the full sample.

As mentioned in this article's Introduction, our results contribute to the, still small, literature that links VoC theory to economic outcomes. The comparative capitalisms literature generally, and VoC in particular, has been burdened by doubts regarding how the observed variation in institutional arrangements influence measurable economic outcomes. Witt and Jackson, succinctly summarize this critique, stating, 'There is little doubt that there are institutional differences, but the 'so what? – whether and where these variations matter – has been much less explored' (Witt and Jackson, 2016: 797). The finding that countries characterized by coordinated institutions collaborate on invention at a significantly higher rate than their liberal counterparts suggests an answer to the question of 'so what?' Namely, institutional configurations matter because they affect the manner in which firm's acquire novel technology.

The exception to the shortage of inquiry into how VoC institutions

Table 6
Correlation matrix, collaboration patents, hypothesis 2 ($N = 917$).

	LME	CME	No. IPC subclasses	Forward citations	No. of cited NPL	No. of pat. family	No. of inventors	US or Japan
LME	1.00							
CME	-1.00	1.00						
No. IPC Subcl	-0.06	0.06	1.00					
Forward citation	0.20	-0.20	0.05	1.00				
No. of NPL	0.23	-0.23	0.19	0.16	1.00			
No. of Pat. fam	0.04	-0.04	0.33	-0.01	0.15	1.00		
No. of inventors	-0.13	0.13	0.16	-0.03	0.08	0.07	1.00	
US or Japan	0.22	-0.22	0.02	0.14	-0.03	-0.12	0.04	1.00

Table 7
Hypothesis tests, full sample.

Variables	Hypothesis 1 Collaboration	Collaboration	Hypothesis 2 STICK	STICK
CME	0.43***	0.70***	0.36	-0.21
	(0.08)	(0.09)	(0.58)	(0.59)
N. of IPC subcl.		0.07**		-0.07
		(0.03)		(0.28)
3Yr forward citation		-0.02		0.12
		(0.01)		(0.10)
NPL		0.01*		-0.05**
		(0.00)		(0.02)
N. of patent family		-0.00		-0.01
		(0.01)		(0.01)
N. of inventors		0.15***		-0.50**
		(0.02)		(0.21)
US or Japan		0.91***		-1.58**
		(0.11)		(0.64)
Constant	-2.65***	-3.85***	-21.30***	-17.85***
	(0.32)	(0.35)	(1.09)	(2.57)
Observations	8,135	8,135	917	917
Year Dummies	YES	YES	YES	YES
IPC Section Code	YES	YES	YES	YES

Note: Hypothesis 1 tested using standard logit regression. Hypothesis 2 tested using generalized linear model with a logit linking function. Robust standard errors reported in parentheses.

Table 8
Hypothesis test, US-excluded sample.

Variables	Hypothesis 1 Collaboration	Collaboration	Hypothesis 2 STICK	STICK
CME	0.57***	0.51**	-0.53	-1.61
	(0.21)	(0.21)	(1.06)	(1.09)
N. of IPC subcl.		0.09**		-0.05
		(0.04)		(0.34)
3Yr forward citation		-0.03		0.27**
		(0.02)		(0.13)
NPL		0.01*		-0.64
		(0.01)		(0.53)
N. of patent family		-0.00		-0.09
		(0.01)		(0.13)
N. of inventors		0.23***		-1.00***
		(0.02)		(0.26)
US or Japan	-3.39***	-4.18***	-35.88	-32.60**
	(0.64)	(0.65)	(.)	(14.16)
Constant	4,610	4,610	577	577
	YES	YES	YES	YES
Observations	YES	YES	YES	YES
Year Dummies	0.57***	0.51**	-0.53	-1.61
IPC Section Code	(0.21)	(0.21)	(1.06)	(1.09)

Note: Hypothesis 1 tested using standard logit regression. Hypothesis 2 tested using generalized linear model with a logit linking function. Robust standard errors reported in parentheses.

affect economic outcomes is the literature on whether the character (as either 'incremental' or 'radical') of the innovative output produced by firms within a given institutional setting conforms to prediction. In such tests, VoC has had mixed results. Hall and Soskice claim that the institutions present in CMEs create a higher propensity to produce incremental changes to products or processes, while those of LMEs produce a higher rate of radical invention. Studies by Taylor (2004), Akkermans et al. (2009), and Witt and Jackson (2016) partially undermine this conclusion. Taylor (2004) uses patent data to examine national variation in the production of incremental or radical inventions and finds that the VoC hypothesis depends heavily on the inclusion of the US amongst LMEs. Akkermans et al. (2009) test the same claim yet use a more diverse set of radicality metrics and compare national innovative output at the industry level. While Akkermans et al. (2009) confirm Taylor's finding that VoC's claims regarding of the character of countries' innovative output do not hold in a general sense, they find evidence that Hall and Soskice's predictions withstand scrutiny in certain industries and contend that 'Taylor's outright rejection of the hypothesis is too strong' (Akkermans et al. 2009: 189). Similarly, Witt and Jackson (2016) find mixed empirical support for VoC's claims regarding whether countries will specialize in incremental or radical invention. Specifically, the authors use fuzzy-set qualitative comparative analysis to analyze national trade data and find that while CMEs specialize in incremental innovation as predicted, LMEs do not specialize in radical innovation.

