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On the sudden rise of Dutch science at the end of the nineteenth century: a core-periphery approach

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ABSTRACT
This paper analyzes the remarkable success of Dutch scientists near the end of the nineteenth century, as exemplified by five Nobel laureates in the period 1901–1913. Some historians suggest that the key factor contributing to the sudden rise of Dutch science was the establishment of a new type of high school, called HBS, which generated unprecedented social mobility of middle-class pupils to Dutch universities. The HBS also provided a pathway for its science teachers to write a PhD thesis outside the walls of the university. Taking a core-periphery approach, we compare the effects of an HBS-background (periphery) and Royal Academy membership (core) on the recognition that Dutch professors. Consistent with core-periphery theory, we find that professors who taught at the HBS while writing their PhD – remote from university influences – made the most creative contributions to science, and also confirm that academy members were attributed more success than non-members.

KEYWORDS
Scientists; creativity; valuation; consecration; networks

1. Introduction

Towards the end of the nineteenth century, Dutch scientists made pioneering contributions in physics, chemistry and astronomy, with five of them winning Nobel Prizes between 1901 and 1913. Among historians, this period has become known as the 'Second Golden Age' in Dutch science, referencing the seventeenth century as the first golden age period (Willink 1980, 1991, 1998; Van Berkel, Van Helden, and Palm 1999; Maas 2001; Van Delft 2007). The Nobel prizes also marked the heyday of the four Dutch universities at the time (Amsterdam, Groningen, Leiden, and Utrecht), with the physics research group at Leiden University – including Einstein as a part-time professor – as a leading international centre up until the early 1930s (Willink 1998; Van Delft 2007).

From a historical perspective, the international recognition of Dutch scientists around the turn of the century is remarkable. According to most historians, Dutch scientists did not make any significant contributions in natural sciences before Van der Waals finished his PhD thesis in 1873 (Willink 1980, 1998; Van Berkel 2008, 2011; Van Berkel, Van Helden, and Palm 1999; Maas 2001). Throughout the nineteenth century, scientific

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research had been poorly funded at Dutch universities, quite contrary to their German and French counterparts. Public funders, as well as university professors themselves, regarded scientific research as a marginal activity emphasising teaching and public service as professors' main tasks. As a result, university labs were ill-equipped and mainly used for teaching purposes (Van Lunteren 1993; Van Berkel 1998). And, scientific research outside the universities remained fragmented and underdeveloped up until the start of professional R&D laboratories, notably the founding of the Philips physics laboratory in 1914 (De Vries 2005).

To explain the sudden rise of Dutch science, Willink (1980, 1988, 1991) was the first to point to the reform of the Dutch high school system. In 1863, the Secondary Education Act established the *Hogere Burger School* (HBS), an institution that was intended to prepare middle-class boys for engineering and managerial jobs as to advance the industrialisation of the Dutch economy. The HBS provided the scientific background which was considered necessary to sustain industrial development, a type of training that was largely overlooked by the existing institutions. As an unintended outcome of the reform, a large number of HBS pupils entered the university and many of them became university professors later on, including four out of the five Nobel laureates (Kamerlingh Onnes, Lorentz, Van 't Hoff, Zeeman), while the fifth Nobel laureate (Van der Waals) had been an HBS teacher at the time he wrote his PhD. According to Willink (1980, 1988, 1991), the inflow of students with an HBS background marked a change both in socio-demographics and disciplinary subjects at Dutch universities, which before were dominated by upper-class students with a Latin-school background, mostly studying medicine or law. Most historians agree with Willink that the establishment of the HBS played a role in training pupils that would later excel in natural science subjects at the university, although they differ in the relative importance attributed to the institutional reform in explaining the sudden success of Dutch science (Van Lunteren 1995; Van Berkel 1998; Maas 2001; Van Delft 2007). Our study takes a different look at the sudden spark of creativity among Dutch natural scientists near the end of the nineteenth century, by systematically collecting and analysing the background and recognition achieved by all Dutch professors during a sixty-year period.

From a theoretical point of view, as we will elaborate below, the influx of students with an HBS background at Dutch universities, many of whom continued to do PhD research, can be understood as an example of innovation by peripheral actors (Cattani and Ferriani 2008; Phillips 2011): a case of low-status actors (middle-class students) engaging in a marginal activity (scientific research). A second group occupying a peripheral position were HBS teachers who did their PhD research outside the walls of the university. For research contributions to become valuated, aspiring scientists partially depend on the recognition from the core members in academia. Here, we consider the Royal Academy, known as the *Koninklijke Nederlandse Akademie van Wetenschappen* (KNAW), as the core of Dutch academia at the time. The academy's members acted as gatekeepers by selecting new members by majority voting, thus granting them access to an elite platform that supported one's further career (Van Lunteren 2004; Van Berkel 2008).

We apply the core-periphery framework to explain professors' success, using an original dataset collecting relevant information on 116 professors in astronomy, chemistry, mathematics or physics. Our analysis strictly focuses on the 'Second Golden Age' in Dutch science (1873–1933). As a dependent variable, we look at the retrospective consecration of Dutch professors in recent reference works on the history of Dutch science. In this way, we can measure the success of professors who stood the test of time, overcoming biases that may have existed during the time they were alive. We analyse whether an HBS background and academy membership contributed to consecration, while also taking into account the possible selection bias of the Royal Academy regarding professors with an HBS background.

The paper is organised as follows. In section 2, we discuss the main tenets of innovation in social networks and zoom in on the more recent core-periphery theory of innovation. In section 3, we provide a summary of historians' work on the rise of Dutch science at the end of the nineteenth century. We then present our data and methods in section 4 and show the results in section 5. The final section concludes.

2. A core-periphery approach to creativity

While creativity and innovation have been studied at the level of individuals, at present most scholars view creativity and innovation as an outcome of distributed interactions within social networks (Fleming, Chen, and Mingo 2007; Cattani and Ferriani 2008). Creative individuals – in science, technology or the arts – do not operate on their own but interact in social networks, primarily with their peers. In such interactions, individuals learn from others as they exchange, criticise and elaborate each other's ideas. This network view has led to a rich literature regarding the effect of network position and network structures on the rate and types of innovation (for reviews, see Phelps, Heidl, and Wadhwa 2012; Cattani, Ferriani, and Colucci 2015).

