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A functionalist framework to compare research systems applied to an analysis of the transformation of the Chinese research system

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ABSTRACT

This paper presents an analytical framework for the comparative analysis of National Research Systems. We follow evolutionary accounts of the research system in combination with insights from functionalist economics of innovation and organisational theorists. We also illustrate the potential use of this framework by applying it to an analysis of the Chinese research system's transformation between 1980 and 2005. During this period, this system is considered to have gradually changed from a centrally planned system to a mixed model. This implies a move in the direction of a 'perfect market ideal type'. The increased performance of the overarching functions of the research system can be partially explained by these institutional changes.

1. Introduction

The main aim of this paper is to develop and apply a novel analytical framework for the comparative analysis of research systems. This framework can be used for cross-country-comparative analyses of research systems. Instead, this framework is used to guide an analysis of the transformation of the Chinese research system in the period 1980–2005. China is an interesting case because, in the early 1980s, it approached the 'centrally planned ideal type', discussed further in the theoretical section. Twenty five years later, it may still have some of these features, but it has moved towards the 'perfect market ideal type'. It is now at an intermediate position in which it shows a mix of features from both types. The framework introduced in the next section, allows us to track this development over time across several functions, which are considered characteristics of research systems. The paper builds on an analysis which was presented in Jonkers (2010). It is limited to public sector (basic and applied) scientific research.

2. Analytical framework

The framework developed here builds on institutional analyses of the research system which adopt evolutionary perspectives. Research is understood as a socially based activity which takes place in a complex multi-layered institutional context.

The complex of institutions, which together govern the intellectual organisation of science, is closely related to the cognitive context in which a scientist operates. It consists of a complex of market-like institutions governing the allocation of credit to actors according to the perceived quality and usefulness of their knowledge claims. A second set of institutional forms governs the societal support and regulation of research. This complex of institutions is related to the material context in which researchers operate; the relationship between the research system; and the other subsystems of a society which supplies these material resources (Whitley, 2000).

It is the societal organisation of research; the National Research System, that is at the centre of this paper, although reference is made to the closely related national and global scientific communities, where scientists exchange knowledge claims for recognition. Apart from being part of a scientific community, researchers are also employed by a professional work organisation (Whitley, 2000). These organisations commonly include a mix of universities and public sector research organisations. Together these organisations, and the organisations that coordinate their activities, form the National Research System. Following Van der Meulen and Rip, 1998 four interrelated levels are identified in National Research Systems: the operational level of research groups; the organisational or management level; the strategic level of research funding organisations; and the policy-level of government actors. The latter formulate the main political, social, and economic objectives and decide on the topics of science and technology policies.

It comes as no surprise that a country's absolute and relative public and private expenditures on scientific research, as well as

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the size and average educational attainment of its population, are reflected in its scientific output. Differences in the performance of research systems, however, cannot be reduced to differences in public investment, human capital, or other inputs alone. Qualitative differences between research systems are also thought to influence their relative performance. The institutional cum organisational set-up of National Research Systems are the result of historically rooted trajectories of growth that are strongly intertwined with the overall economical, social, and political development history of the respective countries. As a result, all nations differ not only in the respective mix of their scientific knowledge base, but also in the institutions that govern the societal organisation of research in their national systems.

These differences exist at all four levels of public sector research systems as well as with the interaction between actors at these levels. Governments differ in the extent to which they exert active control over the direction of research, their motivations for, and the size and nature of their funding of research. National systems also differ in the nature and the 'ecology' of intermediary organisations (Van der Meulen and Rip, 1998). At the level of research organisations, there are differences in the 'ecology' and respective roles of different kinds of public research institutes and universities. The nature of these organisations also differs between countries, in terms of their management and evaluation of the research units within them. At the operational level differences exist in the relative degree of power invested in research chairs, the freedom of these and other actors to decide the direction of their research, and the freedom and opportunities for generating research funding.

National Research Systems have previously been compared on the basis of their organisational set-up. This is not the (sole) approach taken here. Instead, systems are compared on the basis of systemic institutional characteristics. The approach taken draws on the recent literature that introduces the functional analysis of innovation systems (McKelvey, 1997; Liu and White, 2001; Hekkert et al., 2007; Bergek et al., 2008). Such a framework not only captures the structural characteristics and dynamics of a research system, but also the dynamics of a number of key processes or functions that directly influence the development, diffusion and use of new scientific knowledge. Therefore it can be used to capture the overall performance of the research system (Bergek et al., 2008). A general definition of a system is a '*group of components (agents, institutions, networks) serving a common purpose,* i.e. *working towards an overall function*' (Carlsson and Stankiewicz, 1991; Bergek et al., 2008). For research systems, this overall function is the development, diffusion and utilisation of new (scientific and research management) knowledge (adapted from Bergek et al., 2008).

The functionalist classifications used in the systems of innovation literature are not directly applicable to an analysis of the research system, because the functions relevant to both types of system differ. While recent analyses of the research system do not directly take a functionalist approach this paper does draw on the typology offered by Rip and Van der Meulen (1996). They classify research systems according to two dimensions, namely the degree of 'steering' and 'aggregation'. Rather than using these dimensions directly the framework proposed in Fig. 1 includes the function 'influence on the direction of research' which is used by Bergek et al. (2008) albeit differently. Whitley (2003) uses two overarching characteristics to classify research systems; the degree of intellectual pluralism and the intensity of reputational competition. He later expands this by explaining how four institutional features: 'the degree of state delegation of resource control to researchers'; 'the degree of centralisation of decision making within employment organisations; 'the degree to which there is a strong and stable hierarchy of research organisations'; and 'the degree of organisational segmentation of goals and careers', impact on these characteristics. The institutional features as identified by Whitley and the two overarching characteristics of research systems, inform the development of the functionalist analytical framework described in the next section. The fact that the nature and overall function of research and innovation systems differ, does not mean it is impossible to draw lessons from the functionalist innovation literature. Following the evolutionary classification of innovation systems proposed by McKelvey (1997) it can be argued that the main relevant functions of both research and innovations systems revolve around the generation of novelty, selection mechanisms as well as the retention, absorption and diffusion of new knowledge.

The creation of new knowledge in the research system is related to the availability of research infrastructure, the presence of highly skilled manpower and a suitable organisational structure which supports and promotes the generation of new scientific knowledge. At the intermediary level, the generation of knowledge is closely tied to the way resources are allocated. As Whitley (2003) indicated, the level of control over the distribution of resources and the direction of research both between levels of the research system and within research organisations, can also have its impact on creativity. Novelty generation also takes place at the level of research organisations, through the introduction of new organisational forms which can be more apt at performing functions of the research system. The set up of new (sub-) organisations can also have its impact on the hierarchy between research organisations mentioned by Whitley (2003). The resulting ecology of research organisations and the degree of variation between the organisational forms operating in the research system, may also be important.

Evaluation can lead to the selection among alternative knowledge claims and the research programs that build on them, among individual researchers and even among (sub-) organisations. The selection functions are often closely tied to the intellectual organisation of science in most research systems. New knowledge claims are exchanged for credit in the national or global scientific community. Evaluation mechanisms of research organisations and individuals tend to draw on this process either through assessments of the visibility of knowledge claims or through the use of peer review. In some research systems, this process relies primarily on the local scientific community. Others draw on the evaluation by peers working around the world. Scientific quality criteria are not the only factors influencing the evaluation process. Closeness to policy circles and/or the contribution to non-scientific objectives (e.g. industry, policy making) can, in some research systems, have an important influence on evaluation mechanisms. The degree of selection among alternatives can be more or less extreme – depending on its influence on resource allocation decisions.

A third central function of the research system revolves around the retention of scientific knowledge, its absorption and diffusion. Diffusion depends on the nature of: local scientific networks and inter-organisational mobility; international cooperation; collaboration; mobility; the training of new scientific manpower and the interaction with other subsystems of the innovation system (education, industry, government administration).

Apart from the identification of the relevant structural elements (networks, actors and institutions) this paper focuses on the functions introduced in Fig. 1 to analyse the transformation of a research system. This figure provides a framework for the functionalist classification of research systems by placing them on a continuum between two extreme poles (*ideal types*) across seven dimensions. Apart from the comparative analysis of different research systems, the framework can also be used for a comparison of a single research system, at different points in time (see also Liu and White, 2001). This paper uses the latter approach.

