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Institutional change and innovation system transformation: A tale of two academies

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ABSTRACT

This paper investigates interactions between institutional adaptation and the transformation of science and innovation systems by analysing change and adjustment in post-socialist science academies. Two leading examples are examined: the Chinese Academy of Sciences (CAS) and the Russian Academy of Sciences (RAS). A heuristic framework of institutional change markers is applied to the analysis of nanotechnology research in both countries. We draw on bibliometric sources, interviews and secondary sources. We find that while the two Academies share a common past as the dominant research agents in their respective systems, their current positions and trajectories now differ. The nanotechnology case shows that CAS has adapted to China's modernisation, engaged in central government policy initiatives, and interacted with other research performers. CAS remains central to the Chinese research system, and has rejuvenated and expanded its resource base. RAS, on the contrary, has taken a protectionist stance: it still dominates the Russian research system and has a strong nanotechnology position, enforced by its gatekeeper control over journal publication. Nevertheless, RAS has faced difficulties in internal modernisation, leading to the external imposition of reforms and further role diminishment. The paper offers comparative insights into processes of institutional adaptation and highlights how key institutions can influence system transition.

1. Introduction

The capabilities, organisational modes, and practices of public, private, and non-profit institutions, including universities, national laboratories, and academies, are central to the operation and performance of science and innovation systems (OECD, 1997; Edquist and Johnson, 2000). Understanding the strategies and consequences of adaptation in such institutions and how adaptation processes are informed and influenced is central to the study not only of science and innovation but also of broader societal change. It is reasonable to conjecture that changes in key institutions can have the capacity to transform their systems, while at the same time through feedback loops these institutions may also be changed by transition of the systems within which they are embedded. But how do such changes interactions occur and how can we conceptualise and assess the processes involved? In this paper we address these questions by analysing the dynamics of the interaction between change in the science academies of Russia and China with the respective transformation of the Russian and Chinese science and innovation systems.

Academies of Sciences are typically nationally organised associations that seek to advance science and scientific learning (Hassan et al., 2015). There are science academies in about 100 countries (IAP, 2014), although their roles vary considerably. In many countries, science academies focus on recognising outstanding achievements in science, most prominently in the case of the Royal Swedish Academy of Sciences which awards the Nobel Prizes in physics, chemistry and economics. In other countries, scientific academies directly carry out substantial shares of national scientific research with government funding and oversight. Historically, the leading example of this model was the Academy of Sciences of the USSR, which dominated public research in the Soviet Union from 1925 through to 1991. The Soviet Academy's legacy is embedded in its successor, the Russian Academy of Sciences (RAS). It also provided a model replicated by the Chinese Academy of Sciences (CAS), the National Academy of Sciences of Vietnam, the Academia Sinica of Taiwan, and science academies in Eastern Europe, among others. These research organisations oversee functions of scientific knowledge production, accreditation as well as honorary functions of appraisal for outstanding researchers (Graham, 1998).

CAS and RAS are today the largest examples of research-based national science academies. These two academies share a heritage of the

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socialist organisation of scientific research (Radosevic, 1999, 2003), yet have also undergone transformation in recent decades (David-Fox and Péteri, 2000; Liu and Zhi, 2010; Lu and Fan, 2010; Suttmeier et al., 2006) as both Russia and China pursue large-scale reforms to foster economic modernisation. Prior research that considers change in these two academies has tended to take an individual country perspective. RAS has been discussed as part of work on the influence of state-socialist models in science (for example, Graham, 1998), on the post-Soviet transformation of the entire science system (Radosevic, 2003; Yegorov, 2009), and on broad trends in Russian innovation policy (Klochikhin, 2012). The tangled reform processes of RAS have attracted topical attention, usually as short news reports on the latest developments (Clark, 2013; Pokrovsky, 2013; Yablokov, 2014). For CAS, older studies of historical developments and earlier reforms are available (e.g. Cao, 1998, 1999; Kuhner, 1984; Yao, 1989). A stream of bibliometric work highlights the role of CAS in the recent growth of scientific publishing in China (Fu and Ho, 2013; Yang et al., 2014; Yang et al., 2015; Ye, 2010), while attention has been paid to recent CAS programme initiatives (Lu and Fan, 2010; Zhang et al., 2011).

Yet, while both science academies have been subject to reform pressures, the outcomes of change have been strikingly different. CAS continues as a leading and powerful player in its research system, with increasing international reach. In contrast, in 2013 RAS saw its research status whittled away as the Russian government implemented radical reforms that facilitated a shift to a university-based setting of scientific research (UNESCO, 2015). These divergent outcomes present opportunities for comparative research to test conceptual frameworks about institutional change in transitional economies and the role of key institutions, and for study of the contrasting transformations in the two academies. In this paper, we put forward a framework that conceptualises processes of institutional modification in transitional countries and explore drivers, capacities, and enabling and constraining factors for transformation. We use indicators based on outputs of the two academies in the broad interdisciplinary field of nanotechnology, coupled with insights from interviews and secondary sources.

The next section introduces our conceptual framework in the context of a broader literature review. We then describe the methodology and data used in our empirical analysis. We then discuss recent initiatives in both countries in promoting nanotechnology. This is followed by a presentation of evidence related to the institutional change markers for the two academies. The last parts of the paper discuss findings and conclusions.

2. Institutions and transition: understanding and demarking change

An 'institution' is defined by its 'hard' components, which can be described as 'the rules of the game' (North, 1990) or 'schemas', and 'soft' components - resources, or social networks, which sustain the 'hard' components (Clemens and Cook, 1999). Much scholarship has been produced on institutions and how they are structured, function, and change. Understanding the scale and scope of institutional transformation requires the concept of a wider 'systems of institutions' (Roland, 2008) that share 'complementarities' (Aoki, 2008). There is interdependence between institutions and the systems into which they are embedded (Hira and Hira, 2000; Peters, 2005; Pierson, 2004). Comparisons of systems of institutions can lead to wider interpretive models, for instance, in work on the varieties of capitalism, which highlights how comparative differences in institutional and political dynamics contribute to distinctive paths of growth and distribution (Acemoglu and Robinson, 2015; Piketty, 2014).

Country-level approaches to the study of institutional change have tended to differ. In developed countries, institutions are usually seen as mature, with a focus on continuous and incremental institutional modification (Crouch and Keune, 2005; Vogel, 2005). In contrast, in developing countries there is more attention to institutional building, institutional disruption, and interactions of formal and informal institutions (Estrin and Prevezer, 2011; Grzymala-Busse, 2010; Slater, 2010). Institutional change in the developing world is typically viewed in a paradigm of discontinuous change that occurs as a consequence of exogenous shocks to unstable institutional environments (Slater, 2010; Weyland, 2008). We note, however, recent calls to reconcile these perspectives on abrupt/discontinuous change and incremental/continuous change (Mahoney and Thelen, 2010; Streeck and Thelen, 2005).