From a relational point of view, the attribution of creativity to a product or a person also results from social interactions. The very definition of creativity is largely consensual as novelty is assessed by experts in a field (Amabile 1996). This implies that for individuals to be regarded as creative in a particular field, they need to convince the field's experts about the originality and importance of their contribution. Note that, in many cases, experts in a field have been regarded as creative themselves at an earlier point in time.

Cattani and Ferriani (2008) proposed a theory of creativity that integrates the role of social networks with the role of experts. Experts generally occupy very central positions in the social network of a field thus constitute the network's core. Being structurally embedded, experts will tend to adhere to the field's institutionalised norms and standards (Granovetter 1985) and to favour ideas that fit the canons they helped to create (Bourdieu and Passeron 1990). Yet, they can only maintain their reputation if they continue to be involved in the production of novelty. On the one hand, they are supported in this by access to financial resources (e.g., wage, grants, investment capital), as well as human resources (assistants, interns, visitors, etc.). On the other hand, the tendency to adhere to established norms may hamper their creativity. In contrast to experts in the network's core, individuals occupying a peripheral position are less constrained by institutionalised norms and standards. Hence, they have more freedom to experiment with new ideas and practices (Phillips 2011) and lower risks of reputation loss (Cattani and Ferriani 2008).

From an innovation point of view, core and individual actors occupy complementary positions. While peripheral actors are freer to develop new ideas and practices, core actors can promote novelty at the field level if they deem them valid. Following Amabile

(1996), for novelties to be accepted as creative and important, it needs to be 'valuated' by experts in the field. Peripheral actors and core actors have an incentive to connect (Cattani and Ferriani 2008). Peripheral actors need core actors to promote their ideas within the field and get them accepted, while core actors need peripheral actors to maintain their status as contributing to the field's creativity and continue to legitimise their core position in the network. Following this theory, one expects that novelties most often originate from peripheral members of a field, but only become accepted if core members actively promote them.

In the context of scientific research, the core-periphery theory also speaks to the notion of scientific paradigm (Kuhn 1962). Radical novelty challenges the prevailing paradigm and may not be readily accepted. The core members in a particular domain, like physics or chemistry, will generally also be the ones that promote the established paradigm and to push its frontier incrementally. In this process of cultural reproduction (Bourdieu and Passeron 1990), professors train PhD students, who contribute to the continuity of a paradigm and to its diffusion to other places as they get professorships later on in their careers.

Radically new ideas in scientific research, in this view, will be more likely to emerge from peripheral actors (Hautala and Ibert 2018). However, even if a peripheral position provides more freedom to pursue radically new lines of thought, it generally comes with fewer resources given that funders – often advised by experts – are unfamiliar with proposed ideas. As a result, funders will be reluctant to invest in risky endeavours that are still to be evaluated by actors in the core. This would imply that peripheral actors may have to rely on outside funding to support their activities.

3. The 'Second Golden Age' in Dutch science through a core-periphery lens

Since the mid-eighteenth century, scientific research was largely carried out outside universities in regional societies of 'amateurs' with which only some professors had any engagement with. These societies would occasionally organise contests and events, but lacked any systematic infrastructure and research agendas (Mijnhardt 1988). The institutionalised tasks of university professors concerned the teaching of students and public service through committee memberships, advisory roles and public lectures. Conducting scientific research at the university was an optional, and largely undervalued, activity throughout the nineteenth century (Willink 1988; Van Lunteren 1993, 1995). Only around the end of the nineteenth century many university professors engaged in scientific research, mostly by training PhD students in newly established labs.

Against the background of scientific research as a marginal activity throughout most of the nineteenth century, historians indicate the high school reform establishing the HBS as a driver of the sudden the rise of world-class scientific research at the end of the nineteenth century. Starting with 15 establishments around the country in 1863, the new high school type became very popular and continued to expand cumulating into 64 HBS establishments in 1900 (Willink 1980). While the main goal was to train middle-class male pupils for engineering and managerial jobs as to advance the industrialisation of the Dutch economy, the reform – unintendedly – set in motion a process of social mobility of middle-class pupils entering the university (Willink 1980, 1988, 1991). At the HBS, physics and chemistry were core subjects in contrast to the elite Latin school which prepared upper-class pupils mainly for the university programmes in law and medicine. The HBS was well funded, both in terms of teachers' salaries and lab infrastructure used in physics and chemistry classes (Van Berkel 1985). Note that the investment in research skills was not made by the core members in academia, but by the national government to promote industrialisation. Yet, as an unintended consequence of the establishment of the HBS, many university students in the natural sciences got well equipped with research skills that helped them later on in doing research on their own (Van Berkel 1985; Willink 1991).

Coming from modest backgrounds, however, the parents of HBS pupils were generally reluctant to have their children continue at a university to get an MSc degree, let alone a PhD degree, given the high fees and the poor job prospects of students in mathematics, physics or chemistry. There was, however, one attractive job prospect after receiving the MSc degree, which was to continue as an HBS teacher. Given this prospect, several HBS pupils continued their studies at the university.

The systematic recruitment of HBS teachers from universities ensured high-quality teaching for the next generation of students (Willink 1998). The school reform creating the HBS in 1863 thus set in motion an endogenous – and autocatalytic – dynamic of social mobility that motivated HBS pupils to continue their studies at universities. Many of them, in turn, became teachers at an HBS later on, thus socialising the next generation of pupils, and so forth.

University students who attended the HBS as pupils occupy a disadvantageous socio-economic position as their middle-class origin provided them with fewer resources than upper-class students coming from the Latin school. As explained, many parents were generally reluctant to send their sons to university. What is more, the HBS did not grant automatic access to universities given the deficiency of HBS pupils in Latin and Greek. This made them either take extra courses in Latin and Greek or go to the Polytechnic School in Delft as to enter the university afterwards.[1] The high schools' teachers, most with a university degree themselves, had an important role in motivating pupils to enter the university (Willink 1988; Maas 2001). When spotting talents, teachers at an HBS would typically recommend them to the university professors they knew. Once enrolled in the university, many students got involved in research and wished to pursue a PhD degree.

