The impact of policies influencing the demography of age-structured populations: lessons from academies of sciences

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Research Report 2012-08
December 2012

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1. INTRODUCTION

Population aging is transforming the demographic makeup of many nations (e.g. Bongaarts, 2009; Uhlenberg, 2009). While longstanding patterns of low fertility have been major contributors to the observed trends, significant reductions in adult mortality - including the oldest-old ages - have had and will continue to have a nontrivial impact on the age structure (Preston *et al*., 1989; Rowland, 1996; Kim and Schoen, 1997). Under prevailing systems of social security, labour market policies and institutional frameworks these demographic developments may pose economic challenges and could endanger the sustainability of economic growth in most industrialised countries (see works in Prskawetz *et al*., 2008).

Various kinds of age-structured organisations (e.g., universities, armies, airlines) face similar challenges as they age more rapidly than general populations. An interesting case study is that of academies of sciences because academicians have historically exhibited, and still exhibit, remarkable longevity (e.g., Andreev and Jdanov, 2007; Winkler-Dworak, 2008), contributing to aging from the top. Furthermore, academies have been aging from the bottom as many have increasingly elected older members over the years (detailed in Section 2 below; see also Van den Kaa and Roo 2003; Leridon, 2004; Cohen, 2009). For these reasons, some academies have expressed a certain degree of interest in regulating their pace of aging (Van de Kaa and

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Roo, 2003; Feichtinger *et al*., 2007) and growth (Cohen, 2009)[1].

To be sure, academies of sciences, along with most other organisations, have features that make their population dynamics somewhat different to those of general (or geographically-defined) entities such as those of nation-states. For instance, unlike general populations, where the current generation of individuals will spawn the following one (and so on), current academicians will not, in a strict sense, spawn the next generations of academy members (they will indeed elect them, but that is conceptually different, at least from the point of view of population dynamics). Yet, as we discuss in more detail below, some features of the models used to study the steady-state aging and growth implications of age-structured intake in academies of sciences are very similar to various models used to study the consequences of (age-structured) immigration on the size and age composition of nation-states (e.g., Espenshade, Bouvier, and Arthur, 1982; Feichtinger and Steinmann, 1992; Alho, 2008). As such, as we also posit below, the study of academies of sciences is not only an application of these models but can potentially inform them.

Furthermore, even though academies face particular challenges and constraints not faced by nation-states if these were to regulate their pace of aging through immigration, they can also exert more control with regards to the number and age distributions of elections than most governments. As such, we argue it is particularly fitting to evaluate the implications of different intake policies in learned societies.

Prior research on the aging and growth implications of academies has, by and large, focused on one academy (e.g., Van de Kaa and Roo, 2003; Leridon, 2004; Feichtinger *et al*., 2007; Cohen, 2009) and, as such, a particular type of intake policy (explained in more detail below). In this paper, we assess the role of a more diverse set of policies aimed at regulating the size and age structure of intake in influencing the potential evolution of full membership of a broader set of academies of sciences: the Austrian, Berlin-Brandenburg, Russian and Norwegian Academies and the Royal Society of London. We first provide some background to the problem by summarising the types of intake policies and practices carried out by many academies, discussing their potential implications for the size and age structure of these societies, and relating their study to that of age-structured intake in general populations. Next, we briefly describe the data and history of each of the academies we hereby study, showing the degree of variation in policies across them, and introduce the methodology used to evaluate these policies. Finally, we illustrate the effect of different policies on aging by contrasting the steady-state and transient dynamics of different projections of

[1] The pace of aging even prompted the Académie des Sciences to undertake a major reform in 2002. The latter involves (1) introducing an age threshold, where members surpassing this age do not count for the maximum number of members and a new member may be elected in their place, and (2) by stipulating that half of the new entrants had to be under 55 (Leridon, 2004, p. 102). The first of the aforementioned policies is also followed by the Austrian Academy of Sciences, the Berlin Brandenburg Academy of Sciences as well as the Norwegian Academy of Sciences.