It is clear that the functions shown in Fig. 1 overlap considerably. Consider, for example, the 'openness of the system to the global scientific community'. Indirectly this function has an impact

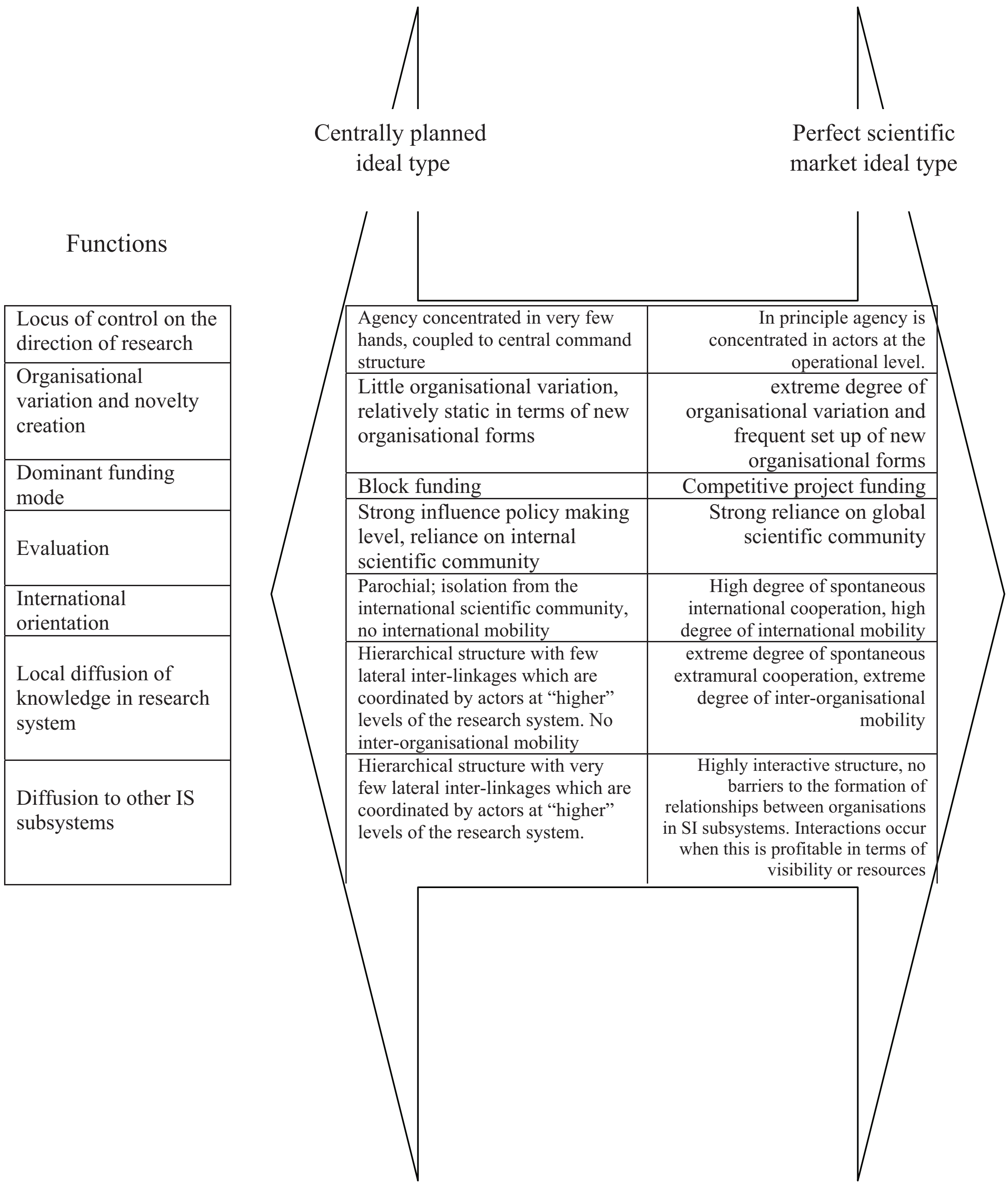

Fig. 1. The classification of research systems across seven functions.

Adapted from Jonkers, 2010.

on evaluation procedures, e.g. through international peer review and the use of international citations indices. It could also affect organisational variation and novelty creation, since institutional learning from other countries may be easier in a system that has a larger international orientation. The influence on the direction of research depends partially on the extent that global science influences local research agendas. Even local diffusion, and diffusion to other SI subsystems, can be influenced by international orientation. For example, research organisations employing scientific experts which are integrated in the global scientific community, can perform a gatekeeper role for both the local science system as well as business and higher education.

What is not included in this schematic functional classification of research systems is the overall function of the creation of new scientific knowledge. Neither are the secondary overarching functions related to the research system's potential positive impact on technological innovation and economic activity, as well as the training of human scientific and technological capital (Bozeman and Mangematin, 2004). The reason for excluding these central functions in Fig. 1 is that as the main dependent variables they can be used to measure the output of the system in terms of the production and visibility of new knowledge claims. While there is some ground to assume that centrally planned models do not perform well at the creation of new scientific knowledge, the 'perfect scientific market ideal type' may not fare any better. Considering that most research systems in OECD countries have a mixed model lying somewhere between the two extreme poles, one could assume that such a mix offers a better outcome. Whether mixed systems that lie closer to the 'centrally planned pole' vs. those who are closer to the 'perfect market ideal type' fare better on this overall function is an empirical question. In general the more competitive systems are thought to be more amenable to intellectual pluralism and creativity, than the more centralised ones (Whitley, 2000, 2003).

3. Methodology and sources

The paper will engage in an analysis of the transformation of the Chinese research system. It starts by analysing the starting position of this system across the seven functional dimensions introduced in Fig. 1. In describing this starting position in the early 1980s, it will provide some limited historical background on the building up of the centrally planned research system in the 1950s; early 1960s; and the period of turmoil which followed during the Cultural Revolution. This is important because the features of a research system are the result of historically rooted trajectories of growth. Second and third, it will provide diachronic analyses of the main changes introduced in two time periods 1986–1995 and 1996–2005 and the way in which these changes are related to the functions introduced in Fig. 1. The two ten year time periods under consideration coincide with important periods in the Chinese policy cycle.

The first period coincides with that of the 7th and 8th five year plans. The second with the 9th and 10th five year plans. In the first of these five year plans (the 7th and 9th respectively) Chinese S&T planners have outlined comprehensive new sets of measures and goals. The first five years are, therefore, characterised by the implementation of new changes. These are then developed in more detail during the remaining ten year period. In 2005–2006 a new period started which aims were outlined in the 11th five year plan and the medium to long term S&T development plan which sets aims for the year 2020 (Cao et al., 2006). At the time of writing it was still unclear how the announced measures will be implemented and what their effects will be. The discussion of this period is therefore limited in scope.

The substantive part of this article draws on existing literature on the development of the Chinese research system. It consciously avoids presenting a large amount of available historical data that is unnecessary for the argument. In addition to scientific literature, it uses data collected through interviews with scientists and officials in organisations at different levels of the Chinese research system. This includes ministries, the research council, universities and the *Chinese Academy of Science (CAS).* It draws both implicitly and explicitly on background and statistical data produced by the *Chinese National Bureau of Statistics*; the *Ministry of Science and Technology*; the *Ministry of Education*; the *Chinese Academy of Sciences*; and the *National Science Foundation of China*. Finally it uses information from publications in the Chinese media and background and news articles published in scientific journals.

4. The transformation of the Chinese research system

4.1. The starting position; locus of decision on the direction of research

In the 1950s, the Chinese research system was remodelled on the Soviet system. The *CAS* had ministerial status. Like its Soviet counterpart, it was the central national administration agency responsible for the organisation of scientific and technological research (Suttmeier, 1974). Both the *CAS* and leading scientists asked for a greater level of scientific autonomy and resources. However, actors at the policy and political level had a strong influence over both the planning as well as the content of science (Wang, 1993). In this period, some strands of scientific research were under attack in the Soviet Union. Under this influence, relativity theory, quantum mechanics, resonance theory, mathematical log *c* and cosmology were all, at one point, discarded because they were deemed to be incompatiable with communist/maoist ideology. Lysenkoism (called Michurianism in China), maintained a considerable influence on biological and agricultural research, even after it had been discarded in the Soviet Union (Wang, 1993; Schneider, 2003).

4.2. The starting position; variation in research organisations

The 1950s saw a reduction in the variation of scientific research organisations. The *CAS* institutes were primarily responsible for conducting basic research. Before the communist revolution, universities also had an important research function. But in the new systemic constellation their mission was limited to higher education. As discussed by Schneider there were occasional exceptions in this respect (IDRC, 1997; Schneider, 2003, Cao, 2004). Mission oriented ministries started to establish other academies for applied research in health (the Chinese Academy of Medical Science), Agriculture (the Chinese Academy of Agricultural Science), etc. Provincial and municipal governments also supported their own academies and universities (Wang, 1993, Cao, 2004).