Thus, in empirical tests of the character of national innovative output and of patterns of inter-organization collaboration, the VoC thesis performs ambivalently. Namely, there does appear to be some correlational evidence that firms with CMEs specialize in incremental change and have a high propensity to collaborate on innovation. This suggests that the VoC approach cannot be dismissed as a mere taxonomy of institutional environments, but a plausible explanatory theory about how these conditions determine observed economic outcomes. Thus, further research into whether the proposed institutional mechanisms are indeed causal is warranted. In regard to inter-firm collaboration, comparative case studies may be instructive as to the contribution of the proposed institutions (contracting, institutions of deliberation, and labor markets) to firm-level decisions to collaborate.

5. Conclusion

This article sought to test whether the institution-centered explanation offered by Varieties of Capitalism can explain international variation in rates and patterns of collaboration on invention. The performance of the VoC framework towards this end was mixed. Our results suggest that the predictions of Varieties of Capitalism regarding the frequency with which firms collaborate on invention *are* supported by the patenting data. However, Hall and Soskice's claim that inter-organization relationships will be more durable in CMEs than in LMEs *does not* hold up to empirical scrutiny. These findings could be extended in several ways.

Hall and Soskice's claim that inter-organization collaboration will be more common in CMEs than LMEs does appear to hold in our data. However, it should be pointed out, that our study does not offer the means to directly test whether the proposed underlying mechanisms (e.g. relational vs. formal contracting, the relative strength of

institutions of deliberation, and the character of labor markets) are responsible for this observation. Determining the operative mechanism (s), whether institutional or otherwise, will likely require a more granular approach. Towards this end, cross-national comparative firm-levels studies may be of use.

The observation that inter-firm collaboration on innovation is more common in CMEs holds significance for managers. Collaboration has been empirically linked to increased firm-level innovation (Ahuja 1996). Our findings suggests that the domestic institutions in which a firm operates are an important enabler of collaboration on innovation. While our research design does not allow the identification of the particular institutions that drive this collaboration, our findings point towards the CME institutions such as relational contracting as strong candidates. Recently, management scholars have recommended formal relational contract to "foster trust and collaboration" and cite the role of such contracts in driving innovation (Frydlinger et al., 2019). Our findings offer additional support that the use of relational contracts may be appropriate for managers seeking to facilitate collaboration with other firms.

In regard to the durability of collaborative ties, our study does not find evidence supporting the VoC prediction that the institutional environment within CMEs results in greater historical stickiness in collaboration on invention. Again, future researchers may benefit from increasing the level of granularity considered. Studying the behavior of particular firms may point scholars towards theories such as resource dependence theory or transaction cost economics that explain collaboration behavior based on firm-specific characteristics. The key task for researchers will be in operationalizing the logic of these theories with respect to collaboration on invention.[14] Indeed, the postulation and substantiation of an explanation for our failure to observe a VoC effect on collaboratives ties, could prove to be a useful point of departure for positive theory building.

Our findings also point towards another potentially productive line of research related to the role of collaboration in driving radical innovation in LMEs. Boschma and Capone (2015) consider the effect of the CME and LME institutional configurations on industrial diversification. They find the relatedness of the sectors in question to be a stronger determinant of industrial diversification in CMEs than LMEs and that firms in LMEs are more likely to diversify into unrelated industries. Castaldi et al. (2015) find unrelated variety – pieces of technical knowledge that have not previously been combined – to be an important driver of radical technological innovation. Research into whether collaboration within LMEs tends to be distant – i.e. more likely to lead to the recombination of unrelated variety – could shed light on whether distant collaboration explains higher rates of radical innovation in LMEs.

While collaboration on invention represents an important type of inter-organization collaboration, and one that is central to the VoC thesis, it may be fruitful to investigate weather our findings extend to other manifestations of collaboration. For example, future research into whether international patters of merger and acquisition, collaborative R&D (Belderbos et al., 2013), strategic alliances, or joint ventures vary according Hall and Soskice's model would go far toward demonstrating the generalizability of our findings. Indeed, both hypotheses tested here could be tested for alternative types of collaboration.

Finally, prior studies have suggested that patterns of collaboration between firms are associated with firm-level characteristics and non-market institutions such as the cultural or normative distance between the countries in which firms operate (Choi and Contractor, 2016). Our study does not include these factors due to the absence of data and established methods by which these factors could be operationalized at the level of the patent. Future research into the determinants of inter-firm collaboration may benefit from research into the appropriate means of operationalization these variables and, then, into the investigation of their impact on inter-firm collaboration in invention.

Author contribution statement

The manuscript was co-authored – 50/50. Each portion of the research process was collaborative. The writing, data processing, conceptualization, and statistical analysis were all conducted jointly.

Appendix. Regression with control variables only

	(1)	(2)
VARIABLES	Collaboration	STICK
N. of IPC subcl.	0.09***	-0.07
	(0.03)	(0.28)
3Yr forward citation	-0.02**	0.13
	(0.01)	(0.10)
NPL	0.00	-0.04*
	(0.00)	(0.02)
N. of patent family	-0.00	-0.01
	(0.01)	(0.01)
N. of inventors	0.16***	-0.50**
	(0.02)	(0.20)
US or Japan	0.63***	-1.52**
	(0.10)	(0.68)
Constant	-3.40***	-18.69***
	(0.34)	(1.84)
Observations	8,135	917
Year Dummies	YES	YES
IPC Section Code	YES	YES

Robust standard errors in parentheses
*** $p<0.01$.
** $p<0.05$.
* $p<0.1$.

[14] While they do not examine patenting specifically, Robertson and Gatignon (1998) use firm-level survey data to find that a transactions cost approach is useful in explaining firms' technology acquisition strategy.

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