Upon completion of the MSc degree, there were two typical routes to a PhD degree. The regular route concerned people who continued to do PhD research right after they completed their MSc degree. They would typically be employed as teaching assistants with access to university labs to do research and would be supervised by a university professor. The second route concerned people who, after finishing the MSc degree, started working as an HBS teacher in some (small) city in the country, while doing the PhD research on the side. Being geographically remote and without formal university employment, HBS teachers engaged little with university professors and did not have access to university labs or travel grants. In all these respects, HBS teachers doing PhD research were more peripheral in academia than those working at the university with

[1]Only pupils from the Latin school were automatically admitted to the university. For HBS pupils to enter the university, they had to take a course in Latin and Greek (which would typically take another year) or to go to the Polytechnic School in Delft first and ask the minister of education for dispensation to enter a university afterwards (Willink 1988). These regulations lasted until 1917.

direct contact with university professors. The lack of resources for HBS teachers may well explain their focus on theoretical rather than empirical subjects. Out of the known 11 professors in our database who wrote their PhD thesis while teaching at an HBS school, eight graduated in mathematics, two in theoretical physics (Van der Waals and Lorentz), and only one in applied chemistry (Posthumus).[2]

From the angle of core-periphery theory, we can thus indicate two positions as peripheral. First, there are professors with a middle-class background having attended the HBS as pupils versus professors with a high-class background having attended a more elite school as pupils. This distinction reasons from a societal periphery in socio-economic terms and is in line with the original thesis that the establishment of the HBS led to upward social mobility (Willink 1980, 1988, 1991). Second, there are professors who taught at the HBS while doing their PhD research versus professors who did their PhD research at the university. This distinction focuses on periphery in the academic system, with HBS teachers being remote from universities and without formal PhD supervision. This view on periphery reasons from the organisational field of academia as is common in organisational sociology (Cattani and Ferriani 2008; Phillips 2011).

Regarding the core positions held in Dutch academia, we point to the Royal Academy known as the *Koninklijke Nederlandse Akademie van Wetenschappen* (KNAW). This elite organisation was originally founded in 1808 under French occupation, but got its present form only in 1851. The Royal Academy was funded by the national government, who regarded it mainly as an expert organisation that the government could consult for policy advice regarding public health, water works, measurement standards, *et cetera* (Van Berkel 2008). Progressively, it became a forum for discussing, coordinating and publishing scientific research among its members, next to policy advice. Academy members discussed the latest research results of their assistants and PhD students in regular meetings and maintained international contacts with foreign scientists and their academies (Van Berkel 2004, 2008). The Royal Academy also hosted a unique library with subscriptions to the main international journals and started publishing its own proceedings in English from 1898 onwards. Thus, while it was politically legitimated by the advisory services it delivered for the national government, the Royal Academy also provided a national network of research-minded university professors, eventually leading to the decline of regional societies near the end of the nineteenth century (Van Berkel 1998).

Being elected as a member of the Royal Academy provided scientists with prestige as well as access to an elite network and financial resources. The number of members was fixed and vacancies only emerged as members left or died. New members were elected by current members according to majority rule whereby each member could vote only for one candidate (Van Lunteren 2004). From 1878 onwards, a candidate's disciplinary background did not play any formal role anymore, while scientific publications got more decisive. This explains that prolific researchers could enter the academy already a few years after they received a PhD degree, while those who focused on teaching and

[2]The chemist Kees Posthumus was the only one out of the eleven who taught at an HBS in a university town (Leiden). Nevertheless, for his PhD research, he made use the lab facilities at his own HBS school. See: https://www.tuencyclopedie.nl/index.php?title=Posthumus_K.

civil service had much less chance of being elected (Van Berkel 2008). Historians further argued that, for young researchers, academy membership significantly increased one's chances of getting a professorship (Van Lunteren 2004; Van Berkel 2008).

With the total number of academy members being rationed, there was strong competition among candidates. What is more, the total number of scientists was rising over time and scientific research itself also became more legitimate and valued, which further added to the prestige of the academy's membership. Given the prestige of the Royal Academy, its members acted as 'gatekeepers' (Van Berkel 2008, p. 484) in Dutch academia. They controlled the new memberships, influenced professor appointments, and could steer publication decisions as editors. In terms of the core-periphery framework, one can consider someone who entered the Royal Academy not just as receiving a positive valuation by core members, but also as actually becoming one of them.

4. Data collection

4.1. Sampling

In our application of the core-periphery framework, we look at PhD students who received their degree at a Dutch university during the 'Second Golden Age' of Dutch science in the natural sciences (astronomy, chemistry, mathematics, physics). Historians generally locate the beginning of the Second Golden Age in 1873, which is the year in which the first dissertation appeared by someone who later on won the Nobel Prize (which was Van der Waals) (Van Berkel, Van Helden, and Palm 1999; Willink 1998). This year is also ten years after the HBS was created, thus capturing the very first cohorts of HBS pupils who entered the university. Historians are less in agreement as to when the Second Golden Age would have ended (Van Berkel 2004). We follow Willink who was the first to put forward the HBS thesis (Willink 1980), and who argued in a more extensive work (Willink 1998) that the year 1933 can be considered as the end of the heyday period of Dutch science. In that year, Ehrenfest – by far the most prolific physics professor at Leiden University at the time (Van Lunteren and Hollestelle 2013) – committed suicide at the age of 53. In that same year, Einstein accepted a full-time position at Princeton in the United States and never visited the Netherlands since (Willink 1998). Moreover, in the midst of the 'Great Depression', the national government decided in 1933 to reduce the funding for Dutch universities by 18 percent, in contrast to primary education which saw a reduction of only 1.5 percent of the budget (Van Berkel 1998). This decision illustrates the declining status of science and scientific research at the time.