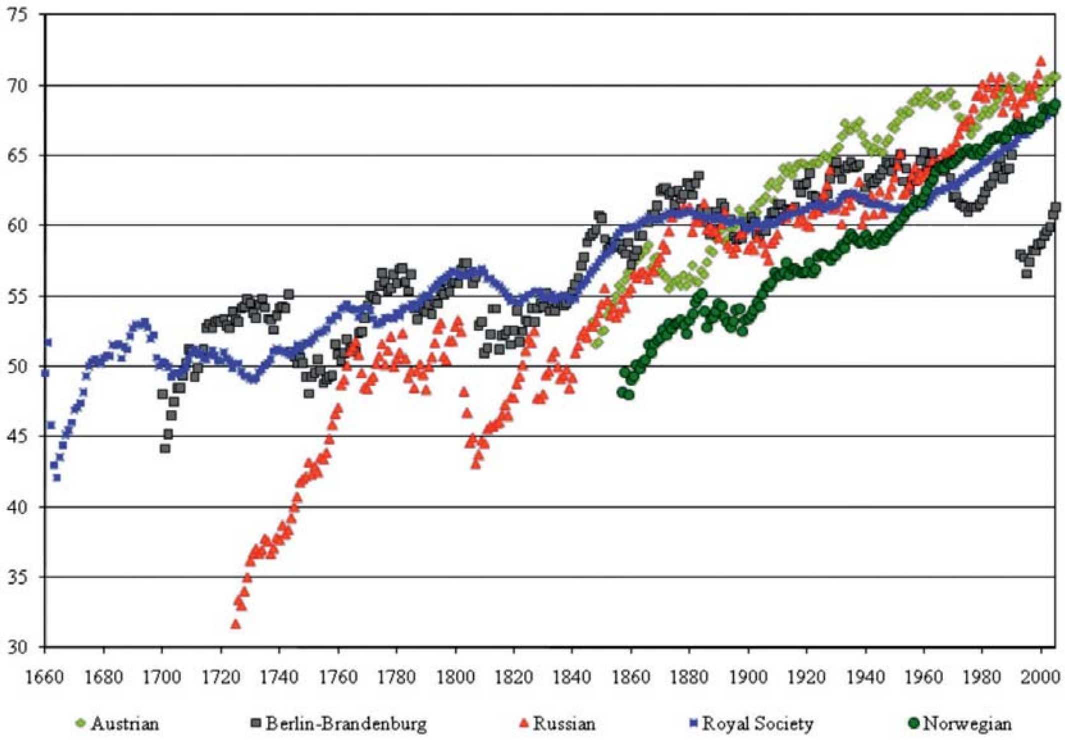
full members (hereafter FM) in each academy into 2070 and measuring the size and age-compositional effect of enacting a given policy vis-à-vis a standard policy scenario. We conclude by discussing the implications of our findings for academies, other organizations, and for the study of the effects of age-structured intake on population dynamics.

2. ACADEMY POLICIES IN THE CONTEXT OF STABLE POPULATION MODELS OPEN TO AGE-STRUCTURED INTAKE

2.1 *Background*

Academies of science have aged considerably in the last few years (Van de Kaa and de Roo, 2006; Cohen, 2009). To illustrate, Figure 1 shows trends in the mean age of the population in the five European academies of sciences in our study (introduced and described in more detail in Section 3). Four of these academies currently have mean ages above 68, a result of a rapid, secular trend due to both aging from the top and bottom.[2] Academicians' longevity, already