Post-socialist transformations have been a special case in the stream of research on institutional change as new institutional schemas were introduced into post-socialist contexts (Appel, 2004; Boettke et al., 2008; Crouch and Keune, 2005; Kornai, 2008; Smallbone and Welter, 2012). Major ruptures in system trajectories and frameworks have occurred, for example, the collapse of the Soviet Union, which precipitated the formation of current-day Russia. Yet, institutions have proven to be deeply embedded. Institutional change remains a core problem for post-socialist economies. Russia, still heavily reliant on natural resources (Puffer and McCarthy, 2007), seeks modernisation of institutions that could promote broader economic innovation. China struggles to find balance between external pressures, extensive accumulative growth and new technological priorities, under central government direction (Bell and Feng, 2007; Gabriele, 2002). In both countries, there are challenges of shaping new institutions, dealing with institutional inertia (Chen, 2008), and transforming existing institutions so they work more effectively (Amable, 2000). The issues become ever more pressing in the context of the global shift to innovation-based models of development, where strong science and technology systems influence the competitive advantage of national economies (Archibugi and Pietrobelli, 2003; Fagerberg et al., 2007; Fagerberg and Srholec, 2008; Porter, 1998).

Understanding institutional change has also been important for the study of innovation (Hage and Meeus, 2009; Hollingsworth, 2000). The institutional analysis of research and innovation has increasingly drawn on the national innovation systems (NIS) concept (Edquist and Johnson, 2000; Lundvall et al., 2009), itself rooted in an evolutionary perspective on institutional change (Nelson and Winter, 1982). National systems of innovation are comprised of institutions, organisational forms and interactions between them (Etzkowitz and Leydesdorff, 2000). NIS research recognises the role of learning and path dependence in institutional change (Hollingsworth, 2000) and the complex relationships between a 'system of institutions' and 'key' institutions within this system. Yet, other approaches appear more readily able to deal with cases of change in a dominant institution. For example, Powell and DiMaggio (1991) and, more recently, Mahoney and Thelen (2010) devise modular frameworks to understand institutional change, although with a focus more on outcomes than process. Clemens and Cook (1999) focus on the institution itself, with relatively less attention to the environment.

To bridge these approaches to understanding how institutions change in the context of system transition, we devise a conceptual framework that integrates change within a system-defining dominant institution and the system it is embedded into (in a national research system context). While we posit relationships between institutional actors and transformative change, our approach is an exploratory and grounded effort, which marshals a range of relevant qualitative and quantitative evidence to identify key factors and the scale and direction of their influence. This 'institutional change markers' framework draws on concepts used to understand institutional change, including path dependency, agency, learning, and interaction (Bell, 2011; Berk and Galvan, 2009; Lawton-Smith, 2006; van Waarden and Oosterwijk, 2009), and consolidates them into four categories. From this framework, we demarcate indicators that highlight the nature of change and which can be used to track continuities and discontinuities within institutions and in the environment. The four markers of change and their sub-components are as follows (see also Table 1).

Outputs and Performance considers the research accomplishments of the institution and potential challengers and competitors in the system.

Table 1
Institutional change markers framework.

Institutional marker	Component marker	Key institution	National research system	Data sources for empirical analysis
Outputs and performance	Volume	What volume of research does the institution produce? How has this changed over time?	What volume of research does the system produce? How has this changed over time?	Published papers
	Quality	Who produces excellent research?	Who else produces excellent research? Are there alternative centres of excellence?	Citations and journal placements
Re-creation	Rejuvenation	How well does the institution replenish its human resources?	How many new researchers are joining the system? Where from and where to?	New researchers and new author publications; secondary data
	Learning and innovation	How does the institution reflect on its performance and develop and implement new practices?	How creative is the system in inventing or adopting new practices and incorporating novel components?	Secondary data; interviews
	Path dependence	How likely is the institution to reproduce inhibiting components and practices?	How likely the system as a whole is to reproduce inhibiting components and practices?	Publication strategies; secondary data
Centrality	Thematic centrality	What are the strong areas of the institution's research? Is there much diversity?	What are the subjects the system has traditionally been strong in?	Disciplinary research publishing patterns
	Spatial centrality	How diverse is geographical structure of the institution?	What is the regional structure of the national research system?	Institutional research publishing patterns
Competence and autonomy	Collaboration and diffusion	How is the institution embedded into domestic and international research networks?	What are the general patterns of national and international research collaborations?	Co-authorship, inter-institutional and international collaboration patterns
	Institutional agency	How flexible is the institution in adopting endogenously-driven change in its practice?	What is the overall degree of liberty in strategic decision-making in the organisations within the system?	Secondary sources; interviews
	Resources	What are the main tangible and intangible assets of the institution? What is the degree of diversity of funding sources?	What is the general funding structure of the system? What is the degree of diversity of funding sources?	Funding acknowledgements; secondary sources

'Volume' tracks the scale of institutional activity and its change over time in relation to the growth of the system. 'Quality' examines research excellence and other sources of excellence in the system.

Re-creation considers how the institution maintains and regenerates itself. 'Rejuvenation' is a measure of the replenishment of an institution with high quality human resources. 'Learning and innovation' demonstrates institutional capacity to develop and diffuse innovations that facilitate endogenous change and can be described in terms of learning capacity (Lundvall et al., 2002), component innovation (Boas, 2007), and institutional entrepreneurship (Battilana et al., 2009; DiMaggio, 1988). 'Path dependence' addresses whether change follows or deviates from established trajectories (Jackson and Deeg, 2008).

Centrality is concerned with the location of an institution's outputs in relation to national activities. 'Thematic centrality' considers the extent to which science academies possess unique competencies and play central roles in certain subject research areas, although it is also possible that their dominance may smother the emergence of new approaches by other research performing organisations. 'Spatial centrality' indicates the way in which the geographical structure of the institution relates to regional patterns in the national research system.

Competence and autonomy takes into account collaborative activities of the institution and the position of the institution in networks. The 'collaboration and diffusion' component examines embeddedness and diffusion with other institutions as the embeddedness of an institution in international networks reflects relative benefits that it can extract from global research flows (Gök et al., 2016). 'Agency' measures the level of independence of the institution in its agenda setting. 'Resources' relates to the institutional habitus (Bourdieu, 1977) and the capability of the institution to support its activities and also to influence others.

3. Methodology and data

We apply the institutional change markers framework described in the prior section to probe the characteristics of institutional transformation in the Chinese and Russian academies of science, using the case of nanotechnology. Nanotechnology involves the engineering of matter at extremely small scales (typically 1 to 100 nm) leading to the design of materials, devices and systems with novel properties (PCAST, 2010). Research in nanotechnology spans multiple disciplines including chemistry, materials science, physics, engineering, biotechnology, environmental science, and computer science. From Feynman's early ideas of atomic-scale manipulation at the end of the 1950s and the coining of the term nanotechnology in the 1970s to the invention of the scanning tunnelling microscope in the early 1980s, nanotechnology has now emerged as significant in the advancement of science and technology as well as an important policy domain, with a bourgeoning of research institutions and technology centres around the world, undertaking knowledge generation across a broad range of topical and application areas (Kautt et al., 2007; Romig et al., 2007; Shapira et al., 2011). Nanotechnology presents a realm for comparative analysis, appropriate for the present study for three reasons. First, after a round of growth in the 1990s, nanotechnology research noticeably accelerated worldwide in terms of scientific papers in the 2000s through to the present (Arora et al., 2013b; Youtie et al., 2008; Shapira and Wang, 2010). This time period broadly matches with the current generation of changes in the Chinese and Russian systems of research and political economy. Second, nanotechnology requires sophisticated equipment and approaches and encompasses many strategically important disciplines. It is a domain that offers an insightful test bed to explore how established institutions address a novel, leading edge, interdisciplinary research area. Third, nanotechnology has been a priority of science and technology policy in both China and Russia (Appelbaum et al., 2011; Klochikhin and Shapira, 2012; Michelson, 2008), with some studies noting China's dramatic rise in nanotechnology publications and patents (Kostoff et al., 2007; Klochikhin and Shapira, 2012). This tests the capabilities of science academies to influence and be influenced by national flagship policies and to contribute to commercialisation and economic development.