Table 1 provides an overview of some of the key events occurring before, during and after the Second Golden Age. The events refer to the organisational foundings and PhD graduation dates of later prize Nobel laureates and Bruce medallists (the equivalent of the Nobel Prize in astronomy). During the Second Golden Age (1873–1933), roughly three generations of prize winners can be distinguished: a first generation of mostly theoretical pioneers who received their PhD degree in the 1870s and became professors shortly after (Van der Waals, Van 't Hoff, Lorentz, Kapteyn, Kamerlingh Onnes),[3] a second

[3]Lorentz was appointed professor within two years after receiving the PhD degree, Kamerlingh Onnes and Kapteyn within three years, and Van der Waals and Van 't Hoff within four years.

Table 1. Key events in the history of Dutch natural sciences.

1813	End of the French occupation
1815	Re-start University of Groningen, Leiden University and Utrecht University as state universities
1851	Start Royal Academy ('KNAW')
1863	Start HBS as part of high school reform
1873	PhD Van der Waals at Leiden University (Nobel laureate 1910 physics)
1874	PhD Van 't Hoff at Utrecht University (Nobel laureate 1901 chemistry)
1875	PhD Lorentz at Leiden University (Nobel laureate 1902 physics)
1876	Start University of Amsterdam as part of university reform
1876	PhD Kapteyn at Utrecht University (Bruce medallist 1913)
1879	PhD Kamerlingh Onnes at University of Groningen (Nobel laureate 1913 physics)
1893	PhD Zeeman at Leiden University (Nobel laureate 1902 physics)
1901	PhD De Sitter at the University of Groningen (Bruce medallist 1931)
1905	Start Delft University of Technology
1914	Start Natlab at Philips, Eindhoven
1915	PhD Zernike at University of Amsterdam (Nobel laureate 1953 physics)
1918	Start Wageningen University
1919	Appointment Hertzsprung at Leiden University (Bruce medallist 1937)
1920	Appointment Einstein at Leiden University (Nobel Prize 1921 physics)
1921	PhD Luyten at Leiden University (Bruce medallist 1968)
1925	PhD Minnaert at Utrecht University (Bruce medallist 1951)
1926	PhD Oort at the University of Groningen (Bruce medallist 1942)
1927	PhD Brouwer at Leiden University (Bruce medallist 1966)
1929	PhD Tinbergen at Leiden University (Nobel laureate 1969 economics)
1930	Start Faculty of Science at Vrije Universiteit Amsterdam
1932	PhD Bok at the University of Groningen (Bruce medallist 1977)
1933	Migration Einstein
1933	Suicide Ehrenfest
1940	Start German occupation
1945	End German occupation
1956	Start Eindhoven University of Technology
1957	Start Faculty of Science at Radboud University Nijmegen
1961	Start University of Twente

generation who were supervised by the first-generation scholars (Zeeman, De Sitter, Zernike) or with training from abroad (Einstein, Hertzsprung), and a third generation of mainly empirically-oriented scientists with PhD degrees awarded in the 1920s (Luyten, Minnaert, Oort, Brouwer, Tinbergen, Bok).

To sample the scientists active during the Second Golden Age, we start from the Mathematics Genealogy Project, an online initiative launched in the 1990s that aims to collect information on all recipients of a PhD degree in mathematics and related fields (Jackson 2007). Each entry compiles the full name of the scientist, the name of the university which awarded the PhD degree, the year of graduation, the title of the dissertation, the name of the advisor(s) and a list of supervised PhD students. Individual records are crowd-sourced and stretch from the late Middle Ages to the present day.

From the Mathematics Genealogy Project database, we collected all the scientists who satisfied the following three criteria: (1) having obtained a PhD in astronomy, chemistry, mathematics or physics, (2) at a Dutch university, (3) during the Second Golden Age period (1873–1933).[4] This query led to 557 observations. We then selected those who later on became professors, as indicated by either having at least one PhD student listed in the Mathematics Genealogy

[4]For the purpose of this study, we exclude PhD laureates *honoris causa*.

Project database (be it at a university in the Netherlands or abroad) or by being mentioned as professors in the online historical archives of Dutch universities[5] or on other relevant websites.[6] Finally, we checked in the same online historical archives of Dutch universities for professors who were omitted from the Mathematics Genealogy Project database. If they met our inclusion criteria, we added these scientists to the ones obtained from the Mathematics Genealogy Project database. Our final dataset of scientists who received their PhD degree at a Dutch university in the natural sciences during the period 1873–1933 and became professors consists of 130 professors. However, for 14 professors, we were not able to recover the information on the high school attended (HBS or other), which implies that the dataset used for the statistical analysis consists of a total of 116 observations.

Figure 1 depicts the 116 professors according to their graduation year (count and five-year moving average). The figure clearly shows, up until the peak in 1927, the rising number of PhD students from Dutch universities who became professors. The rapid increase is only partly due to appointments at foreign universities. Rather, the opportunities to become professor were mainly due to the domestic expansion of chairs at Dutch science faculties, both at the three oldest universities in Groningen, Leiden and Utrecht and at seven newly established universities: University of Amsterdam (1876), Delft University of Technology (1905), Wageningen University (1918), Free University of Amsterdam (1930), Eindhoven University of Technology (1956), Radboud University Nijmegen (1957) and University of Twente (1961).

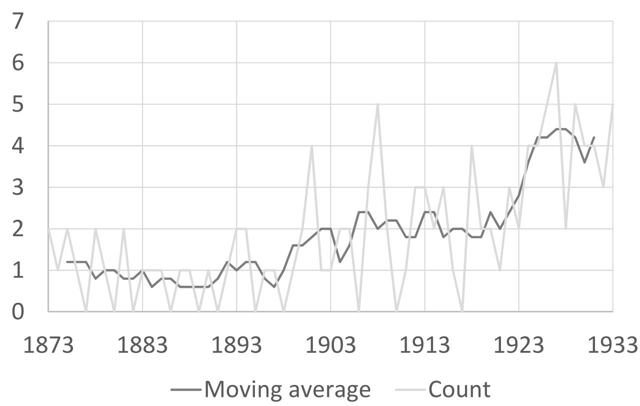

Figure 1. Number of PhD graduates from Dutch universities (1873–1933).