Figure 1 – *Mean age of full members by academy and period*

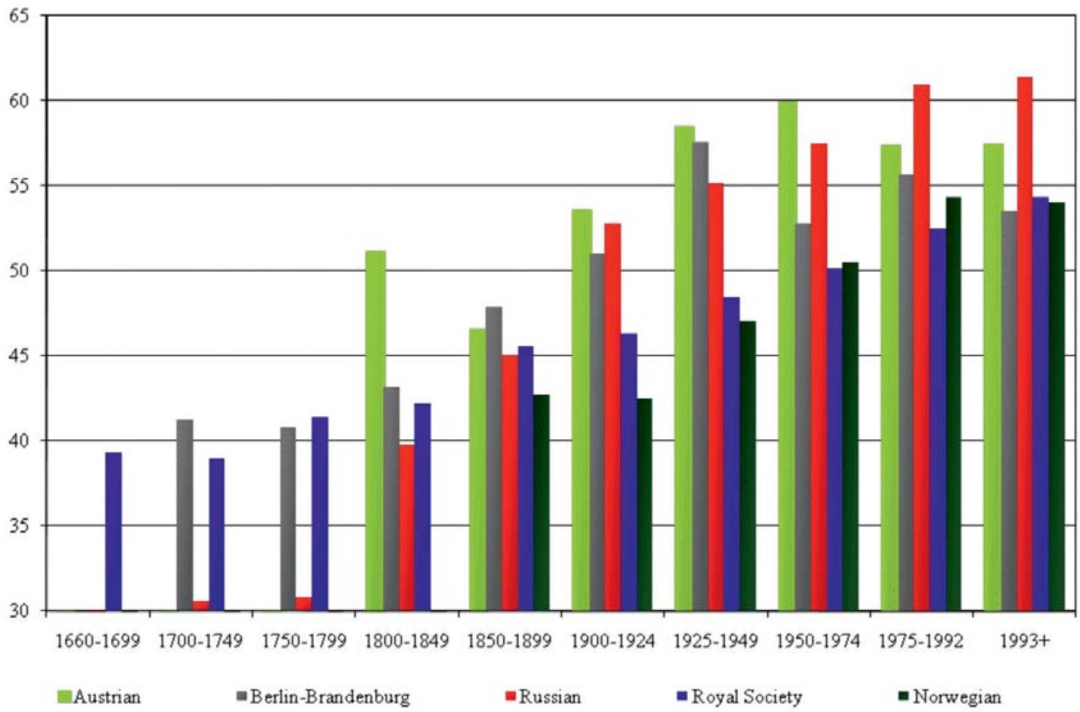


[2] Although the mean age of the Berlin-Brandenburg Academy of Sciences is somewhat lower, this may be an artifact of the election of very young members after the academy was re-founded in the wake of German reunification (see Section 3.1 below for more details). As such, it may be more of a transitional stage than a radically different regime relative to other academies.

remarkable throughout history (Houdaille, 1980; Leridon, 2004; Matthiesen, 1998; Andreev and Jdanov, 2007; Van de Kaa and de Roo, 2008; Winkler-Dworak, 2008; Cohen, 2009; Andreev *et al*., 2011; Winkler-Dworak, 2012), has continued to increase over the past few decades at a more rapid rate than life expectancy improvements in the general population (Andreev and Jdanov, 2007; Van de Kaa and de Roo, 2008; Winkler-Dworak, 2008; Andreev *et al*., 2011).

In most academies, aging due to high and increasing life expectancy has been compounded by an upward trend in the mean age at election (see Figure 2). On the one hand, academy practices in Austria have remained more stable, electing relatively older members since the early to mid-20th century (older than the average in all academies but the Russian). On the other hand, the mean age at election in the Royal Society of London and the Russian and Norwegian academies increased a non-trivial 4 years from 1950-1974 and 1993-2005 (see Section 3 for an explanation of the lower age at election in Berlin-Brandenburg in 1993-2005). Note that the Berlin-Brandenburg academy, as we explain in more detail in Section 3, is a special case given its more recent foundation

Figure 2 – *Mean age of full members by academy and year*



Compared to nation states, the age structure of these (and other) organisations is especially sensitive to changes in survival and intake. This is because an academy's entire intake is itself age-structured (as opposed to populations that also grow of course through sizable birth flows), which tends to yield milder rejuvenation effects (Schmertman, 1992). The prospects of large growth pose a challenge for most academies, which wish to remain selective bodies, and which also have financial constraints to elect many new members (particularly those that may provide research funds or a stipend to their members).