4.3. The starting position; resource allocation, and the main funding mode

The work units (‘dan wei’) which employed researchers controlled most of the social, political and economic aspects of their researcher’s life. These work units received block funding through a non-competitive allocation process. In theory, the work units guaranteed their employees lifelong employment. Both Yu (1999) and Schneider (2003) argue that this mode of funding resulted in considerable waste, redundancy and a general lack of responsiveness to the changing needs of the scientific community. In addition to block funding research institutes also receive part of their funding through government planned research projects which were often decided in the five-year national economic plans (Xue, 1997).

4.4. The starting position; Evaluation

In the early 1980s there was little in terms of systematic evaluation of programs, research organisations or individual scientists. In this period there were some reviews by foreign experts. The system of national and provincial level awards for researchers who made an important contribution to, for example, agriculture, was re-established after being abolished during the Cultural Revolution.

4.5. The starting position; international orientation

During the 1950s, the Soviet Union was the main foreign source of scientific knowledge, expertise and influence. Scientific articles as well as textbooks were translated from Russian (Harlan, 1980; Wang, 1993; Schneider, 2003). After the two regimes fell out in the late 1950s; early 1960s; the Chinese leadership promoted autarky in science. This resulted in even weaker relations to the international scientific community. Contact with foreigners, even the use of foreign knowledge, was met with suspicion. During the Cultural Revolution the increase in the repression of intellectuals, including many scientists, further isolated Chinese research (Wang, 1993; Schneider, 2003).

4.6. The starting position; Local diffusion of knowledge in research system

Funding was allocated to work units rather than to individual scientists. Also in many other ways these work units had a great degree of control over the life of their researchers. As a result, they often developed a sense of ownership over their workers. Schneider (2003) argues that this feeling of ownership could extend to the researcher's field of expertise and even to specific research questions. The work unit system in combination with other elements of the centralised nature of the research system, led to a lack of inter-organisational mobility as well as spontaneous extramural interaction between research organisations (Schneider, 2003). Extramural collaboration did occur, but often in a centrally planned fashion. In the late 1950s and early 1960s, large numbers of researchers were mobilised to target specific topics of national interest. Eye-catching examples of this includes the development of atomic bombs and satellites (Wang, 1993). These achievements are still often referred to as examples of achievements of the centrally planned research system.

4.7. The starting position; interaction with non scientific users

As was the case in the Soviet Union, the 'innovation' system was characterised by hierarchical planning and functional differentiation between organisations responsible for basic research, applied research, product development and higher education (Xue, 1997; Liu and White, 2001; Sigurdson, 2002). In the later 1950s the *CAS* had been complemented by the *State Science and Technology Commission (SSTC)*. This commission was mainly responsible for applied research and technological development. It was intended to control and coordinate the interaction between organisations in the different segments of what today is referred to as the 'national innovation system' (Wang, 1993). Between the 1950s 1980s the transfer of knowledge from public research institutes to production oriented enterprises was limited due to their functional separation. State owned enterprises also had limited R&D capabilities and few incentives to engage in R&D (Xue, 1997).

4.8. The starting position; ideal type

Before the Cultural Revolution and still in the early 1980s the research system thus approached the 'centrally planned ideal type' introduced in Fig. 1. Of course this centralisation was not complete. For example, provinces and municipalities became active in funding and coordinating research in their own research academies and institutes. The existence of several potential patrons could have offered researchers some more leeway to influence the direction of research (Berry, 1988). Research funding at the provincial level was, however, mainly restricted to applied research and technological development.

4.9. Period leading up to the transformation process

The Cultural Revolution resulted in a large upheaval of the research system. The R&D budget suffered radical cuts (the 1967 budget was 15% of what it had been in 1965). The *CAS* lost its ministerial status and much of its influence and research institutes. The SSTC was disbanded. Universities and research institutes were closed. Scientists suffered severe forms of harrassment. They and prospective students, were sent to the countryside to be 're-educated'. There was minimal scientific autonomy and most scientific research grounded to a halt (Suttmeier, 1980; Wang, 1993; Cao, 2004). When scientists were again allowed to publish, both scientific praxis and content were subject to strong political and ideological influence (Wang, 1993; Cao, 2004). Scientific autonomy remained minimal as was the role of the scientific community in quality control and resource allocation. These resources had suffered radical cuts (Wang, 1993). Universities were closed in 1966 and when they re-opened in 1973, curricula and the selection of students emphasised ideology above academic training (Cao, 2004; Hayhoe, 1996). Only in 1978, did the Chinese leadership rehabilitate scientific research and scientists at the 'Second National Conference on Science and Technology'. It gave a central place of the modernisation of the research system in the modernisation of agriculture, the military, industry and the economy (the four modernisations). Despite ambitious plans, repairing the damage which the Cultural Revolution had inflicted upon the research system, characterised the initial years. Both the Chinese leadership and the scientific community realised, however, that the 'centrally planned research system' had important systemic weaknesses which needed to be addressed (Wang, 1993; Suttmeier and Cao, 1999). In the early 1980s, the government started a gradual transformation of the research system. This is discussed in the following sections.

4.10. The first period of transformation, resource allocation, main funding mode

In the early 1980s, the *CAS* experimented with a research council for the distribution of funding. Its motivation for this was to counterbalance the new focus on applied research. In the mid 1980s the *Natural Science Foundation of China* (*NSFC*) was set up on the basis of this experiment (CAS, 2002a). The *NSFC* is a 'pure' research council, which allocates project funding on a competitive basis, after an open bid for proposals. It follows a relatively strict process of peer review. In its organisation it was modelled on its Western counterparts such as the *US National Science Foundation* (Schneider, 2003; Cao, 2004). Its budget increased rapidly over the past 20 years from 80 million RMB in 1986–2.7 billion RMB in 2005 (NSFC, 2005a; NBS, 2006). This corresponds with an annual increase of approximately 20%. It is important to realise, however, that the value of the RMB did not stay the same throughout this period. The establishment of the NSFC and the rapid growth of its budget resulted in:

- Greater scientific autonomy: the control of the scientific community over the direction of research increased.
- An increase in the relative share of competitive project funding at the expense of block funding.
- The gradual re-establishment of scientific research capabilities in universities which are among the main recipients of NSFC funds (NBS, 2006).

Another major development in the mid 1980s was the establishment of another mechanism for the allocation of competitive project based funding. The high technology development or '*863 program*' was established in response to the American, European and Japanese large scale strategic funding programs from the 1980s. The main aim of the *863 program* was to prevent China from loosing connection with the developed world in 'high-tech' sectors. Eventually it was meant to allow for a 'catch up' in priority fields of research and development (Suttmeier and Cao, 1999; MOST, 2003). The program was coordinated by the re-established *SSTC*. In 1998, the SSTC was replaced by the newly established *Ministry of Science and Technology (MoST)*. In comparison to the *NSFC*, non-scientific administrators have a relatively large role in the setting of priorities and the selection of projects in the *863 program*. However, to a lesser extent, peer review also played a role in the allocation of funding. Some analysts argue that considering the broad scope of the *863 program*, it was characterised more by an attempt to be inclusive than by its stated aim of concentrating resources in a few priority areas (Wang, 1993; Suttmeier and Cao, 1999). *863 project*s are considerably larger in size than the average NSFC project. The increase of the budget of the *863 program* over the past decade was slower than the NSFC budget, though still considerable size (NBS, 2001, 2006).

The increase in project funding resulted in a decline in the share of block funding in the budgets of research organisations. The government also reduced the block-funding of research institutes. It did so to force research institutes to look for other ways of generating resources (IDRC, 1997; Suttmeier and Cao, 1999).

For research institutes focused on basic research, the government continued to fund their basic operating costs while the rest of their operating costs and research funding would have to be raised from other sources including the *NSFC* (Xue, 1997). Stronger cuts were made in central government block-funding of research institutes engaged in applied research. These measures were used in an attempt to enforce greater interaction between research institutes and enterprises as well as an attempt to foster productivity through competition over resources. The responsibility for the allocation of operating costs shifted from the *Ministry of Finance* to the *SSTC* (and later *MoST*) which became the key coordinating body of China's research and innovation system (Xue, 1997).

4.11. The first period of transformation; variation in research organisations

According to a 1987 review by the *State Education Commission* (SEC) there were already universities with similar or better research capabilities than research institutes. The *SEC* and its successor the *Ministry of Education,* tried to strengthen these capabilities (SEC, 1987 in Liu and Jiang, 2001). In general, Chinese universities had a strong orientation towards applied research and this was still the case in the later 1990s (OECD, 2007). As discussed previously, the *NSFC* played an important role in strengthening the research capabilities of universities. Another mechanism to achieve this was the establishment of elite sub-organisations in research universities and, to a lesser extent, in the institutes of the academies (see among others Jin et al., 2005). In these sub-organisations groups of researchers were clustered together around common research priority. The decision for the establishment of this system was made in the mid 1980s. The first *National Key Laboratories* (*NKL*) started operating in the early 1990s. These *NKL*s were equipped with up to date research infrastructure. They also received some block funding for buying research equipment and to supplement the salaries of their faculty members. The increasing importance of universities in scientific research resulted in a greater diversity of actors in the research system. The management of research institutes and universities was granted a greater degree of autonomy in the early 1990s. This led to a further diversification of organisational forms (IDRC, 1997).