This work uses three types of data (bibliometric, interview and secondary – see Table 1 for details and sources for each marker) within a multiple case study methodology (Yin, 2013). We combine analyses of bibliometric outputs and other available data sources to construct indicators. The Web of Science (WoS) is the bibliometric data source. Using the

Porter et al. (2008) and Arora et al. (2013a) nanotechnology query approach, we identified and analysed publications where one or more authors is located in Russia or China. VantagePoint Software enabled disambiguation and grouping of different institutes of the Russian and Chinese science academies. After cleaning and removal of duplicates, the dataset comprised 176,472 publications for China and 33,538 publications for Russia covering the period 1990 to 2012. For further details of the bibliometric method, see Karaulova et al. (2014.) The bibliometric analysis is complemented with information from secondary sources and insights from 54 field interviews conducted in China and Russia in 2014.

The next section provides a contextual overview of the science academies of both countries.

4. The science academies of China and Russia

The Chinese and Russian science academies are each massive research organisations. By all papers published in 2014 in Web of Science journals, CAS (with about 34,000 papers) was the world's second most prolific research organisation (after the multi-campus University of California). RAS (with more than 16,000 papers) ranked sixth globally by this measure. Both academies have extensive research portfolios, numerous research institutes and large numbers of research staff deployed over an array of regions within their respective countries (Table 2).

The RAS lineage dates back to the Petersburg Academy of Sciences – established in 1724 to promote scientific discovery and education (Lipski, 1953). Following the 1917 Revolution, the Soviet government sought to harness science to state development: the Academy was placed under the education ministry, while other new research institutes were founded. These were consolidated in 1925 into the Academy of Sciences of the USSR (also known as the Soviet Academy of Sciences). After further mergers in the mid-1930s, the Soviet Academy became the dominant research institution, receiving public largesse but also subject to state supervision over scientific agenda-setting processes. The Academy had exclusive rights to conduct fundamental and advanced research, which was separated from industrial research in specialised ‘branch’ institutes and teaching in universities (Graham, 1998). The Academy grew extensively during the 20th century, with about 330 research establishments and 217 thousand employees, including 57 thousand research staff, by the mid-1980s (Cross, 1997; Vucinich, 1984). It supervised science academies in the Soviet Republics, with the most important of these being the Ukrainian Academy of Sciences (Kassel and Campbell, 1980). The Academy's monopoly in fundamental research and its administrative power in the allocation of resources, alignment with the state apparatus, influence in the determination of national research priorities, and control over scientific careers and privileges, combined together to give the Academy the central role in the organisation of Soviet science.

The Soviet model was emulated by science academies in Eastern Europe and other socialist countries. In the late 1940s and 1950s, the Soviet Union was allied with the new People's Republic of China, and Soviet science models were influential. During this period, CAS was established (Dolla, 2015; Yao, 1989). Yet, the institutional design of the Chinese Academy did not entirely mirror that of its Soviet counterpart. The Soviet Academy of Sciences undertook basic research but the application of research was the responsibility of other organisations. In contrast, CAS was established to contribute to economic development – an expectation that existed both before and after the Cultural Revolution (Yao, 1989). Importantly, CAS was not only a research organisation but also an administrative department of the State Council. The Chinese Academy embodied ministerial aspects and key responsibilities for the overall planning and guidance of Chinese science and technology. CAS greatly expanded after the Cultural Revolution: the number of research institutes increased from 116 in 1978 to 199 in 1998. By the 1980s, CAS was the second largest research organisation in the world after the Soviet Academy of Sciences (Kuhner, 1984).

The end of the 20th century was a testing period for both academies. With China's wider shift from state planning to a more market oriented economy, and leadership ambitions to encourage a technology-advanced and internationally competitive economy, CAS faced serious challenges in the 1990s. Overstaffing of non-research personnel, an aging researcher cohort perceived to have limited research potential, and out-dated research priorities were some of the main problems. In response, CAS launched a ‘Knowledge Innovation Program’ (KIP) to ‘re-invent itself’ (Suttmeier et al., 2006). KIP had four main elements (Zhang et al., 2011): changes in funding procedures, construction of science and technology infrastructure, human resource management, and ongoing evaluation. Through KIP, ‘innovation funds’ were introduced for research institutes to renew their facilities and enhance innovative performance. Research institutes were restructured and reduced in number to just 84, with some applied research institutes turned into enterprises (Liu and Zhi, 2010). To streamline operations, lower costs, and enhance capability, CAS simultaneously cut existing personnel and made efforts to recruit young talented researchers from abroad. About half of the 49,000 researchers in CAS, mainly those aged over 50, lost their life-long employment. For overseas Chinese researchers, high salaries, generous financial support and prestige positions were incentives to return back to the mainland (Liu and Zhi, 2010; Suttmeier et al., 2006). New evaluation mechanisms created competitive research environments where ambitious and talented researchers could strive to access greater resources and support. Zhang et al. (2011) report that KIP much increased CAS productivity, efficiency and technological performance.

Towards the end of the Soviet era, the Soviet Academy also faced accumulated problems and challenges. Inefficiency was a major concern, with shortcomings between funding and outputs. The Soviet Academy prioritised quantity over quality in terms of staffing and the sheer number of its institutes reinforced path dependent structures and limited accountability (Graham, 1998). In 1991, RAS was re-established – at first in uneasy relationship with the Soviet Academy of Science, but – as the Soviet Union broke-up – becoming the successor to the Soviet Academy (Fortescue, 1992). RAS became independent from the state, but retained a large infrastructure of institutes, science cities and hospitals across the Russian Federation. Over almost the next two decades, RAS remained relatively unchanged, inheriting the physical assets, ethics, attitudes, and practices of its Soviet predecessor (Fortescue, 1992; Josephson, 1994; Yegorov, 2009).

This inertia further aggravated the challenges facing RAS. It oversaw a vast and outmoded network of research institutes that it lacked the means to support. Block funding from the state dropped dramatically in the early 1990s as Russia struggled through multiple economic crises, and RAS was unable to replace this with competitive project funding.

Table 2
Chinese and Russian Academy of Sciences in 2012.