At the same time, these organisations can certainly regulate the number of newly-elected members in a more effective way than, say, a (democratic) nation-state, which is generally able to set strict limits on immigration (e.g., due to family reunification provisions), or influence fertility changes. As such, academies are better equipped to regulate their pace of aging through several policies affecting the number and, with a bit more difficulty, the age structure of newly-elected members. Moreover, the potential of age-structured inflow (i.e., net immigration) as a solution to population aging in nation states appears somewhat limited (Schmertmann, 1992; Espenshade, 2001; United Nations, 2001; Coleman, 2002).

Academies can have an impact on aging by regulating their pace of growth (to some extent given the reasons summarized above). The byelaws (or otherwise, common practices) of most academies regulate growth either by setting the number of elections per year to a (relatively) fixed number. Alternatively, it has been the policy of some academies to fix the number of members below a certain age and if a member surpasses this age, a new member may be elected in his place. Hence, the number of vacancies and, thus, the number of elections is linked to the number of academy members reaching this age (ignoring the almost negligible low mortality of the academicians below this age). As explained next, under certain conditions, either fixed or linked intake will lead to a stationary steady-state. This is a useful feature to evaluate and compare different intake policies in academies. Furthermore, it implies that these two intake regimes are part of a family of stable population models open to age-structured intake.

2.2 *Previous research on stable population models open to age-structured intake*

Scholars have studied the implications of age-structured intake on population size (and age structure) by looking at steady state (generally stationary) conditions. After Pollard (1973) and Espenshade, Bouvier, and Arthur (1982)[3] showed that populations with below-replacement fertility and fixed mortality schedules reached a stationary equilibrium (a few generations) after adding a

[3] Pollard (1973) and Espenshade *et al*. (1982) showed similar results for the discrete and continuous case respectively. For further details and discussion this and other (less used) stable population models open to migration, see Preston and Coale (1982), Mitra (1983), Cerone and Mitra (1986), Cerone (1987), Feichtinger and Steinmann (1992), Schmertmann (1992), Wu and Li (2003), and Alho (2008).

fixed (age-specific) immigrant flow, this general idea has been used more recently to understand the impacts of immigration on population ageing and growth (e.g., Arthur and Espenshade, 1988; Schmertmann, 1992; United Nations, 2002; Riosmena *et al*., 2012). Following a similar logic (and as we illustrate empirically in Section 4), a fixed mortality schedule with a fixed number of new members by age will imply stationary conditions for academies in the future. Given that intake (and to a lesser extent, mortality) have been somewhat more stable than the demographic regimes of most nation-state populations, we use this property to evaluate the implications of fixed intake on the growth and ageing of academies.

As shown by Feichtinger and colleagues (Feichtinger *et al*., 2007; Dawid *et al*., 2009), linked intake policies also lead to a stationary steady state under a fixed mortality schedule and a constant age structure of intake. This is because the flow of newly elected members eventually becomes fixed after a period of pre-transitional dynamics, thus yielding the conditions needed for a stationary steady state.[4] As such, one can also study the effects of linked intake policies on the growth and aging of academies using a similar approach to that used when evaluating fixed intake policies. It follows, of course, that both policies can then be compared in terms, for instance, of the pre-transitional growth they generate.

Furthermore, note that the fact that both fixed and linked intake regimes become stationary implies they will lead to the exact same age structure as long as the age composition of new members is the same. Under conditions leading to a stationary steady state (regardless if the regime is fixed or linked), high and low growth regimes with the same mortality schedule and the same age composition of elections will lead to the exact same stationary structure. However, these two regimes will differ in their pre-equilibrium aging and growth dynamics and in their stationary size, but not in terms of age structure (see Section 4 below).