[5]Websites concern the archives of the University of Amsterdam (www.albumacademicum.uva.nl), University of Groningen (hoogleraren.ub.rug.nl), Leiden University (hoogleraren.leidenuniv.nl), and Utrecht University (profs.library.uu.nl).
[6]Websites include Huygens ING (www.huygens.knaw.nl), Chemistry Historical Group (www.chg.kncv.nl), MacTutor History of Mathematics Archive (https://mathshistory.st-andrews.ac.uk), and Wikipedia (www.wikipedia.org).

4.2. Dependent variable

4.2.1. Consecration

To assess the importance of research contributions of each scientist, we do not rely on the valuations they received at the time they were active. Adherents of prevailing theories and research standards may be valorised as more important at the time than proponents of radical contributions that go against prevailing theories and standards, precisely because core actors engaging in valuation have an interest in maintaining such theories and standards. Hence, within our study, the importance of a scientist's research can best be assessed over a long period, that is, retrospectively. We therefore consider 'retrospective consecration' (Allen and Lincoln 2004; Braden 2009) as our dependent variable, which we measure as the number of pages mentioning a scientist in recent overviews on the history of Dutch science.

Retrospective consecration is a composite indicator of fame. We constructed a count variable that sums up the number of pages mentioning a scientist within three Dutch bibliographic sources on the history of science: *In het Voetspoor van Stevin. Geschiedenis van de Natuurwetenschap in Nederland 1580–1940* (Van Berkel 1985), *De Tweede Gouden Eeuw, Nederland en de Nobelprijzen voor Natuurwetenschappen 1870–1940* (Willink 1998), and the two volumes on the history of the Royal Academy with the title *De Stem van de Wetenschap* (Van Berkel 2008, 2011). We choose these sources as they offer general and comprehensive histories of science without a specific focus on particular universities or people. We thus use this variable as an indicator of the significance of the research contributions that a scientist made over a lifetime.

4.3. Independent variables

For all scientists receiving a PhD degree during the Second Gold Age in the natural sciences, we compare the scientific contributions of university professors depending on their high school background and academy membership. Following our theoretical framework, we construct two independent variables to indicate if scientists came from the periphery. First, we check who has been a pupil at an HBS, and, second, we look at who has been a teacher at an HBS while doing the PhD research. As an indication of moving into the core of academia, we constructed a dummy variable identifying who is a member of the Royal Academy at some point in their career. Note that this membership is a contemporary acknowledgement of value ('valuation') as opposed to the retrospective value ('consecration'), which is our dependent variable (Braden 2009).

This leads us to define the following three dummy variables:

HBS_pupil: takes on the value of 1 if a professor attended HBS as a pupil, and 0 otherwise.

HBS_teacher: takes on the value of 1 if a professor taught at an HBS during the PhD research, and 0 otherwise.

Academy_membership: takes on the value of 1 if a professor achieved membership of the Royal Academy, and 0 otherwise.

Table 2. List of variables.

Name	Type	Description
Consecration	Count	Number of pages mentioning the scientists
HBS_pupil	Binary	Whether a professor attended HBS as a pupil
HBS_teacher	Binary	Whether a professor taught at an HBS
Academy_membership	Binary	Whether a professor became a member of the Royal Academy
PhD_year	Continuous	Year of PhD graduation
PhD_Leiden	Binary	PhD degree of Leiden University
PhD_physics	Binary	PhD degree in physics
N_prof_descendants	Count	Number of PhD students supervised who became professors

4.4. Control variables

4.4.1. PhD_year

To control for time trends, we include the professors' year of PhD graduation. As Figure 1 shows, the main time trend in the number of PhD students (all becoming professor later on) is upwards. Hence, professors who are active in the early period may get more attention from historians compared to the later period during which many more professors were active.

4.4.2. PhD_Leiden

In historical accounts of the Second Golden Age, Leiden University is often considered the centre of creativity. As further indications of Leiden's dominance, we can look at the Nobel Prize winners and Bruce medallists. Three Nobel laureates got their PhD degree at Leiden University (all in physics) (Van der Waals, Lorentz, Zeeman). The economics Nobel laureate Tinbergen also received a PhD degree in physics from Leiden University, while Bruce medallists Luyten and Brouwer were trained as PhD students at Leiden's observatory. At the professor level, Leiden hosted several Nobel Prize winners throughout the Second Golden Age, including Lorentz, Kamerlingh Onnes and Einstein (part-time) as well as Bruce medallists De Sitter and Hertzsprung. This remarkable concentration of prolific professors and their students may thus cause historians to focus disproportionally on any scientist with a Leiden PhD background. We therefore introduce a control variable, which takes on the value of 1 if a professor received the PhD degree from Leiden University, and 0 otherwise.

4.4.3. PhD_physics

Historians of the Second Golden Age may place most emphasis on the advances made in theoretical and experimental physics at Dutch universities. Nobel prizes also point to the success of Dutch physics given the four physics Nobel laureates in the 'heyday period' 1901–1913 (Van der Waals, Lorentz, Zeeman and Kamerlingh Onnes) as well as the physics Nobel Prize awarded later in 1953 to Zernike and the economics Nobel prize awarded in 1969 to physicist Tinbergen. The high standing of Dutch physics may thus cause historians to focus disproportionally on any scientist with a PhD degree in physics. Therefore, we introduce a control variable, which takes on the value of 1 if a professor received a PhD degree in physics, and 0 otherwise.

4.4.4. N_prof_descendants

As a final control variable, we include the number of supervised PhD students who then became professor themselves. The inclusion of 'professor decedents' as a control variable is especially important given that we use consecration as the dependent variable: descendants becoming professor may actively promote the memory of their dissertation supervisor.

The variables are summarised in Table 2.