	Chinese Academy of Sciences	Russian Academy of Sciences
Acronym	CAS	RAS
Headquarters	Beijing	Moscow
Institutes	98 research institutes; 2 universities; 12 management organisations; 26 legal entities; 22 CAS invested holding enterprises	Over 450 research establishments, among them over 160 in natural sciences
Total staff	60,600	116,322
Research staff	48,400	48,315
Regional distribution	12 regional branches in 20 provinces	3 regional divisions in 83 federal subdivisions; 15 regional science centres
Budget	USD 6.62 bln	USD 2.64 bln
WoS papers (2014)	34,100	16,300

Sources: (CAS, 2012a, 2012b, 2013; Kostyuk, 2012; RAS, 2014; Rogov, 2013). WoS = Web of Science (SCI, SSCI, A&HCI), $N = 1.42$ million articles (accessed July 24, 2015).

RAS appeared unable to adapt to the new conditions of a non-planned economy. Favouritism and the lack of transparency intensified in allocating limited funds, doctoral awards and academy membership. Female membership of RAS remained low (Noordenbos, 2002). Many capable researchers moved to industry or pursued opportunities in other countries, particularly in Western Europe and the US. Years of debate ensued about reform. In 2013, RAS finally underwent major restructuring. A Federal Law removed RAS autonomy and it assets were returned to government control. These reforms were controversial and resented by many academicians. Nonetheless, further reforms are under discussion to change the mechanisms of science funding in Russia, with a view to making them competitive and fully grant-based (President of Russia, 2014). If implemented, this reform would obviate the block funding relied on by the Academy since its foundation and require RAS to compete with universities and other organisations for public research funding.

5. Nanotechnology research and the two academies

To further probe how the Chinese and Russian science academies have addressed recent processes of change in their respective countries, we use the case of nanotechnology to provide a comparative basis. Nanotechnology research in CAS began in the mid-1980s and has been supported by various nanotechnology programs (Bai, 2005; Wan and Bai, 2003; Zhang and Liu, 2007). China further expanded its national nanotechnology drive shortly after the US established the National Nanotechnology Initiative (NNI) in the early 2000s (Appelbaum et al., 2011). By the end of the first decade following the launch of the NNI, China had caught up with the US in the annual number of nanotechnology publications (Shapira et al., 2011). By 2011, depending on the source and method used (Cientifica, 2011), China was closing the gap with (in real US$), or had already exceeded (on a purchasing power basis), US nanotechnology R&D investment.

RAS also boasts a long tradition of nanotechnology research, going as far back as the early 1980s with research in microelectronics (Terekhov, 2013). The first large-scale non-military funding priority was approved in 2004. However, Russia was a latecomer in developing a high profile national nanotechnology programme. The Russian programme, adopted in 2007, mainly targeted commercialisation (Gokhberg et al., 2012), but a number of corresponding changes were made with the adoption of the 2008–2012 Federal Targeted Programme, which directed large blocks of science funding towards nanotechnology research. Increased funding, targeted priorities in few chosen areas, and government support for infrastructure and equipment gave a push to existing as well as emerging areas of Russian nanotechnology (Terekhov, 2012). In 2007, with initial government funding of about $4.4 billion, the flagship Russian Corporation of Nanotechnologies (now Rusnano) was founded to commercialise nanotechnology. Further initiatives were announced in 2009 involving $11 billion in public investment in nanotechnology development and commercialisation (Schiermeier, 2009). On a purchasing power basis, Russian government spending on nanotechnology exceeded that of both the US and China from 2008 to 2011 (Cientifica, 2011). Yet, as public investments in nanotechnology R&D and commercialisation in Russia expanded, numerous concerns arose about management and administration (Connolly, 2013; Moscow Times, 2015; RT, 2014; Westerlund, 2011).

The following sections further expand upon the nanotechnology case to explore markers of institutional change in the two academies.

5.1. Output and performance

In recent years, China has seen rapid growth in scientific publications (Liu et al., 2014, 2015; Zhou and Leydesdorff, 2006) and USPTO patent applications (Wang and Li-Ying, 2014), both in absolute terms and in comparison with other emerging economies. We find a similar pattern of rapid nanotechnology publication growth in China, especially when compared with Russia (Fig. 1). However, there are differences in how the relative national shares of the two science academies in nanotechnology paper outputs have evolved. CAS produced about 38,700 nanotechnology publications between 1990 and 2012. While CAS dominated Chinese nanotechnology publication activity in the 1990s early growth phase, the CAS share declined from about 70% in 1991 to 16.5% in 2012. RAS published nearly 22,800 nanotechnology publications from 1990 to 2012. RAS was dominant in the early development of nanotechnology in Russia, and has remained dominant, contributing roughly 70% of Russian nanotechnology papers over the full time period.

The increased role of other research performers in nanotechnology suggests dynamism in China's research system (Hong, 2008). Large research universities in Beijing, Shanghai, and other regions have developed rapidly over the past two decades. As the Chinese research system has expanded and become more nuanced, CAS no longer monopolises nanotechnology. Aided by university reforms, Russian universities have also expanded their roles in nanotechnology research, but less sturdily. Output in the leading RAS nanotechnology institute, the Ioffe Institute of Physics and Technology, plateaued from the late 1990s through the 2000s, and it was overtaken in nanotechnology publications by Moscow State University in 2006. However, when all the outputs of institutes are aggregated, RAS has maintained its sustained domination over Russian nanotechnology publication activity.

In terms of research quality, CAS produced 30% of the top-100 most highly cited Chinese nanotechnology publications in 1990–2012. Overall, the average number of CAS citations per paper was 5.2, which is higher than average citations of other institutions in the system: for university actors it is 3.9, and only 2.7 for public research organisations. Its relatively higher citation count corroborates CAS as an elite institution in the Chinese research system. Others also find that CAS has maintained higher average citation levels than top research universities in China (Ye, 2010). Some KIP analysts suggest that CAS reform was central to the success of the entire Chinese science and technology system (Huang et al., 2006).

RAS also demonstrates a concentrated picture: it garners the largest number of citations in Russian research system. RAS authors are associated with more than four-fifths of the 100 most highly cited Russian nanotechnology publications. RAS also has higher average citation than other institutions in Russia: 4.6, where publications with university affiliations and public research organisations are cited on average 3.2 and 3.9 times respectively. Nine out of the top ten cited Russian nanotechnology scientists have RAS affiliations, while the remaining scientist has a double affiliation with a university. Yet, while overall RAS still produces research of the highest quality in the Russian research system, there is a high degree of stratification within the Academy itself. A few key centres sustain high research standards, while peripheral institutes have lagged.

5.2. Re-creation

The development and engagement of new human resources is among the most important parameters for re-creation of an institution, particularly one involved in scientific research. Here, Chinese nanotechnology research demonstrates a steady increase in the share of new authors throughout the period of 1990–2005. About one quarter of these entrants are new authors with an affiliation with the CAS Graduate School.[1] The Academy's KIP reforms increased the training of graduate students – climbing from about 12,000 students in 2000 to over 40,000 students in 2015, which includes over 22,000 doctoral candidates (Ding, 2001; UCAS, 2015). The share of new nanotechnology authors with CAS affiliations remained at about one-tenth of all new

[1] Although we have undertaken efforts to distinguish individuals through text mining, many Chinese researchers share the same names and are associated with the same institution and sometimes department. This means that measures of new (and existing) authors are approximate.