For this reason, the age structure of elections may be an even more important policy variable to regulate than the age structure of the organisation. The age structure of intake has been shown to be a very important factor influencing the size and age structure of both nation-states (Arthur and

[4] For a similar logic on the study of the effects of immigration on the size and age structure of nation-states, see Alho (2008) and Riosmena *et al*. (2012). Alho (2008) used a result derived by Pollard (1973) to show that a population will reach stability by linking the number of immigrants to (a fraction of) the birth flow under a fixed fertility and mortality schedule (note, however, that the steady state may not be stationary, depending on fertility levels, see Mitra, 1983). The case of linked intake of academies of science (under fixed mortality conditions) is not much different than if intake is linked in a similar way as in the case of these studies (but to another age structure parameter).

Espenshade, 1988; Schmertmann, 1992) and academies of science (Feichtinger *et al*., 2007). As such, we study the pre-transitional dynamics and steady-state size and age structure under different age structures of intake.

The age structure of the academy can vary for several reasons. Some are exogenous, such as the age composition of the potential pool of potential academicians, affected by supply-side factors beyond the scope of this paper (e.g., substantial differences in the quality of different cohorts of scientists). Assuming that these exogenous factors are negligible or, less strictly speaking, that there is no shortage of qualified candidates to become academy members within a reasonable age range (e.g., between 40 and 70 years of age), demand-side factors, somewhat controlled by academies through different kinds of policies and practices, then become the main factor determining the age structure of elections.

Academies control the age structure of elections by their desire, for instance, "[…] to stay in touch with the community of working researchers if it is to continue to play a useful role as an advisory body in society." (Leridon, 2004, p. 83), as older academies may be seen as "not dynamic enough and no longer well-informed." (Van de Kaa and Roo, 2006, p. 20). Academies, particularly those under linked intake, may also control the age structure of elections for the explicit purpose of regulating the balance between aging and growth, or (put differently) aging and open vacancies in linked intake academies as the following illustration by academician Gerhart Bruckmann (cited in Feichtinger *et al*., 2007) clearly demonstrates for the case of the Austrian Academy of Sciences:

> "With an average age at election of 55 years and ruling out mortality, a member has 15 remaining years until the age threshold. At a maximum number of 90 members, you are bound to see 6 vacancies per year on average. However, if entry at earlier ages were favoured (in order to establish a 'younger Academy'), e.g., at 47.5 years, then these new members would stay in the system for 22.5 years until the statutory retirement age - exulting in 90/22.5 = 4 vacancies per year."

Although, in theory, academies should then be able to choose the age structure of elections they find more appropriate in order to regulate growth and aging (along with any other purposes the academy may have), it is important to mention that some academies do face *self-imposed* structural constraints to the age structure of new members they may be more likely to elect. While not formally stated in their bylaws, the Austrian and Russian academies elect the vast majority of new 'full' members (i.e. those with voting rights and full access to any other benefits held by academicians) from a pool of another membership category, generally known as 'corresponding' membership, which thus *de facto* serves as full-membership candidacy. [5]

As suggested in Figure 2, the age structure of elections may be higher in the Austrian and Russian academies due to the existence of a corresponding membership status in both. This is so as a candidacy period may delay election into full membership (for a formal model depicting these dynamics, see Feichtinger *et al*., 2011). To illustrate this, Table 1 shows estimates of lifetime probabilities of being promoted from CM to FM in Austria for those elected as CM between 1960 and 1990. The probability of becoming a FM was *lower* the older academicians were when elected as CM. Transition probabilities ranged from 88 % for (the few) members elected before their 46th birthday to 38% for those elected as CM after age 55 (probabilities decrease monotonically for the age groups in-between). Thus, if most members are elected from the ranks of CM and their ages at election as CM signal the strength of their records and potential for being elected as FM, then the age structure of FM intake is a function of and, as such, is constrained by the age structure of CMs (for a formal exposition, see Feichtinger *et al*., 2011).