5. Results

5.1. Descriptive statistics

Table 3 presents the descriptive statistics of our variables. It is clear that the consecration variable is highly skewed, ranging from 0 to 115 pages with a median value of only 2 pages and a mean of 9.17. Concerning HBS pupils, no less than 70 percent of all professors were trained at an HBS high school. The HBS also provided the opportunity for 9 percent of the scientists in our sample to pursue a PhD degree while teaching. And, 62 percent of professors had been elected as members of the Royal Academy at some point of their career.

In line with its reputation as the centre of creativity at the time, we can observe that a remarkable share of 37 percent of all professors got their PhD degree from Leiden University. Physics emerges as the most important discipline, covering 38 percent of all PhD theses in natural sciences, while astronomy, chemistry and mathematics had smaller percentages. Finally, we observe that the number of professor descendants is on average quite low, with a median value of 1 and a mean value close to 2.

Table 3. Descriptive statistics.

Variable	n	Mean	S.D.	Minimum	0.25	Median	0.75	Maximum
Consecration	116	9.17	18.02	0.00	0.00	2.00	9.00	115.00
HBS_pupil	116	0.70						
HBS_teacher	116	0.09						
Academy_membership	116	0.62						
PhD_year	116	1912	17.29	1873	1901	1915	1927	1933
PhD_Leiden	116	0.37						
PhD_physics	116	0.38						
N_prof_descendants	116	1.99	2.63	0.00	0.00	1.00	3.00	20.00

Table 4. Correlation table (*<0.05; n = 116).

	Variable	1	2	3	4	5	6	7	8
1	Consecration	1.00							
2	HBS_pupil	0.04	1.00						
3	HBS_teacher	0.27*	0.02	1.00					
4	Academy_membership	0.33*	0.03	0.01	1.00				
5	PhD_year	−0.43	0.06	−0.05	−0.17	1.00			
6	PhD_Leiden	0.14	0.08	0.00	0.12	−0.09	1.00		
7	PhD_physics	0.10	−0.03	−0.19*	−0.01	0.01	0.21*	1.00	
8	N_prof_descendants	0.23*	0.08	0.12	0.24*	0.06	0.03	−0.04	1.00

5.2. Correlation

Table 4 reports the correlation levels, which overall are very low. Looking at the independent variables, we only find three significant correlations. The HBS_teacher and PhD_physics dummies correlate negatively, reflecting that 8 out of the 11 HBS teachers who pursued a PhD degree, did so in mathematics. The positive correlation between the PhD_Leiden and PhD_physics dummies reflects the success of physics professors Kamerlingh Onnes, Lorentz and Ehrenfest who trained a large number of talents in Leiden. Finally, the positive correlations between Academy_membership and the N_prof_descendants may not come as a surprise, as it reflects that – on average – academy members trained more PhD students who became professors than non-members did.

5.3. Regression results

We estimate a two-equation system using a Generalised Structural Equation Model (GSEM). Figure 2 shows the path diagram of the structural equation model. The first equation estimates a logit model testing whether core actors (academy members) discriminated against peripheral actors (HBS pupils and HBS teachers) in choosing new academy members. The second equation considers the simultaneous effects of HBS_pupil, HBS_teacher and Academy_membership on consecration. Due to the over-dispersion of the consecration variable, we specify a negative binomial regression model (Cameron and Trivedi 1998). We estimate five models in Table 5, starting with only the key independent variables in the two equations (Model 1) and then adding the four control variables one by one (PhD_year, PhD_Leiden, PhD_physics, and N_prof_descendants).

Looking at the results with Academy_membership as the dependent variable, we find insignificant effects of the dummy variables HBS_pupil and HBS_teacher. These results indicate that, despite their peripheral positions, neither pupils nor teachers at the HBS were discriminated against by the Royal Academy. Former HBS pupils and former HBS teachers were not less (neither more) likely to become academy members than others. This suggests that the core members in academia were meritocratic in that neither the lower socio-economic status of former HBS pupils nor the lower academic status of former HBS teachers affected their chances to enter the Royal Academy.[7]

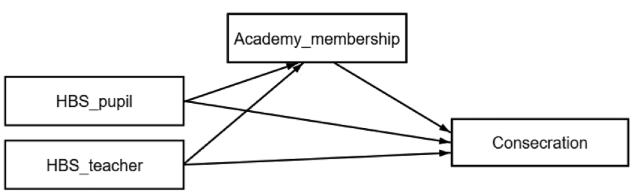

Figure 2. GSEM path diagram.

[7]Possibly, professors with an HBS background progressively became more accepted in the Royal Academy assuming that it became easier to enter the academy as the share of academy members with an HBS background grew over time. We checked whether such a dynamic can be detected by interacting PhD_year with Academy_membership, but we did not find evidence for this.

Table 5. GSEM-models (†<0.1, *<0.05, **<0.01, ***<0.001).

Consecration	Model 1	Model 2	Model 3	Model 4	Model 5
(negative binomial)					
HBS_pupil	−0.09	0.04	0.01	0.09	0.04
	0.23	0.23	0.22	0.24	0.24
HBS_teacher	0.52	0.68†	0.70*	0.92**	0.75*
	0.45	0.36	0.35	0.31	0.31
Academy_membership	1.35***	1.32***	1.31***	1.34***	1.22***
	0.26	0.26	0.26	0.25	0.26
PhD_year		−0.03***	−0.03***	−0.02***	−0.03***
		0.01	0.01	0.01	0.01
PhD_Leiden			0.16	0.12	0.14
			0.24	0.25	0.24
PhD_physics				0.58*	0.64**
				0.24	0.23
N_prof_descendants					0.08**
					0.03
Academy_membership (logit)	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
HBS_pupil	0.12	0.17	0.14	0.13	0.13
	0.42	0.42	0.42	0.42	0.42
HBS_teacher	0.07	0.02	0.04	−0.02	−0.02
	0.67	0.63	0.63	0.65	0.65
PhD_year		−0.02†	−0.02†	−0.02†	−0.02†
		0.01	0.01	0.01	0.01
PhD_Leiden			0.48	0.51	0.51
			0.42	0.42	0.42
PhD_physics				−0.17	−0.17
				0.42	0.42
N	116	116	116	116	116
BIC	825	813	821	823	821
AIC	803	785	788	784	780

Looking at consecration as the dependent variable, we find that those who became academy members are more consecrated than those who did not. The coefficient is highly significant and robust for the inclusion of control variables. The effect is also sizeable: academy members have exp(1.22) = 3.39 pages more devoted to them than non-members. The effect of the academy membership on consecration reaffirms the notion that the Royal Academy acted as an elite organisation hosting the most important scientists.