4.12. The first period of transformation; evaluation

The *National Key Laboratories* set up their own, internal evaluation mechanisms in response to the overarching evaluation mechanisms announced for the *National Key Laboratory* system. *CAS* institutes and universities also started more systematic reviews. There was still little systematic evaluation of research funding programs in this period (OECD, 2007). There were some missions for the evaluation of institutes and fields by foreign experts (see e.g. Hamer and Kung, 1989). The evaluation of research proposals by the *NSFC* relied primarily on peer review. Anonymous peer review was problematic, however, because there were insufficient experts and because of other practical reasons (for example computer software which could handle Chinese characters only became available in the late 1990s (Sandt, 1999)). The still relatively small number of qualified reviewers in most fields, in combination with the rapid growth in the number of applications, resulted in an overwhelming workload.

4.13. The first period of transformation; international orientation

The reform process was characterised by an 'opening up' of the research system to the global scientific community. Foreign experts, often overseas Chinese, gave advice on the transformation process. Foreign intermediary agencies such as the *US NSF* and the German *Max Planck Gesellschaft* also provided input (among others CAS-MPG, 2004). A central part of the opening up process was the strategy to send students and scientists for training abroad and sponsoring visits to international conferences. From the mid 1980s onwards self financed overseas study was also allowed (Jonkers, 2010). Over the years the outbound flow of students and researchers increased rapidly. During the 1990s it grew exponentially before levelling off in the early 2000s (Zhang and Li, 2002; Jonkers, 2010). Many of the overseas students chose to remain abroad. This led to a considerable growth in the number of expatriate Chinese scientists (see also Jonkers, 2009). These expatriate Chinese scientists were an important source of scientific knowledge and institutional learning. For example, overseas Chinese helped with the (re-)establishment of graduate and doctoral education during the 1980s (see e.g. Poo, 2004). They also provided policy advice (see e.g. Hamer and Kung, 1989). Government sponsored students and researchers and those who were sent abroad by their research organisation returned in large numbers. These returnees were important in staffing and rejuvenating Chinese research organisations. Several high profile returnees in the late 1980s and early 1990s were given large responsibilities. In the course of the 1990s, various governmental organisations established programs to promote temporary or permanent return of expatriate Chinese scientists (see e.g. Jonkers, 2008a, 2010). Attempts were also made to stimulate research organisations to 'open up' to the global scientific community. The *National Key Laboratories*, for example, were meant to be 'open' to international interaction. They received a budget for inviting foreign researchers, to sponsor visits to international conferences and to engage in international cooperation.

4.14. The first period of transformation; local diffusion of knowledge in research system

Spontaneous horizontal, extramural cooperation was still limited in the early 1990s. If it did take place, it was often within the same city or region. The projects of the *863 program* often involved researchers from different research organisations. It therefore played a role in stimulating extramural interactions. The *NKLs* had the mission to provide training to researchers from all over China. They were also meant to engage in other forms of cooperation with other research organisations in their field. Their establishment could partially be regarded as an attempt to increase the level of domestic extramural interaction within the research system.

4.15. The first period of transformation; interaction with non-scientific users

A share of the *863 project*s involved researchers from firms (including state owned enterprises). Funding agencies also set up a number of other programs and measures to promote the interaction between research organisations and industry. As was discussed previously, another central part of the strategy to stimulate the interaction between research organisations and (state owned) enterprises was to reduce the block funding of applied research organisations. This forced them to look for alternative sources of funding. Furthermore, during the 1990s, a large number of applied research organisations were privatised or merged with companies (IDRC, 1997). The greater level of autonomy given to research organisations allowed them to establish new technology enterprises (NTE). For some organisations, these NTEs became important sources of revenue. A related element of the strategy to stimulate the interaction with potential non-scientific users was the establishment of technology markets and high tech parks in university areas (Sigurdson, 2005). As a consequence of the changes in S&T personnel management systems, scientists and engineers in overstaffed public research institutes were encouraged to move to industrial and agricultural sectors through mechanisms such as job-transfers, long term assignments and leave-without-pay (Xue, 1997). The increasing research capabilities of universities led to a greater degree of interaction between science and higher education. The *CAS* also became more active in providing graduate education in its university and graduate school. Despite measures to increase industrial research, the level of R&D activities of (state owned) enterprises remained low. The share of industrial investments in total R&D expenditures decreased further from 35.3% to 22.7% between 1987 and 1993 (Xue, 1997).

4.16. The second phase of the transformation process

In 1995 the 'Third National Conference on Science and Technology' and a central government decision to accelerate the research system reform marked the start of the second phase of the transformation process. This phase was characterised by measures to strengthen: (1) the linkages between science and higher education and (2) the linkages between science and technological innovation.

4.17. The second phase of the transformation process; resource allocation

Between 1995 and 2005, the budget of the *NSFC* continued to have an average annual growth of 20% (NSFC, 2005a; NBS, 2001, 2006). In 2005 the total annual budget of the *NSFC* was well over 2.5 billion RMB, or approximately one third of the total public basic research expenditure. As discussed, the *NSFC* mainly funds investigator driven research projects and follows a relatively strict system of peer review. As a result of its growing weight, the influence of the scientific community over the allocation of research funding increased. By consequence the level of scientific autonomy in the research system also grew considerably. In addition to the relatively small investigator-driven project funding in its general program, the *NSFC* has also established several other programs. These currently take up around 35–40% of its budget (NSFC, 2005b). The main examples of these programs are larger research programs in selected priority fields and the 'excellent young scientist' program. The latter provides investigator-bound funding for promising researchers with a good track record and in many cases foreign work experience. In this period the budget of the *863 program* also grew. In 1997 the *MoST* became responsible for a newly established large basic research program. This program funds large scale basic or strategic research projects in selected priority areas. Interviews with active scientists indicated that these projects mobilise most research groups throughout China with expertise in a particular topic. These groups work together around a common theme to realise specific goals.

Fig. 2 illustrates the increasing importance of competitive project based funding in the total budget of research organisations. It is important to realise, however, that the funding mix varies between organisations. At present the expenditures on basic research in universities and *CAS* institutes is more or less the same (CAS, 2006; NBS, 2006). Most universities receive relatively little block funding for scientific research. The top research universities that take part in the 985 program and the National Key Laboratories do receive more. In contrast to universities, block funding still accounts for a considerable share of the budget of *CAS* institutes. A director of a *CAS* research centre indicated that block funding accounts for around 30% of its resources. Researchers at universities receive a relatively large share of the *NSFC* funding (NBS, 2006). Researchers in *CAS* institutes are well placed to mobilise large research teams. As a consequence they are relatively successful in the competition for the larger projects allocated through the *973* and *863 program*. In 2004, *CAS* institutes received 39.4 and 30.2% of the funding from these programs (CAS, 2004a). The work unit system continues to exist, but it has changed in nature. Some researchers have implemented policies that would, in theory, lead to the dismissal of underperforming researchers. Interviewed scientists questioned whether this often happened in practice as long as these researchers can generate sufficient funding to survive (Jonkers, 2010). Another change in the researcher population is the relative growth in the share of non-permanent researchers in research institutes (see also Jonkers, 2010).

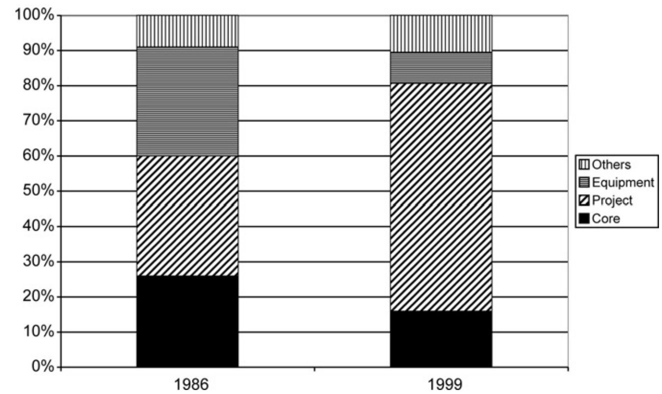

Fig. 2. Share of types of research funding for plant biotechnology research organisations.
Adapted from Huang et al., 2002 in Jonkers, 2010.