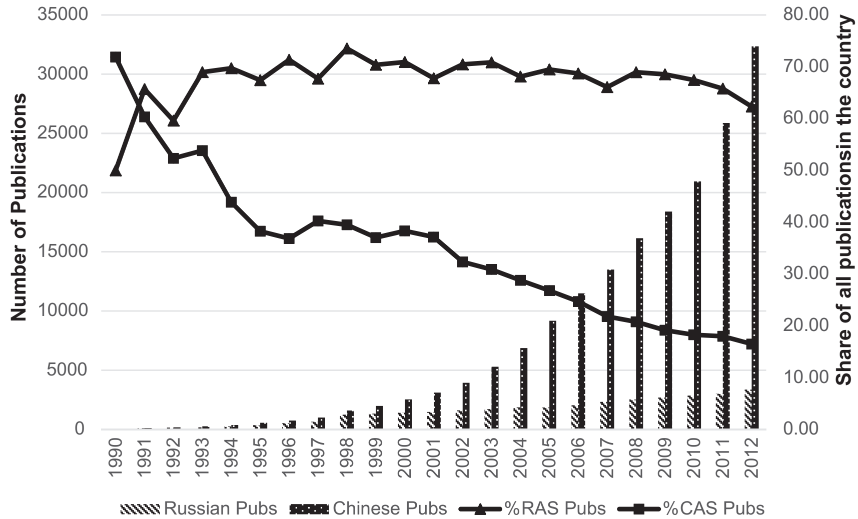

Fig. 1. Annual growth of nanotechnology publications in Russia and China, with shares of RAS and CAS, 1990–2012. Source: Web of Science. See text for details. For China $N = 176{,}472$; for Russia $N = 33{,}538$.

authors during the 2005–2012 period, reflecting the high rate of expansion elsewhere in the Chinese research system.

Home-grown students publishing their first papers with the Chinese Academy are not the only newcomers. Others are 'returnees': Chinese-born, foreign-educated researchers who return to China after research careers abroad, normally in Western countries (Zhang et al., 2011; Zhou and Leydesdorff, 2006). Talent programmes, including "1000 Talents", "Young 1000 Talents", and the "Recruitment Programme for Foreign Experts", were launched as a part of a broader political agenda of the Chinese government to emphasise human resources as the asset of the nation, and target overseas human capital, thereby complementing programmes to increase the quality of domestic human capital (Simon and Cao, 2009). It has been estimated that between 1999 and 2005 alone academic return to China increased from 7 to 30 thousand annually (Catcheside, 2011). While it has been reported that universities contributed most out of these programmes, within CAS, overseas talent management was also prioritised since KIP's second stage. From 1998 to 2009, over a thousand scientific returnees from abroad received positions in CAS (KIP Evaluation Group, 2011). Concerns that only the most elite Chinese research organisations have the necessary infrastructural conditions to support Western-style research, with continued research funding often influenced by informal networks that exclude newcomers, have prompted fears of follow-up brain drain from China. Nonetheless, the talent programmes, especially the "1000 Talents", continue to receive high volume of applications each year (Schiermeier, 2014). Despite the concerns, the circulation of talent, knowledge and skills have provided ongoing rejuvenation of research in China, from which CAS has benefited.

RAS demonstrates a contrasting tendency. The average age of nanotechnology research staff was 51 years in 2008, compared with 43.2 years in 1990 (Terekhov, 2011). The lack of newcomers is at the root of many structural problems of RAS, affecting rejuvenation, creativity and the improvement of scientific practices. Most importantly, RAS is suffering from negative selection (Chyernich and Grusdeva, 2011). The transition paths from university education to RAS research are archaic, and support stipends are unattractive, especially in expensive cities such as Moscow and St Petersburg, motivating the outflow of talented students to industry. Scientists have also been leaving Russia since the late 1980s, creating a human resources 'brain drain' (Gokhberg and Nekipelova, 2002). Efforts to facilitate return migration and to improve early career recruitment through 'Mega-Grants', 'Federal Target Programmes' and 'Young Researchers Awards' are yet to yield positive result (Erawatch, 2008).

The Chinese and Russian science academies also diverge in terms of organisational change. CAS initiated significant organisational innovation efforts throughout the late 1990s and early 2000s. KIP's attention to human resources management, training, and personnel circulation contributed to improvements in research output quantity and quality despite reductions in research institutes and personnel. CAS adopted management practices from developed countries and organised training for personnel abroad including visits to European and American research organisations. Merit-based evaluations were introduced for all staff – research associates and academicians alike, while financial incentives have promoted an intense 'publish-or-perish' culture (Huang et al., 2006; Jonkers, 2011; Suttmeier et al., 2006; Zhang et al., 2011). The evaluation procedures used by CAS have evolved in recent years and become linked to governance mechanisms (Luo et al., 2015).

In contrast, at RAS, mainly negative responses from Russian researchers were generated by state efforts to introduce peer-review and other standard academic practices. After funding declines, limits on new recruitment, and a perceived fall in prestige, RAS institutes took a defensive stance and adopted survivalist attitudes (Mirskaya, 1995). Low outputs were justified because of limited resources. There was resistance to any reforms attempts, and the Academy eschewed active engagement with government, business, and the public.

For about two decades, this isolationist stance preserved RAS as it was at the point of the breakup of the Soviet Union, albeit depleted of resources. For some academicians, the continuation of Soviet-era practices appeared to preserve their position but such rigidities weakened RAS in a world of rapidly globalising research. Autarky in sourcing and publishing research in-house (Josephson, 1994) was maintained despite new international publishing opportunities. About two-fifths of all WoS RAS nanotechnology publications appear in 20 journals; of these, 15 are translated versions of RAS journals first issued in Russian (Karaulova et al., 2016). Review is completed before English-language publication. Additionally, RAS authors frequently publish in their institutes' journals, akin to a working paper series. Such papers are widely read in Russia and then translated into English. Throughout the observed period in the top 20 journals, the number of nanotechnology publications originally published in Russian and then translated into English grew faster than publications submitted to international peer-reviewed journals. Until 1997, more publications appeared in international journals, but since 1997 publications in RAS journals grew at an average rate of 14.2%, compared with 7.9% for publications in international journals.

These and other path-dependent internal patterns inhibited international links and recognition, constrained interdisciplinary and inter-institutional collaboration, yet reinforced RAS dominance. By controlling access to the most prestigious and journals in Russia, especially in physics and chemistry, RAS acts as a 'gatekeeper'. Maintaining this privileged status quo is beneficial for the Academy hierarchy, but it also means that the broader Russian research system, including the 30% of nanotechnology publications that are not produced by the Academy, function under RAS oversight.