Looking at the two HBS variables, it becomes clear that both past HBS pupils and past HBS teachers tend to have higher levels of consecration. However, only the coefficient of HBS_teacher is statistically significant. HBS teachers have exp(.75) = 2.12 more pages devoted to them than others. This result is in line with our core-periphery framework in which we characterised the HBS teachers as having the most peripheral position. Writing their PhD thesis outside the university and largely on their own, these teachers – in hindsight – made the most creative and important contributions. Within the core-periphery framework, this result shows that scholars who worked remotely from university professors were also the most consecrated ones.

Regarding the control variables, we find that more recent PhD graduates are associated with lower levels of consecration. This may reflect a congestion effect: as the number of professors at Dutch universities steadily increased over time, it may have become increasingly harder to stand out. We further see a bias towards physics and an

Table 6. Robustness checks (†<0.1, *<0.05, **<0.01, ***<0.001).

Consecration	Model 5	Model 6	Model 7	Model 8	Model 9
(negative binomial)	Reference Table 5	Interaction effects included	Without Van Berkel (2008, 2011)	Oxford Dictionary (logit)	Encyclopaaedia Britannica (logit)
HBS_pupil	0.04	0.02	0.10	0.17	0.26
	0.24	0.48	0.28	0.70	0.67
HBS_teacher	0.75*	0.35	0.75*	0.32	0.96
	0.31	1.13	0.29	0.81	0.97
Academy_membership	1.22***	1.16**	1.24***	15.81***	0.95
	0.26	0.45	0.36	0.38	0.63
PhD_year	−0.03***	−0.03***	−0.04***	−0.03	−0.01
	0.01	0.01	0.01	0.02	0.02
PhD_Leiden	0.14	0.13	−0.14	−0.12	0.05
	0.24	0.24	0.26	0.64	0.51
PhD_physics	0.64**	0.64**	0.73**	0.39	1.56**
	0.23	0.23	0.27	0.61	0.53
N_prof_descendants	0.08**	0.08**	0.11*	0.05	0.19
	0.03	0.03	0.05	0.07	0.12
Academy_membership*HBS_pupil		0.04			
		0.55			
Academy_membership*HBS_teacher		0.45			
		1.17			
Academy_membership (logit)	**Model 5**	**Model 6**	**Model 7**	**Model 8**	**Model 9**
HBS_pupil	0.13	0.13	0.13	0.13	0.13
	0.42	0.42	0.42	0.42	0.42
HBS_teacher	−0.02	−0.02	−0.02	−0.02	−0.02
	0.65	0.65	0.65	0.65	0.65
PhD_year	−0.02†	−0.02†	−0.02†	−0.02†	−0.02†
	0.01	0.01	0.01	0.01	0.01
PhD_Leiden	0.51	0.51	0.51	0.51	0.51
	0.42	0.42	0.42	0.42	0.42
PhD_physics	−0.17	−0.17	−0.17	−0.17	−0.17
	0.42	0.42	0.42	0.42	0.42
N	116	116	116	116	116
BIC	821	831	643	283	307
AIC	780	784	602	244	268

effect of the number of descendants becoming professors later on in their career. The latter effect was expected as these descendants may have been active promotors of their supervisors' name and fame.

5.4. Robustness checks

In Table 6, we report on four robustness checks (Model 6–9) and compare the results with Model 5 (taken from Table 5) as a reference. As a first robustness check, we interacted the Academy_membership dummy variable with each of the two HBS dummy variables as shown in Model 6. A positive interaction effect between Academy_membership and the HBS_pupil or HBS_teacher dummy would indicate that those with an HBS background would benefit more from academy membership than those without any connection to the HBS. Put differently, a positive effect would suggest that a positive valuation by core members would matter more for those who are peripheral than those who are already well connected. The interaction effects are not significant and the BIC and AIC criteria indicate that the performance of Model 6 decreased compared to Model 5. These results show that scientists benefitted equally from academy membership, independently of their backgrounds.

As a second robustness check, we measured retrospective consecration only by the number of pages in Willink (1988) and Van Berkel (1985), excluding the number of pages in the two volumes covering the history of the Royal Academy by Van Berkel (2008, 2011). We do this robustness check because the volumes on the Royal Academy may create an upward bias to the effect size of the Academy_membership variable, as history writing on the Royal Academy as an organisation may focus especially on academy members rather than non-members. Re-doing the analysis in Model 7 and comparing the results with Model 5 shows that all variables keep their sign and significance. This thus confirms the results obtained from Model 5.

As a final robustness check, we replaced in Model 8 and Model 9 the retrospective consecration variable based on Dutch sources with two alternative dependent variables based on international rather than national sources. We constructed two binary variables: the first variable takes the value of 1 if a professor is mentioned in the Oxford Dictionary of scientists and 0 otherwise (Daintith and Gjertsen 1999), and the second variable takes the value of 1 if a professor is mentioned in the Encyclopaedia Britannica (2020) and 0 otherwise. The results show that the main effect of Academy_membership remains positive and significant in Model 8, while PhD_physics is the only significant variable in Model 9. In both cases, the coefficient of HBS_teacher loses its significance. Hence, the results of Model 5 are shown to be only partially robust if the national consecration variable is substituted by an international consecration variable.