The Chinese leadership continues to have a strong interest in large scientific projects. These projects can be funded by the *MoST* through its *863* and *973 Programs* or through separate budget lines (CAS, 2002b, 2006; Cao et al., 2006). For example: in the *973 Project* on rice functional genomics interviewees indicated that virtually all Chinese teams active in this field were involved. Chinese scientists, expatriates and analysts have voiced some criticism to this inclusive approach. They argued that it would be more fruitful to concentrate resources on the basis of scientific excellence. There are several potential explanations for the funding of such large scale projects. The concentration of the limited resources for scientific research on specific topics is expected to yield better results than the funding of many different smaller projects. The S&T policy establishment believes that big investment in scientific infrastructure is essential. Another motivation is that large projects can yield both domestic and international prestige and visibility. A good example of the latter was the sequencing of the rice genome by Chinese research teams. Historically rooted tendencies for central planning in China's S&T policy establishment are also expected to form an important explanation Not everyone agrees with the use of a considerable share of the still limited funding for scientific research for large 'top down' implement projects. In recent years several prominent expatriate and returned scientists criticised this approach as being wasteful (Cyranoski, 2004; Wu (2006); Poo (2004) in Cao et al., 2006).

4.18. The second phase of the transformation process; variation in research organisations

Two central developments in the second phase of the transformation process were the quantitative expansion of the higher education system and the further strengthening of research capabilities of research universities. The number of graduate students enrolled in universities increased from around two hundred thousand in 1998 to almost a million in 2005 (NBS, 2006). To strengthen the research capabilities of universities the government established two programs: the *211* and the *985 Program*. The 100 leading Chinese universities took part in the *211 Program*. In the period

1996-2000 (the 9th five year plan) close to 11 billion RMB was invested to improve research infrastructure, buildings and facilities (Qin, 2002). The *985 Program* offered generous funding to a small number of research universities in order to transform them into 'world class research universities'. These research universities would be less focused on applied research and complement the *CAS* institutes in conducting basic research (OECD, 2007). The universities could use the funding from the 985 program to improve their facilities and research infrastructure. In addition they could use it to attract strong researchers from abroad. Initially the program was to involve only *Beijing University* and *Tsinghua University*, which received 217 million USD in the period 1999–2001. The scope of the program was expanded with an additional seven universities in other cities. In recent years, the number has increased further to around fourty, so that most Chinese provinces now have one 985 university. However, the initial group has so far received the largest share of the funding (Li, 2004).

In 1998, the political leadership also approved the CAS Knowledge Innovation Program (KIP). This program aimed to strengthen the CAS' capabilities in basic research, graduate education and innovation (CAS, 2002c). The main objective of this program was to renew and reinvent the *CAS* following a centre of excellence approach (OECD, 2007). The KIP followed several phases in which a growing number of institutes took part. The program involved (1) the restructuring and merger of several institutes; (2) organisational reform including changes in the evaluation structures; (3) the strengthening and rejuvenation of CAS faculty through a manpower development plan and changes in the contract system; and (4) the upgrading of research infrastructure (CAS, 2002c,d,e, 2004a). Between 1996 and 2002 the number of CAS institutes had already decreased from over 120 to less than 90. The number of other units, such as *CAS* invested holding enterprises is also decreasing as a result of privatisations and mergers (CAS statistical yearbook, 2003). Between 2001 and 2005, a larger number of *CAS* institutes took part in this program and the budget increased further (CAS, 2002e). Through the KIP the CAS aimed to create 30 internationally recognised research institutes by 2010, five of which were to be world leaders (OECD, 2007).

From an ecological perspective it is interesting to consider the creation of new organisations and the disappearance of others. As briefly discussed in the previous paragraph, the *CAS* has gone through several major changes but remained a central research coordination and performance organisation. Individual institutes also went through important changes. The *Institute of Development Biology*, for example, was set up in the early 1980s with generous support from foreign funding sources. This institute, which was to be a central locus for 'new biotechnology' research, had only limited success. In a review by experts from the US *National Academy of Sciences,* considerable doubt was cast on some of the claims made by leading researchers in this institute. In 1998 the institute was merged with the *CAS Institute of Genetics* as part of the KIP. This institute is now one of those which aim to compete at an international level and it has succeeded in attracting a large share of foreign trained staff members. In recent years, there have also been other experiments with the set up of new forms of organisations, the most prominent example of which is the *National Institute of Biological Sciences in Beijing*. This institute was modelled on the US' *Howard Hughes Medical Institute*. Researchers are granted generous person-bound funding to engage in research and are not required to seek outside funding. Other examples of new organisational forms are the international joint laboratories and international joint institutes discussed in Section 4.20. By 2005, the number of *NKLs* had expanded to 179 (NBS, 2006) and over 400 second tier *Open Laboratories (OL)*, which have a similar mission, had been established by the *Ministry of Education*, the *CAS*, the Ministries of *Agriculture* and *Health* and other mission oriented ministries in their respective universities and research institutes. One of the most important changes in the research landscape was the set up of the *NSFC* and its increasing importance as a funder of research projects. This has led to various changes in other parts of the system. Competition over funding has increased both at the level of individual researchers and that of research organisations. The system of peer review in various types of evaluations has become more entrenched. Also the growth of the *NSFC* budget allowed universities to become more important as research performing organisations.

4.19. Evaluation mechanisms

The review of project proposals and organisations relied solely on peer review untill the mid 1990s. In the later 1990s quantitative, bibliometric, tools also became used. For these evaluations international bibliographical databases were used as well as the Chinese Science Citation Database. These quantitative tools are mainly used to inform and support the qualitative peer review process. The peer review of proposals by the *NSFC* was not without its problems. One of the main concerns was the limited presence of qualified experts in China. The involvement of foreign experts was one way to address this shortage. These foreign experts tend to be overseas Chinese researchers (the proposals are written in Chinese). Gradually the size of mainland Chinese scientific communities were growing as well, alleviating the problem of reviewer exhaustion. In the programs of the *MoST,* proposals were evaluated by committees of scientists and administrators. Several scientific respondents indicated they had more faith in the peer review process of the *NSFC*. The allocation of funding by the *MoST* and the (limited) system of peer review it adopts, however, received a considerable amount of criticism by scientists in China and overseas Chinese researchers. Some of the researchers interviewed for this project in the period 2003–2006, questioned the transparency of the allocation procedures and the strong role of government administrators in making these decisions, in comparison to the *NSFC* where these decisions are based on peer review. Every five years the *NKL*s are evaluated by the *NSFC* and the *MOST*. These evaluations can lead to the upgrading of *OLs* and the down-grading of *NKLs* (see also Jin et al., 2005, 2006; Jonkers, 2010). Agents in policy circles were however reported – by a respondent involved in the review process – to have reservations about downgrading labs and as a result this does not occur often. As mentioned in Section 4.12 the suborganisations have also set up their own internal evaluation mechanisms for staff members and this is also the case for universities and *CAS* institutes. Some *CAS* institutes have engaged in international reviews of their institutes (e.g. CAS, 2004b,c). Before the creation of the *National Centre for S&T Evaluation (NCSTE)* in 1997, there was little systematic evaluation of S&T programs. In addition to an underdeveloped evaluation culture and practice, the *OECD* considered there to be too little qualified evaluators. Owing to the weakness of existing evaluation mechanisms, it considers the function of evaluation in providing feedback to the policy making process to be very limited. Furthermore since the *NCSTE* is de facto affiliated to the *MOST,* it is difficult for the *NCSTE* to perform independent, critical evaluations of *MOST* policies and instruments (OECD, 2007)

4.20. The second phase of the transformation process; international orientation

The opening up of the research system continued during the second phase of the transformation process. In the period 1996–2005 the number of foreign visitors to the *CAS* institutes and elite universities increased rapidly. The evaluations of organisations, sub-organisations and individual researchers placed special emphasis on publications in international journals. The number of publications in these journals showed a strong increase (Zhou and Leydesdorff, 2006). The absolute number of international co-publications also increased very rapidly, though at a slightly slower pace than the growth in international publications (see e.g. Jonkers, 2009). The increase in visibility can be related to various factors. These factors include the qualitative upgrading of the scientific manpower situation as well as the change in strategy by individual researchers as a result of changes in evaluation, promotion and bonus systems. The implementation of these systems by research organisations is, in turn, partially a response to changes in evaluation structures – and their stronger focus on international visibility – at the intermediary level of the research system.