CAS has been relatively more successful in re-creating itself and in providing leadership for the larger Chinese research system. Yet, CAS also exhibits issues and inefficiencies. Early career researchers that KIP has attracted struggle with unreformed CAS governance procedures (Zhang et al., 2011). There is concern that the rejuvenation approach has introduced imbalances, with CAS hiring too many young scientists, and disproportionately more young scientists from abroad than from home. Additionally, KIP has reinforced collaboration barriers by its stress, in evaluation, on publishing in the Science Citation Index. This serves as a disincentive to collaboration across institutes and disciplines (Lu and Fan, 2010). The pressure to publish has also led to concerns (in universities as well as in CAS) about publication quality, research and authorship ethics, and plagiarism (Economist, 2013; Tang et al., 2015). KIP is also said to have further fragmented research agendas: scientists are compelled to supplement low base salaries by applying for multiple grants at a time (Cao et al., 2013). Such concerns mirror current processes of change within CAS. Yet, CAS also demonstrates self-reflexive learning patterns, launching another round of reforms to promote teamwork across its institutes and to alleviate salary pressures (Cyranoski, 2014).

5.3. Centrality

Both the Russian and Chinese Academies of Sciences were established to undertake fundamental research, supported by block funding from the state. Following the 1950 Sino-Russian break, each science Academy focused on its own model and approach towards agenda setting and subject specialisations, as the nanotechnology case exemplifies. Chinese nanotechnology research is relatively focused, building on existing strengths. Within a broad array of research topics, Chinese nanotechnology publications incline towards basic sciences, with particular strengths in chemistry (24%), materials science (42%), and physics (33.5%). CAS published in 140 subject categories over the observed period, with 76% of the papers covered by the top 10 categories (see Table 3). RAS published in 131 subject categories out of the 157 covered by all Russian nanotechnology. Nanotechnology research in Russia mainly focuses on physics (47.4% of all publications), and, broader, on basic sciences: condensed matter physics (20%), multidisciplinary materials science (13.3%), physical chemistry (9.0%), and optics (4.8%), with 80% of the papers covered in the top ten categories. These are also key system competences: non-RAS organisations published 76.5% of the papers in the top ten categories.

Table 3
Top subject categories, nanotechnology papers, for China, Russia, and the Chinese and Russian Academies of Sciences.
Source: Web of Science (see text for details). N = 175,811 (China); 38,549 (CAS); 33,285 (Russia); 22,611 (RAS).

Subject category	Percentage of all papers (1990–2012)			
	China	CAS	Russia	RAS
Chemistry	20.2	18.5	7.5	7.4
Materials science	18.5	14.3	5.9	5.5
Materials science, multidisciplinary	15.8	18.2	12.3	12.4
Physics	12.9	12.0	13.8	13.4
Physics, applied	10.4	13.8	13.5	13.7
Chemistry, physical	9.6	11.6	9.0	9.3
Science & technology - other topics	7.4	7.0	3.4	2.9
Physics, condensed matter	7.2	9.7	20.0	21.7
Polymer science	7.0	5.6	2.9	3.1
Chemistry, multidisciplinary	6.9	7.9	4.1	4.0
Physics, multidisciplinary	3.0	4.7	6.8	7.0
Optics	2.5	2.9	4.8	3.9

We also consider spatial centrality among our institutional markers. With Russia and China respectively the world's largest and third largest countries by geographical area, both Academies have research institutes spread across their extensive geographies. The Soviet Academy of Sciences was deployed to upgrade and 'enlighten' its regions (Amsler, 2007), resulting in formal presence in every one of Russia's 83 geographical subdivisions. RAS has three regional divisions (Siberian, Ural and Far Eastern) and 15 regional scientific centres, all initially designed to be actors of regional development. This widespread infrastructure imposes significant costs today for RAS. CAS did not, until the 1980s, have a strong regional development mandate, although there was some redistribution of branches and scientists to remote and rural locations during the Cultural Revolution of the 1960s. CAS presently has 12 regional branches, with institutes in about 20 provinces and municipalities, mostly in eastern and central locations in China.

Contrary to expectation, RAS does not exhibit a broad spread in the geographical distribution of its nanotechnology publications. While RAS institutes in 40 regions published in nanotechnology in 1990–2012, the majority of RAS research is produced in three large scientific knowledge agglomerations that together contributed 85.6% of all nanotechnology publications produced in Russia. These are Moscow City (34.8%) and the Moscow Region (12.1%), St Petersburg (25.3%) and Novosibirsk (13.4%). Over the study period, the RAS Moscow cluster has maintained its share at about 31% of annual publication output, whereas growth rates of other large regional centres, especially in St. Petersburg, have stagnated or declined.

The distribution of Chinese nanotechnology publications is somewhat more even, but is weighted towards the eastern coast. Beijing ranks first with 25.0% among the 33 regions with nanotechnology publications followed by Shanghai and Jiangsu with 13.4% and 10.0% of publications respectively. Seven other Chinese regions – Jilin, Anhui, Zhejiang, Hong Kong, Hubei, Liaoning, and Shandong – follow with a contribution of 5–7% each. Nanotechnology research at CAS is more geographically concentrated than for China as a whole: 42.4% of CAS nanotechnology publications are authored in Beijing, followed by Shanghai and Jilin with 16.1% and 12.5% respectively. The Anhui region contributed 5.6% of CAS publications, with other regions contributing less than 5%. In the nanotechnology domain, CAS has not contributed to the regionalisation of Chinese science to the same extent as other institutions in the national research system (Motoyama et al., 2014; Tang and Shapira, 2011).

This historically lower regional dispersion explains the relatively higher concentration of CAS research: the top five CAS institutes published over 90% of all CAS publications (in RAS the share is 85%). However, both within RAS and CAS, the trends point towards the overall relaxation of such high concentrations. While this is not enough to say that RAS and CAS are decentralising, regional and peripheral institutes in both academies are getting more chances at performing internationally. The trend is more noticeable in CAS. For example, Zhejiang had a 26-fold increase in publication rates in 2000–2012, and Guangdong and Shangdong each experienced 15-fold increase. None of the regional RAS branches demonstrated more than 6-fold increase in publication rates.

5.4. Competence and autonomy

Being central to research does not necessarily mean being relevant for other actors in the system. The positions of RAS and CAS differ significantly by their respective standing in their research systems: bibliometric indicators suggest that CAS is much more important for its institutional system than RAS. The isolationist stance of RAS is further aggravated by its lack of resources and its loss of institutional agency throughout the post-Soviet period. On the contrary, the initiative of CAS to re-invent itself and leverage resources to stay at the centre of political decision-making may have been crucial to its current prestigious leadership position.

It is often suggested that scientific collaborations strengthen research systems, facilitate creativity and innovation and serve as channels of skills and tacit knowledge transfer (Baba et al., 2009). Although RAS dominates scientific knowledge production in Russia, it has limited interactions with other actors in the national system (Table 4). Researchers of the RAS prefer to publish papers with collaborators in their own institute (26.3%) or with international collaborators (41.9%), but not so much with other Russian research organisations. CAS is more engaged in collaborative networks with other research performers: 37.2% of CAS publications were produced in collaboration with domestic authors, and another 18.6% with foreign authors. The embeddedness of CAS in the national research system may facilitate the diffusion of accumulated knowledge, best practices and research quality standards.