6. Conclusion and discussion

Our analysis of the sudden success of scientific research in the Dutch natural sciences can be well understood in a core-periphery logic. We find that those selected as members of the Royal Academy – constituting academia's core at the time – boosted their careers and, ultimately, their fame. We further find that HBS teachers, being remote from university and writing their PhD thesis largely on their own, were on average more creative and important than the large majority pursuing a PhD at a university. Both findings speak to the core-periphery thesis in that disconnectedness may foster creativity and novelty, while subsequently entering the Royal Academy, as the network's core, legitimises one's achievements (Phillips 2011; Cattani, Ferriani, and Colucci 2015). We did not find, however, that academy membership mattered more for former HBS teachers or former HBS pupils compared to those without any connection to an HBS.

The results of our study only partially confirm Willink's (1980) initial thesis about the importance of the HBS for the rise of Dutch science. Our analysis shows that HBS pupils with modest socio-economic status did not do better (nor worse) than pupils with a more elitist background. Thus, the establishment of the HBS allowed pupils from modest backgrounds to get a high-school training in natural sciences and then to enter the university, with equal chances to be accepted within the Royal Academy as talents from the social elite. In this sense, the HBS had an important *quantitative* effect (Van Berkel 1998): quite soon after the establishment of the HBS in 1863, the majority of PhD students becoming professors had attended the HBS as a pupil. Our regression results, however, indicate that the HBS did not carry a *quality* impulse, as proxied by retrospective consecration, as professors who attended the HBS as pupils did not outperform professors with another high school background. Only professors who were HBS teachers at the time they did their PhD research are shown to have outperformed other professors who did their PhD research at a university.

We can thus conclude that the sudden rise of world-class science cannot be directly attributed to the introduction of the HBS as a superior high school system. Rather, the HBS – with its high salaries – provided an alternative, self-funded pathway for its teachers to pursue a PhD degree outside the walls of the university. Remote from a professor's influence and practices, these HBS teachers focused on making theoretical contributions in very original ways.[8] Our empirical results thus speak more to the core-periphery framework than to Willink's (1980, 1991) macro-structural claim that HBS pupils were better trained for research than other pupils.

An important question that remains, however, is why scientific research established itself so rapidly as a legitimate activity at Dutch universities in the first place. Willink (1980, 1991) argued that the rise of scientific research was linked to the many new chairs that were opened at the time that the first cohort of PhD students with an HBS background entered the academic labour market (among whom Van der Waals, Lorentz, Kamerlingh Onnes and Van 't Hoff). The establishment of the new chairs followed from a sudden doubling of the national budget for higher education in the period 1876–1878. While a large part of the budget was spent on higher wages, a significant part was invested in new chairs and a higher number of assistants per chair (following the German model). Notably, many of the new chairs were placed in Amsterdam that saw its bachelor college being upgraded to a university with the right to grant PhD degrees in 1876.

While this sudden increase in the national budget explains the possibilities for young talents to become professors at an early age, it does not explain the rise of scientific research as such (Maas 2001). It should be reminded that chair holders only had formal

[8]Note that Einstein had a similarly peripheral position in academia while writing his breakthrough papers in 1905. At that time, he worked at the Swiss patent office in 1905, being an external PhD student without any formal employment at a university (Pais 1982).

teaching duties and were not expected to devote much time to scientific research. What is more, hardly any of the budget increase of the national government was dedicated to new research labs. Instead, most of the research had to be carried out in teaching labs, outside teaching hours and during weekends. Hence, according to Maas (2001), the emergence of world-class research within Dutch universities, cannot be fully, or even primarily, attributed to the increase in financial resources.

From a core-periphery perspective, one can point to another reason why scientific research could develop so quickly in the Netherlands by putting the national development in a wider international context. Throughout the nineteenth century, scientific research in the natural sciences developed rapidly in countries like France, Germany, Austria and the UK. Professors at Dutch universities were particularly aware of the outstanding successes of German colleagues whose labs were much better funded with assistants and equipment (Willink 1988; Maas 2001). It was also for this reason that Dutch professors sometimes sent their most talented students to German universities (among whom Nobel laureates Kamerlingh Onnes and Van 't Hoff), to carry out research projects for which the infrastructure and expertise were lacking in the Netherlands.

Foreign influence also played a role in attributing creativity to the new generation of Dutch scientists (Maas 2001). Foreign scientists were considered to be better able to judge the quality and originality of new research than their Dutch counterparts whose knowledge of international developments was not up to date. As an example, the PhD thesis of Van der Waals, defended at Leiden University in 1873, remained largely unnoticed in Dutch circles until Cambridge professor Maxwell discussed the thesis in *Nature* and celebrated Van der Waals as the greatest talent of the time (Maas 2001). Van der Waals' fame then quickly rose within the Netherlands, and already in 1877, Van der Waals was offered a chair at Leiden University (which he declined) and at the University of Amsterdam (which he accepted). Not much later, his PhD thesis was translated in German, English and French.

The research successes of Van der Waals and his contemporaries greatly contributed to the international prestige of Dutch universities, and as such, to the organisational field of Dutch academy as a whole. The achievements of the new cohort of scientists were glorified as a national success, captured by the very notion a 'Second Golden Age' first mentioned in 1914 (Van Berkel 1998). Within the wider political context of rising nationalism, research excellence even became part of a renewed national identity (Van Berkel 2004), which in turn increased the legitimacy of the Royal Academy with its funder: the national government (Van Lunteren 2004).

Dutch academia thus changed its 'institutional logic' from being primarily a teaching institution for a selected group of students (upper-class) in a selected number of subjects (medicine, law, theology) to a combined teaching and research institution for a wider group of students (now also including middle-class students) in a wider range of subjects (now also including natural sciences). The prestige of scientific research in the natural sciences can be further understood in the core-periphery framework (Cattani, Ferriani, and Colucci 2015). In general, core members in an organisational field have little incentive to embrace new norms and activities that threaten their status and control over resources. However, they are generally willing to support a new activity when the field as a whole can boost its legitimacy (Clemens and Cook 1999). By contributing to the prestige of an entire country, the political and financial support for scientific research in natural sciences increased. In this light, and resonated by our empirical study, the older generation of scientists organised in the Royal Academy, was quick to accept the young generation of research-oriented scientists in their midst. As a result, scientific research got established quickly, and without any serious opposition, as a legitimate, and even prestigious, activity at Dutch universities.

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