During the course of the past ten, and especially the last five years, a large number of international joint laboratories and international joint centres were set up by foreign and Chinese research organisations in China. In recent years, several international joint research institutes were also established (see also Jonkers, 2010; Jonkers and Cruz-Castro, 2010). The *CAS* has also started to offer specialised training abroad to selected managers and administrators. At the intermediary and policy level interactions with foreign counterparts have also increased over time. The *NSFC* and *CAS* have engaged in S&T policy dialogues with Japanese, American and German partners (e.g.: Blanpied and Zhao Gang, 2006; CAS, 2004d,e,f, 2005). In 2000, the *NSFC* and the German *DFG* opened a joint centre for research funding in Beijing (CDZW, 2008). In recent years the *NSFC* is also using foreign based researchers in their peer review process – in part to counter-act the problem of reviewer exhaustion. Various manpower development programs set up by the *NSFC* and the *CAS* have helped in attracting a large number of expatriate Chinese scientists to return permanently, or to 'shuttle' between mainland China and their host country. Especially in the last seven years, the number of returnees recruited through such programs has been substantial. Nowadays more than 60% of the senior faculty members in (plant science) *NKLs* and *CAS* institutes in Beijing and Shanghai are thought to have worked abroad (see among others Jonkers, 2010).

4.21. The second phase of the transformation process; local diffusion of knowledge in research system

Several factors can explain the increase in extramural interaction. The first is that the large scale *863* and *973 programs* required the involvement of researchers from different organisations. A second important factor is that developments in information, communication and transport technologies have decreased the costs of interaction between distant cities. A change in research culture is also thought to have been important. This change can be partially related to the increasing prominence of Chinese researchers who returned from abroad. Clusters of highly interacting elite researchers, nowadays often constituted by returnees, were reported to play an important role in influence the science policy (and funding) agenda. Interviews with returned scientists in elite research organisations indicate that the increased degree of extramural interaction is primarily related to the need for funding from large scale funding programs rather than intra-scientific motivations (Jonkers, 2010). Domestic mobility of researchers between research organisations remains low. As mentioned in the Section on evaluation, there is, at least in theory, downward mobility of senior researchers who do not meet performance criteria in elite level organisations. Upward mobility is still lacking for various reasons: the administration of research organisations may make it difficult for successful scientists to leave; directors of other institutes are reluctant to hire domestically in order to maintain good relations with other institutes; and there is also no culture where mobility is viewed favourably. This may just be a transitory phase and in part a reflection of the still relatively small size of the communities of top level – internationally active – researchers. At the level of junior researchers mobility is thought to be higher (see also Jonkers, 2010).

4.22. The second phase of the transformation process; interaction with non-scientific users

The interaction between research organisation and non-scientific users has increased over time. Research institutes and universities generate a considerable amount of their income through contract research for, and ownership of, private companies. The ownership of companies also implies considerable financial risk. In an attempt to reduce their exposure, universities have started to place the companies in their ownership at a greater distance in the last years of this period (see e.g. Xinhua, 2006). The *CAS* KIP was partially intended to increase the role of CAS institutes in technological innovation. To achieve this the interaction between these institutes and applied research organisations and enterprises was stimulated (CAS, 2002f; Suttmeier et al., 2006). Since 1995, there is also a strong push for a greater integration of higher education with research and development. The strengthening of the research capabilities of universities through the *211* and *985 program* was an important way to achieve this. Another example is the growing role of the *CAS* in providing graduate education.

4.23. Brief summary of current position of the Chinese research system

The current position of the research system on the continua across seven functional dimensions lies closer to the extreme pole of the 'perfect market ideal type' than it did previously. There has been a strong increase in the share of research funding allocated in the form of competitive project funding following a process of peer review (by the *NSFC*). Another large share of the research budget is allocated in the form of mission oriented project funding in which administrators have a relatively large influence on the direction of research. The diversity in research organisations has increased during the two time periods under investigation. This growing diversity is partially due to the growing importance of new organisations and sub-organisations, and also partially due to an expansion in the missions of existing organisations. Elite research organisations such as the leading research universities and *CAS* institutes have become much more 'open' to the international scientific community. Non-elite and applied research organisations still remain more isolated from global science. During the two periods under investigation the frequency and intensity of spontaneous domestic extramural interactions has increased. This increase can be attributed to a change in research culture and to the stimulation of extramural interaction through the large scale funding programs (Jonkers, 2010). The large influence of 'top down' measures suggests that the Chinese system is still located more towards the left of the continuum presented in Fig. 1, than most research systems in OECD countries. A number of measures have been taken to increase the degree of interaction between organisations in different sub-systems of the innovation system. Research organisations and universities generate a considerable amount of their resources from state owned and private enterprises. The linkages between research and higher education have increased as well. New measures to further promote and fine tune these types of interactions are thought to have been taken at all four levels of the research system in the current phase of the transformation process.

4.24. General trends and future development

China's rapid economic growth allowed for the large investments in research infrastucture, the attraction of new staff, the set up of the *NKLs* and research institutes, the growth in the budget of the new funding mechanisms and programs and the transformation of the Chinese research system. R&D spending increased by almost 19% per annum since 1995. Basic research, however, accounted for only 6% of the total R&D expenditure of 30 billion in 2005 (see among others: OECD, 2007). The Chinese government aims to gradually increase this share of basic research in total R&D expenditure to 20% (CAS, 2004g). At the same time, the total R&D expenditure will increase further as well. Between 2005 and 2020, the gradual transformation of the Chinese research system in the direction of the 'perfect market ideal type' is expected to continue through measures announced in the 11th and 12th five year plan and the 'long term program for S&T development' (see among others: Cao et al., 2006; Suttmeier et al., 2006). Though the Chinese system has become similar in institutional setup to *OECD* countries, it will always retain many characteristics which are specific to China and its historically rooted growth trajectory.

Over the past 10 years the output of the research system, as measured by publications in international scientific journals, has increased exponentially (see also Zhou and Leydesdorff, 2006). This growth has not occurred equally for all scientific subfields. While a certain increase in the share of life science research in the research portfolio is visible over the past two decades, it remains heavily concentrated in physics, chemistry and engineering. While world wide over 60% of the SCI publications are made in the medical and life sciences, less than 22% of Chinese publications were made in this broad field in 2006 (Jonkers, 2010). The relative stability of the distribution of the research output is a further indication of path dependency in the development of this research system. If the institutional transformation described in this paper has brought the research system closer to research systems in *OECD* countries, it is not clear from this analysis of the output, that it has indeed become more flexible. Reports of the rapid development of stem cell research and nanotechnology do provide provisional indications that it has become more able to devote resources and manpower in emerging fields of research. Insights in the development of the research portfolio are, however, still insufficiently detailed to sufficiently ground such statements. The *OECD* reports that, even if some universities perform remarkably well, overall quality has not kept equal pace with the increasing quantity of the output (2007). Again there are large differences between scientific subfields. For example, China is performing relatively well in the plant molecular life sciences, when considering a normalised indicator for the average number of citations per paper (Jonkers, 2010). This is not true to the same extent for most other molecular life science subfields.

Since 1995 the output of the higher education system has increased more than five-fold (NBS (MoST) 2007). The *OECD* report raises concerns about the overall quality of the output of the education system. However, there are large differences between universities and many of the students of elite level universities continue their studies at universities in (especially) the United States and Europe. In part as a result of special programs the flow of overseas Chinese scientists returning to China to work in its research organisations has grown (Jonkers, 2010).

5. Discussion

This paper illustrated the use of a theoretical framework for the comparison of research systems by analysing the transformation of the Chinese research system in the period 1980–2005. Before the process of transformation started the research system approached the 'centrally planned ideal type'. By 2005, the research system had moved in the direction of the 'perfect market ideal type' on all the functions identified in Fig. 1. Often institutional changes affecting one of these functions are related to changes in the other functions.

The introduction of new funding organisations at the intermediary level such as the *NSFC* but also the 863 and 973 programs of the *MOST* and especially the *NSFC* have resulted in a greater plurality in the sources of funding for research. They have also strengthened the reliance on *project* over *block-funding*. The project based nature of funding in these programs (especially the growing budget and role of the *NSFC*) has given individual research groups a greater amount of autonomy over their research direction. Over time they have received more opportunities to compete for funding independently of their research organisations, since research contracts are made with individual researchers instead of their work-unit.

The role of some existing organisations has also changed over time; the clearest example of which is the formation of research universities. This trend was stimulated at the beginning of the 1980s and was given a greater impulse from 1998 onwards. In addition to these gradual reforms, attempts were made to introduce novel organisational forms that could help improve the performance of the Chinese research system. The most fundamental of these was the establishment of *NKLs* and *OLs* in research universities and institutes. The *NKLs* were intended to have a positive radiating effect on the research system and they receive a steady stream of visiting scientists from other organisations in China. They are also oriented towards the international scientific community and host foreign visitors for short periods. The establishment of these units and other organisations has led to a greater plurality of organisational forms and ownership models.