The internationalisation of research is now important for Russia and for China, which both were isolated from global research trends for a large part of the 20th century. The Academies in both countries collaborate internationally, although each has preferred partners: the US for CAS (34.5% of all internationally collaborated publications) and Germany for RAS (28.7%). Both CAS and RAS have more extensive and diverse international collaboration networks than their national research systems. Within CAS, programmes, such as the Hundred and Thousand Talents, have bolstered this tendency (CN.gov, 2014). Within RAS, the importance of international collaboration in some instances overrides domestic links. For example, the top publisher, Ioffe institute of Physics and Technology, collaborated 55.7% of its publications with foreign authors and 20% with domestic authors.

The resourcing of an institution is critical to its autonomy. CAS R&D expenditure has been rising exponentially: from $0.53 billion in 1998 to $5.45 billion in 2013 with an annual growth rate of 19% (CAS, 2014). CAS owns most of Chinese mega science facilities and is a focal point for research projects carried out by other research organisations (Suttmeier et al., 2006). RAS R&D expenditure has been climbing up steadily from $0.44 billion in 2002 to $2.26 billion in 2012, with a fall of values in real prices since 2009, when the indicator peaked (HSE, 2007, 2014). CAS and RAS both rely on block funding from the government that constitutes about a third (34% for RAS and 36% for CAS) of their R&D budget. The major difference is in other funding sources. Russian nanotechnology research funding is vertically structured. The funding provided by the Ministry of Education and Science is distributed vertically in a similar manner. RAS complements block funding with small grants from the Russian Foundation of Basic Research (RFBR; 67.3% of publications with funding acknowledgements). The bulk of funding for the Academy institutes comes through large-scale projects that are a part of the Federal Targeted Programme or from complementary funding from the Ministry of Education and Science.

Funding available to CAS is more heterogeneous, coming from different levels of government, among which the Natural Sciences Foundation of China (81.7%) and the Ministry of Science and Technology of China (56.4%) are the biggest, and from large-scale competitive project competitions. This funding structure enables relatively greater autonomy for each institute. However, where CAS research is predominantly funded from domestic sources (96.4%), RAS depends slightly less more on international funding (8.5%) aided by its extensive network of collaborations with Western Europe.

Table 4
Collaboration patterns in nanotechnology, 1990–2012 papers.
Source: Web of Science (see text for details). N = 38,690 (CAS); 22,794 (RAS).

Paper authorship	Percentage of total papers	
	CAS	RAS
Single author academy paper	0.8	5.9
Multiple authored paper published:		
By one academy institute only	26.3	26.3
With two or more academy institutes only	17.5	6.8
With national collaborators only	37.2	19.0
With international collaborators	18.6	42.0

The funding structure of CAS indicates its close links with the national science agencies of China. In fact, CAS has maintained the role of a central science policy-making actor in the Chinese system, as well as the role of a research performer (Huang et al., 2015). CAS executes science advisory function to an extent that is permissible in an authoritarian state. Elite academicians (*yuanshi*) normally have science advisory functions, and the role of science bureaucracy has been increasing in policymaking (Cao et al., 2013). China's NNI was an initiative that originated in CAS, and was promoted in the government science agendas by the Academy (Appelbaum et al., 2011). In the mid-2000s, about one-fifth of the members of the National Steering Committee of Nanotechnology were from CAS (Peng et al., 2005). CAS thus performs a dual role: it is an institution with a significant degree of agency; it sets own agenda and actively contributes to national policymaking. At the same time it is a focal point for frontier research in the Chinese science system and adapts endogenously to meet the central government's expectations.

In contrast, the Russian nanotechnology initiative was government-directed. The initiative came not from RAS, but from Kurchatov Nuclear Institute (Schiermeier, 2007). Excluded from the inside deliberation, RAS researchers were forced to 'catch up'. Moreover, a Russian Presidential Decree in 2006 deprived RAS of its main instrument of autonomy: the President of RAS, while still elected by the Academy, was required to be approved by the President of Russia. Major new science policy projects, such as the 'mega-grant' programme of new laboratories under the supervision of internationally recognised scientists, are now targeted to universities rather than the Academy. The 2013 reform – which deprived RAS of its property and established a Federal Agency to supervise and manage it – further continued this line of policy and placed RAS under tighter federal government control.

6. Discussion

Our analysis of growth dynamics, organisational learning, institutional agency, and other markers has shown key differences in the approaches deployed in Russia and China to modernise their science academies in the context of broader changes in national research systems. Both states have moved towards market economies, and new approaches to innovation through the application of science have been emphasised. RAS and CAS have been deeply affected by these new realities. However, as illustrated through our examination in the nanotechnology domain (Table 5), there are striking differences in performance and outcomes from these two public research organisations.

Both science academies remain key institutions in their respective national research systems. However, the system dynamics differ. The Chinese research system is growing rapidly, including in nanotechnology. In these circumstances, CAS has maintained functional capacities of prestige, high quality research, integration with decision-making bodies, and recognition of outstanding academics, rather than dominating overall research in the system. Instead, it assumed the elite role and became a hub of frontier science, accumulated cutting edge facilities and a research policy decision-making think tank. In Russia, while there is a steady growth of publications and some systemic reforms produced some positive overall dynamics, especially for universities, RAS has shrunk in size and its research is increasingly concentrated in a few central centres. Yet, RAS maintains a dominating role in Russian research by acting as a gatekeeper in research.

Each science academy has its own on-going challenges. Organisational innovations started in the 1990s prepared CAS for active engagement in the recent expansion of Chinese science. While CAS has restructured, it has also increased its openness to newcomers and returnees. However, the emphasis on standardised publication metrics in evaluation has introduced new problems, including those of research integrity and the

Table 5
Institutional change markers: summary.

Marker	Component	Chinese Academy of Sciences	Russian Academy of Sciences
Outputs	Volume	CN rapid output growth: 35.1% ACGR 1990–2012; 32,357 publications in 2012. CAS steady growth: 26.7% ACGR. CAS contribution is 21% of all CN publications but CAS share falling: 70% in 1990, 16.5% in 2012.	RU growth: 23.6% ACGR 1990–2012; 3367 publications in 2012; RAS matching growth: 23.6% ACGR. RAS domination: overall 70% of all RU publications, but share fell to 62,3% in 2012.
	Quality	'Elite' science: CAS has highest average citation among CN institutions, but excellent research is not limited to CAS.	'Leading' role, 'elite' science: RAS dominates RU high quality research.
Re-creation	Rejuvenation	Higher rates of newcomers than other CN institutions: over 25% of new CN researchers (1994–2005) are CAS newcomers.	Low rates of newcomers, negative selection: RAS not attractive place to work, 'brain drain' to industry and abroad after students receive advanced degrees at RAS. Rapid aging of research personnel.
	Learning and innovation	High rate of organisational innovation and diversification: overarching programmes, new institutes and facilities alongside with active system development and implementation of large-scale science and technology policy programmes.	Low rate of organisational innovation. Academy scepticism and conservatism during large-scale government reforms and science and technology programmes. Reform attempts are sporadic.
	Path dependence	Long-term internal and external-induced reforms. Effort to introduce endogenous change, layering of new practices and old path dependencies.	Dependency in journal publication pathways. RAS is gatekeeper. Trend towards setback in internationalisation. Dependency in recruitment, promotion, salary structures, organisational hierarchies, decision-making processes.
Centrality	Subject centrality	Narrow research focus, mainly basic sciences: chemistry (18.5% of all CAS publications), multidisciplinary materials science (18.2%), materials science (14.3%).	Wide research scope, with focus on basic sciences and physics: condensed matter physics (14.8%), applied physics (9.3%), physics (9%). Trend towards narrowing in research scope.
	Spatial centrality	CAS 'centrality' in Beijing (42.4% outputs), Shanghai (16.1%), and research clusters: Jilin and Liaoning. CAS research is concentrated in major areas; Chinese research is more spread out.	RAS 'Supercentrality': Moscow and the Moscow Region, St Petersburg and Novosibirsk produced 85.6% of RAS outputs. RAS research is more diversified than RU research.
Competence and autonomy	Collaboration and diffusion	CAS diffused in the domestic research system: 37.2% of outputs are collaborated nationally. CAS leads CN research internationalisation, especially with the EU.	RAS is less diffused in domestic research, although a preferred partner for universities and public research organisations. Best RAS institutes mostly collaborate internationally.
	Institutional agency	Medium level of institutional agency, internal agenda-setting, participates in policymaking. Independent choice of research themes. Vertical governance structure.	Low level of institutional agency. Isolationism, averse to reform. Internal agenda setting. Vertical governance structure. Decline of agency in 2000s.
	Resources	Growth in resources, from domestic sources. CAS demonstrated greater autonomy due to higher levels of internal funding and greater ability to compete for government funds.	Decreasing real resources. Diversity of funding: RAS receives 1/3 of RU civilian R&D, in block funding; 8.5% funded by the EU. Centralised agenda-setting and funds allocation by RAS Presidium.