The system of quinquennial evaluations of the *NKLs* offers an incentive for the improvement of research and research management quality. It also introduces another level of competition in the research system as *NKLs* can be demoted and *OLs* can be promoted. The rapidly increasing budget of the *NSFC*, which mainly allocates funding to bottom up research proposals, following a process of peer review, indicates that the degree of scientific autonomy has grown. That is, scientists have an important role in deciding which projects to fund. Likewise, the various evaluations of research organisations, sub-units and individual researchers rely on reviews by scientific experts. Furthermore, scientists are evaluated on the basis of their publications in scientific journals. As these journals are peer-reviewed, this introduces a further dimension of quality control by the scientific community, and hence scientific autonomy or influence in societal reward structures. The large programs of the *MoST* are criticised frequently, because researchers are said to have to be close to science policy circles to get funded and also because of the limited role of scientific peer review in grant allocation. The OECD considers a more independent evaluation of these programs as an important way to increase their efficacy.

Domestic extramural interaction has increased as a result of the large scale programs of the *MoST* where teams from different organisations take part. Measures have also been taken to increase domestic mobility. These include the establishment of a post doc system. The *OLs* and *NKLs* also play a role in training researchers from outside their own organisation. Downward mobility of researchers who cannot perform to certain standards in elite level research organisations to a lower level applied research organisations or companies is said to have been promoted. As a potential indication of this there has been a considerable reduction in the size of permanent staff members in *CAS* institutes. Some respondents in this project questioned whether this type of mobility happens frequently in top level research universities. Upward domestic mobility, i.e. the recruitment of high performing researchers by other research organisations, was considered very rare. This may be a temporary phase related to the still small size of the part of the scientific community which competes at an international level in most scientific fields. In the long term both upward and downward domestic scientific mobility is thought to be important for the diffusion of knowledge, quality control and the functioning of the Chinese science system because of its relation to reputational competition and intellectual pluralism.

Since 1998, the Chinese science system has become more cosmopolitan in nature. The *NSFC* is using overseas experts in its peer review of research proposals. The *CAS* has also set up a database of foreign (mainly overseas Chinese) researchers which it can use in the review of its institutes and researchers. Research and funding organisations push researchers to publish in preferably high impact international journals and this is reflected in their bonus allocation mechanisms. Giving greater importance to (high impact) international journals in such reviews is, in itself, an indication of a greater cosmopolitan orientation and a realisation of the benefits that integration in the international scientific community can bring. Similarly, several of the leading Chinese journals are now published in English, sometimes finding a foreign publisher and foreign editor, and thus subject their knowledge claims to the international scientific community. Finally, a large share of researchers in top level research organisations have worked for several years abroad bringing with them 'western' attitudes towards research and retaining their orientation to the international scientific community. This helps to improve evaluation and quality control mechanisms and the absorption of scientific knowledge developed overseas. The increasing international visibility in some fields helps to attract new returnees which in result may lead to a further upgrading of the Chinese research system. The various elements of the internationalisation thus affect other elements of the transformation process and therefore can be considered a central part of this development.

Over the past two decades inter-linkages between organisations in the public sector research systems and organisations in other subsystems of the national innovation system have increased. One important factor in the integration of the research and higher education systems is the increasing role of universities in carrying out research and the further strengthening of their capacities through the *211* and *985 Programs*. The role of the *CAS* in graduate education has increased as well. The linkages between organisations responsible for basic and strategic research and those focused on applied research, product development and commercialisation, have also increased. This was partially done through forcing the government research institutes involved in applied research to become more market oriented. Universities and *CAS* institutes have also been active in the commercialisation of their research both through establishing *CAS*- and university-owned enterprises and by conducting more contract research for state owned, private and multinational enterprises.

Changes in the research system are not just a matter of changing policies but the aggregate result of changing actor strategies. As discussed, the output of the science system in terms of the number and quality of its international publications has increased considerably over time. This increase in international visibility can be partially explained by the introduction of new actors (returnees) and different publication strategies. This change in publication strategies is also a consequence of the evaluation systems in individual research organisations which were established in response to the stress on international publications in evaluation systems implemented by organisations at the intermediary level. Furthermore, it is strongly related to the greater international orientation of the system. Apart from institutional transformation, however, the increase in visibility is also partially related to changes in the inputs in the science system in terms of increased funding and the qualitative increase in the available scientific manpower. The extent to which individual elements of the institutional transformation process have resulted in the improved performance of the scientific research system in terms of its overarching function of the development of new scientific knowledge as well as the related functions of training highly qualified scientific manpower and contributing to technological innovation is difficult to assess. As made clear in this discussion the different functions are also strongly inter-related. It is more the overall functioning of the system, and thus the extent to which it meets all the functions of novelty generation, selection, absorption and diffusion which determines the extent to which it meets these overarching functions.

The transformation process has been gradual, often following a trial and error approach. This process has not yet ended. At present, there are still considerable differences between the Chinese research system and research systems in Western Europe and North America. Indeed there are many differences between the research systems in OECD countries as well. It is not surprising that elements of the transformation of the research system lead to new problems. It will take time for new institutions to fully develop in the Chinese system. The discussion of these problems in the scientific community, policy circles and even the popular press may be a positive sign. It may help to spur institutional changes that further improve the functioning of the science system. Overall the institutional transformation of the Chinese research system is considered to have made it better capable of performing its overarching functions and hence contribute to Chinese society..

In order to become more useful for cross country comparisons the theoretical framework introduced in this paper can be expanded further. It would be of particular interest to explore whether insights from the variety of capitalism literature can be used for classifying the various continental European, Anglo-Saxon and Asian research systems. Further conceptual work would thus be needed to fully exploit the basic functionalist framework introduced in this paper.

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References

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A., 2008. Aanlyzing the functional dynamics of technological innovation systems: a scheme of analysis. Research Policy 37, 407–429.

Berry, M.J., 1988. Science and Technology in the USSR. Gale Research Co, University of California Press, Burnt Mill, Harlow, Essex, UK, Detroit, MI, USA, Berkeley, CA, USA Longman.

Blanpied, W.A., Zhao Gang, 2006. Proceedings of the China-US forum on Science and Technology Policy. Beijing, Peoples Republic of China, October 2006. Available at http://www.law.gmu.edu/nctl/stpp/pubs/Proceedings_000.pdf (accessed May 2008).

Bozeman, B., Mangematin, V., 2004. Editor's introduction: building and deploying scientific and technical human capital. Research Policy 33 (4), 565–568.

Cao, C., 2004. China's Scientific Elite, Routledgecurzon Studies on China in Transition, 21. Routledge, Abington.

Cao, C, Suttmeier, R.P., Simon, D.F., 2006. China's 15-year science and technology plan, Physics Today, December 2006, page 38. Available at http://scitation.aip.org/journals/doc/PHTOAD-ft/vol_59/iss_12/38_1.shtml (accessed October 2007).

Carlsson, B., Stankiewicz, R., 1991. On the nature, function and composition of technological systems. Journal of Evolutionary Economics 1, 93–118.

CAS News, 2002a. Restoration and Exploration (1977–1986). CAS News. Beijing, Chinese Academy of Sciences, available at http://english.cas.ac.cn/eng2003/news/detailnewsb.asp?InfoNo=20968 last accessed March 2008.

CAS News, 2002b. Five Mega Science projects at CAS. CAS News. Beijing, Chinese Academy of sciences, available at http://english.cas.cn/english/page/T263116.asp (accessed March 2008).
CAS News, 2002c. Overall Planning for the KIP Pilot Project. CAS News. Beijing, Chinese Academy of Science, available at http://english.cas.cn/english/news/detailnewsb.asp?InfoNo=20965 (accessed March 2008).
CAS News, 2002. CAS Readjusts Implementation of Its Talent Program. CAS News. Beijing, Chinese Academy of Sciences. Available at http://english.cas.cn/english/news/detailnewsb.asp?infoNo=24387 (accessed March 2008).
CAS News, 2002. Progress in the Initial Phase of the KIP Pilot Project. CAS News. Beijing, Chinese. Academy of Sciences, available at http://english.cas.cn/english/news/detailnewsb.asp?InfoNo=20964 (accessed March 2008).
CAS News, 2002. Main Goals for the Phase of All-round Implementation of the KIP Pilot Project. CAS News. Beijing, Chinese Academy of Sciences. Available at http://english.cas.ac.cn/english/news/detailnewsb.asp?InfoNo=20963 (accessed March 2008).
CAS News, 2004. Knowledge innovation program pays off in its six-year trial implementation. CAS News. Beijing, Chinese Academy of Sciences. Available at http://english.cas.cn/english/news/detailnewsb.asp?InfoNo=25094 (accessed March 2008).
CAS News, 2004. International Evaluation for CAS Institutes CAS News. Beijing, Chinese Academy of Science, available at http://english.cas.cn/english/news/detailnewsb.asp?InfoNo=24893 (accessed March 2008).
CAS News, 2004. Overseas scholars are invited for consultation and evaluation at CAS. CAS News. Beijing, Chinese Academy of Sciences. Available at http://english.cas.cn/english/news/detailnewsb.asp?InfoNo=25074 (accessed March 2008).
CAS News, 2004. Sino-Japanese Seminar on Science Policy Held in Beijing. CAS News, Beijing, Chinese Academy of Sciences. Available at http://english.cas.cn/english/news/detailnewsb.asp?InfoNo=25220 (accessed March 2008).
CAS News, 2004. Sino-German Workshop on S&T evaluation Held in Beijing. CAS News, Beijing, Chinese Academy of Sciences. Available at http://english.cas.cn/english/news/detailnewsb.asp?InfoNo=25200 (accessed March 2008).
CAS News, 2004. Sino-Japanese seminar on S&T strategies held in Kunming. CAS News, Beijing, Chinese Academy of Sciences. Available at http://english.cas.cn/english/news/detailnewsb.asp?InfoNo=25038 (accessed March 2008).
CAS News, 2004. More Money for Pure Science. Xinhua in CAS News, Beijing, Chinese Academy of Sciences. Available at http://english.cas.ac.cn/english/news/detailnewsb.asp?InfoNo=25305 (accessed March 2008).
CAS News, 2005. CAS and MPS administrators discuss science management. CAS news, Beijing, Chinese Academy of Sciences. Available at http://english.cas.cn/english/news/detailnewsb.asp?InfoNo=25717 (accessed March 2008).
CAS News, 2006. CAS Statistical Data 2005. Bureau of Comprehensive Planning of the Chinese Academy of Sciences. Chinese Academy of Sciences, Beijing.
Cyranoski, D., 2004. Biologist lobby central government for funding reform. Nature, 430, 495. Available at http://www.nature.com/nature/journal/v430/n6999/full/430495b.html (accessed March 2008).
Hamer, D.H., Kung, S.D., 1989. Biotechnology in China. In Committee on Scholarly Communication with the People's Republic of China, US National Academy of Sciences. National Academy Press, Washington, DC.
Harlan, J., 1980. Plant breeding and genetics. In: Orleans, L.A. (Ed.), Science in Contemporary China. Stanford University Press, Stanford, California.
Hayhoe, R., 1996. China's Universities 1895–1995: A Century of Cultural Conflict. Garland, New York/London.
Huang, J.K., Rozelle, S., Pray, C., Wang, Q.F., 2002. 'Plant biotechnology in China', Science, 295, 674–7, supplementary material. Available http: http://www.sciencemag.org/cgi/data/295/5555/674/DC1/4.
Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S., Smits, R.E.H.M., 2007. Functions of Innovation Systems: a new approach for analysing technological change. Technological Forecasting and Social Change 74, 413–432.
IDRC, 1997. A Decade of Reform; Science and Technology Policy in China, IDRC, Ottawa Canada.
Jin, B.H., Rousseau, R., Sun, X.X., 2005. Key labs and open labs in the Chinese scientific research system: qualitative and quantitative evaluation indicators. Research Evaluation 14 (2), 103–109.
Jin, B.H., Rousseau, R., Sun, X.X., 2006. Key labs and open labs in the chinese scientific research system: their role in the national and international scientific arena. Scientometrics 67 (1), 3–14.
Jonkers, K., 2008. A comparative study of return migration policies targeting the highly skilled in four major sending countries, MIREM analytical report, AR2008-05, RSCAS/EUI, Florence, 2008.
Jonkers, K., 2008. Scientific mobility and the internationalisation of the Chinese research system – the case of the plant molecular life sciences, Ph.D. Thesis, Department of Social and Political Sciences, San Domenico di Fiesole Italy, European University Institute.
Jonkers, K., 2009. Emerging ties; factors underlying China's Co-Publication Patterns with Western European and North American research systems in three Molecular Life Science Subfields. Scientometrics 80 (3), 775–795.
Jonkers, K., 2010. Mobility, Migration and the Chinese Scientific Research System. Milton Park (UK), Routledge.
Jonkers, K., Cruz-Castro, L., 2010. The internationalisation of public sector research through international joint laboratories. Science and Public Policy 37 (8), 559–570.
Li, L.X., 2004. China's Higher Education Reform 1998–2003: a summary. Asia Pacific Education Review 5 (1), 14–22.
Liu, H., Jiang, Y.Z., 2001. Technology Transfer from higher education institutions to industry in China: nature and implications. Technovation 21, 175–188.
Liu, X., White, S., 2001. Comparing innovation systems: a framework and application to China's transitional context. Research Policy 30 (7), 1091–1114.
McKelvey, M., 1997. Using evolutionary theory to define systems of innovation. In: Edquist, C. (Ed.), Systems of Innovation: Technologies, Institutions and Organisations. Pinter, London, pp. 200–222.
MOST, 2003. National Basic Research Program of China 973 program. S&T programs. Beijing, Ministry of Science and Technology, People's Republic of China. Available at http://www.most.gov.cn/eng/programmes1/200610/t20061009_36223.htm (accessed March 2008).
NBS, National Bureau of Statistics Ministry of Science Technology, 2001. China Statistical Yearbook on Science and Technology 2000. China Statistics Press, Beijing.
NBS National Bureau of Statistics Ministry of Science Technology, 2006. China Statistical Yearbook on Science and Technology 2006. China Statistics Press, Beijing.
NSFC, 2005a. National Natural Science Foundation of China Catalogue. National Natural Science Foundation China, Beijing.
NSFC, 2005b. Guide to Programs Fiscal Year 2006. National Natural Science Foundation China, Beijing.
OECD, 2007. China Synthesis Report. OECD Reviews of Innovation Policy. Paris, Organisation for Economic Cooperation and Development in collaboration with the Ministry of Science and Technology of the Peoples Republic of China.
Poo, M.M., 2004. Cultural Reflections. Nature, 428, 11 March: 204–205. Available at http://www.nature.com/nature/journal/v428/n6979/full/428204a.html (accessed March 2008).
Qin, C., 2002. '211' schools lead pack in research. China Daily. Beijing. Available at http://news.tsinghua.edu.cn/eng__news.php?id=249 (accessed March 2008).
Rip, A., Van der Meulen, B.J.R., 1996. Post-modern research system. Science and Public Policy 23 (6), 343–352.
Sandt, J., 1999. Breaking the PRC Iron Test Tube: Peer Review and the National Natural Science Foundation Of China. Beijing, US Embassy. Available at http://www.usembassy-china.org.cn/sandt/nsfchca.htm (accessed May 2004).
Schneider, L.A., 2003. Biology and Revolution in Twentieth-Century China. Rowman & Littlefield Publishers, Inc., Lanham, MD/New York.
Sigurdson, J., 2002. A new technological landscape in China. China Perspectives 42, 37–53.
Sigurdson, J., 2005. Technological superpower China. Edward Elgar, Northampton, MA, Cheltenham, UK.
Suttmeier, R.P., 1974. Research and Revolution, Science Policy and Social Change. Lexington Books, Lexington, Massachussetts.
Suttmeier, R.P., 1980. Science, Technology and China's Drive for Modernization. Stanford University Press, Stanford, California.
Suttmeier, R.P., Cao, C., 1999. China faces the new industrial revolution: achievement and uncertainty in the search for research and innovation strategies. Asian Perspectives 23 (3), Available at: http://www.nsftokyo.org/rm99-13.html (last accessed June 2009).
Suttmeier, R.P., Cao, C., Simon, D.F., 2006. 'Knowledge innovation' and the Chinese Academy of Sciences. Science 312 (5770), 58–59.
Van der Meulen, B.J.R., Rip, A., 1998. Mediation in the Dutch science system. Research Policy 27 (8), 757–769.
Wang, Y.F., 1993. China's Science and Technology Policy: 1949–1989. Avebury, Aldershot, U.K.
Whitley, R., 2000. The Intellectual and Social Organization of the Sciences. Oxford University Press, Oxford, U.K.
Whitley, R., 2003. Competition and pluralism in the public sciences: the impact of institutional frameworks on the organisation of academic science. Research Policy 32 (6), 1015–1029.
Xinhua., 2006. Chinese Universities to Overhaul Start-Ups: Ministry People's Daily online; English. Beijing, People's Daily online. Available at http://english.peopledaily.com.cn/200611/17/eng20061117_322684.html (accessed March 2008).
Xue, L., 1997. A historical perspective of China's innovation system reform: a case study. Journal of Engineering Technology Management 14, 67–81.
Yu, Y.Q., 1999. The Implementation of China's Science and Technology Policy. Quorum, Westport, Conn./London.
Zhou, P., Leydesdorff, L., 2006. The emergence of China as a leading nation in science. Research Policy 35 (1), 83–104.
Zhang, G.C., Li, W.J., 2002. International mobility of China's resources in science and technology and its impact, Chapter 11, International Mobility of the Highly Skilled. OECD, Paris.