Notes: CAS = Chinese Academy of Sciences; CN = China; RAS = Russian Academy of Sciences; RU = Russia; ACGR = Annual Compound Growth Rate; WoS = Web of Science. Percentages refer to 1990–2012, unless indicated.

misalignment of effort. For RAS, its resistance to change has induced exogenous intervention and subsequent disruption in the context of a system that cannot further wait for the Academy to change. While Russia's government is investing in universities (Gokhberg et al., 2009), RAS is still troubled by declining resources, the lack of rejuvenation, and unreformed scientific practices. It suffers the loss of facilities, decaying laboratories, and an aged workforce.

Since the early 1990s, we saw that CAS has shifted strategic priorities and engaged with the national policy system. This institutional reinterpretation (Jackson, 2005) has led to a reconfiguration of the position of CAS within Chinese research and policy, yet also reinforced its centrality and importance. RAS has undergone a different experience: it has remained isolated and lacked institutional diffusion with other actors in the system. It has become dependent on its control over scientific knowledge production channels, prestigious journals, awards of doctorates and second doctorates and other factors that have allowed it to maintain a central position in the research system and act as a quality control body or a 'gatekeeper'. These privileges provided RAS with incentives to resist attempts at changing the institutional rules, despite many calls to do so. RAS has tended to preserve its internal structures and resist 'soft' attempts to change the 'rules of the game', including those which have come from government in the recent years (Allakhverdov and Pokrovsky, 2004). The mismanagement of the Academy property and low levels of diffusion with industry made it possible for the government to impose change on RAS, as seen in the exogenous reforms of 2013 which have reduced agency on the side of the RAS. Rather differently, CAS draws other major research organisations in the Chinese research system to engage in collaborative projects or compete for funding. The explicit 'publish-or-perish' culture of current Chinese science fosters competition among domestic research organisation for funding and awards. As an institution that produces research, but also actively participates in policymaking and the rule-setting procedures, CAS stands out among other research organisations, stimulating the competition as well as itself. In this context, while both countries continue to face persisting challenges and new problems, institutional activities and internal dynamics of 'leading' institutions are in both cases linked to system change.

7. Conclusions

The development and testing of the institutional change markers framework presented in this paper integrates existing approaches in the literature into an overarching model applicable for measuring institutional change in research systems. The framework relies on an institutionalist approach that recognises the tensions induced in existing structures by change. The framework suggests that many path dependent features of the RAS are rooted in a longer historical legacy of the Soviet Academy. For instance, the lack of institutional diffusion in the Russian science system today is due to academic practices of thematic segregation of research in the Soviet era, which fostered disciplinary divisions, narrow specialisation in training and limited collaboration (David-Fox and Péteri, 2000). Similarly, CAS has historically been a hybrid organisation, combining research and policymaking functions. Unlike RAS, however, the process of change within CAS preserved and cultivated this distinctive trait. Most recently, the President of China, Xi Jinping, has set CAS the dual goal of become a cutting-edge research institution, as well as a top think tank, to which CAS leadership responded by launching a new Pioneer Initiative (Bai, 2016). Xi also seeks to foster research capability and innovation in Chinese universities; while this could potentially challenge CAS, it seems more likely

CAS will find ways to also benefit from China's new innovation initiatives. To date, we have shown that CAS is adept in both integrating national policy imperatives and in recognising the importance of globalising research systems and the increasingly networked academic practices of scientists.

Although this paper does not seek to prescribe new directions for Chinese or Russian research policy or for their respective academies, we hope that the comparisons of institutional adaptation in these two systems does encourage reflection and discussion. More broadly, the paper contributes to the debate on the variety of institutional forms within public research systems. In the last decades of the 20th century, many countries made state-initiated moves towards reforming research institutions and their funding mechanisms. At the same time, some systems have become public and university research exemplars, especially the US system (Crow and Bozeman, 1998). Emerging economies benchmark such institutional schemas elsewhere (Rip and van der Meulen, 1996) as they seek to improve the performance of their own systems. In this context, other models to organise public research, such as science academies, are scrutinised and debated. For our case study countries, the outcome of this debate has been different. The Russian government has taken a course towards a university-based model, and has largely eschewed the Academy. In China, despite criticisms of some of its practices, the Academy of Sciences has successfully accomplished a transformation to remain an integral part of China's heterogeneous research landscape and adjusted to imported approaches that highlight university research. Reinvigorated models of public scientific research organisations may continue to be central to the research systems of some transitional economies, as in the case of the Chinese Academy of Sciences, paralleling the situation in established mature research systems with leading state-funded non-university research organisations, such as France's CNRS and Germany's Max-Planck Society.

This comparative case study of the Russian and Chinese science academies also highlights how available evidence can be applied in the context of an institutional change marker framework to develop comparative insights related to processes of institutional adaptation. The nanotechnology field selection and sources used in this study offer advantages of comparability. However, the limitations of the study should be kept in mind. For example, while we have used nanotechnology to probe the nature of institutional change in China and seen the growth in research outputs, this is not in itself evidence of success in China's nanotechnology commercialisation effort. Multiple concerns exist for nanotechnology commercialisation in China, including challenges of technology transfer and limited ethical and environmental regulation (Shapira and Wang, 2009; Gouvea et al., 2012). Further study of the dynamics of institutional change in these two science academies would benefit from examining other fields and would be complemented by in-additional in-depth case studies. Nonetheless, the contextual application of the institutional change markers framework offers insights about the processes of institutional change in transitional states, which often occur over lengthy periods rather than as short-term shocks.

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