Table 1 – *Probability of ever becoming a full member, mean duration before FM election, and mean age at election as FM in the Austrian Academy of Sciences by age and period of election as corresponding member, members elected as CM in 1966-1990.*

Age at election as Corresponding Member (CM)	*Raw* probabilities of ever becoming a Full Member (FM)	Mean duration as CMfor those who became FMs	Mean age at election as FM
Less than 45	0.872	8.0	49.6
45 to 49	0.792	8.1	55.7
50-54	0.764	6.0	58.4
55 and over	0.378	4.6	64.6
All ages	0.629	6.7	57.3

[5] According to our analysis of membership data for the Austrian and Russian Academies (described in the next Section), full members in the Austrian Academy of Science are elected almost exclusively from the pool of corresponding members (the exceptions being: during the very first years of the academy; during years when the maximum number of members is increased; and in historically extraordinary periods, such as during WWII). Although the share of full members who have been previously corresponding members in the Russian Academy is lower than in the Austrian Academy, it has been rising over time. In the 19th century as well as in the beginning of the 20th century, the number of elections were much lower and the share of full members, previously corresponding members, was quite erratic (bouncing between 0 and 100%), with a mean of 32% for 1798-1949, 48% for 1800-1849, and 55% for 1900-1949. For the years 1950-1974, the share ranged between 67% and 91% (mean = 85%). For the most recent period, 1975-2006, at minimum 80% of the academicians at each election have been corresponding members before and at most 98%, where the mean over all 31 years equals 92%.

Whether or not the existence of a corresponding member status delays election into full membership, considering different age structures of elections is very relevant to evaluate the trade-offs between aging and growth, particularly in academies with linked intake regimes (see Feichtinger *et al*., 2007; Dawid *et al*., 2009). Before introducing our methodology, we next describe our data and provide a brief profile of each academy under study.

3. DATA AND METHODS

3.1 *Data and a brief portrait of the academies*

We base our comparisons of different election policies on data from historical membership records (up to 2005, the last year of availability for most academies) of five European learned societies: the Austrian Academy of Sciences, the Berlin-Brandenburg Academy of Sciences, the Royal Society in London, the Russian Academy of Sciences and the Norwegian Academy of Sciences and Letters. We use first-hand data provided by the respective academy and membership registers published either online (The Royal Society, 2005; Russian Academy of Sciences, 2008; Berlin-Brandenburgische Akademie der Wissenschaften, 2009) or in hard copy (Amundsen, 1957; Hittmair and Hunger, 1997; Österreichische Akademie der Wissenschaften, 1996-2005; Russian Academy of Sciences, 1999; Helsvig, 2007) as well as from Andreev and Jdanov (2007). The size and age structure of full membership varies considerably across academies (see Table 2, Figure 1) and can be explained by variation in intake rates, the age structure of new members (Figure 2), and - only to a minor extent - by the mortality conditions to which members are exposed (Andreev *et al*., 2011; Winkler-Dworak, 2012).

The Austrian Academy of Sciences (OEAW), founded in 1847, limits the number of members below a statutory ‘retirement’ (henceforth SR) age of 70 years (since 1972-1975 years in 1950-1971) to 45 in each of its two Sections: Mathematics and the Natural Sciences, and Humanities and the Social Sciences (Feichtinger *et al*., 2007). Despite the total number of FMs below that age thus being limited to 90, the actual size of the academy as of mid-May 2005 (just after elections took place) was 164, as 45 per cent of FMs were over age 70. New members are required to have Austrian residence and stellar academic records. They also generally come from the ranks of Corresponding Members (henceforth, CMs).

The Berlin-Brandenburg Academy of Sciences (BBAW) was founded, strictly speaking, only in 1993, though many of its members had previously belonged to the roster of the old Prussian Academy, which became the German Academy of Sciences in Berlin in 1946 and was renamed Academy of Sciences of the German Democratic Republic in 1972 (Berlin-Brandenburgische

Akademie der Wissenschaften, 2009). In the wake of German reunification, the academy was closed in 1992 and re-constituted in 1993 with the new name. Upon 're-foundation', the Academy dropped the CM status, enacted a retirement age of 68 and established a limit of 200 members below the statutory retirement (SR) age. However, as of early 2005, membership under the SR age was still well below the limit, namely at 169. The *whole* full membership of the BBAW sums up to 173 (Table 2), making those above the SR age only 2.3 per cent of total membership.

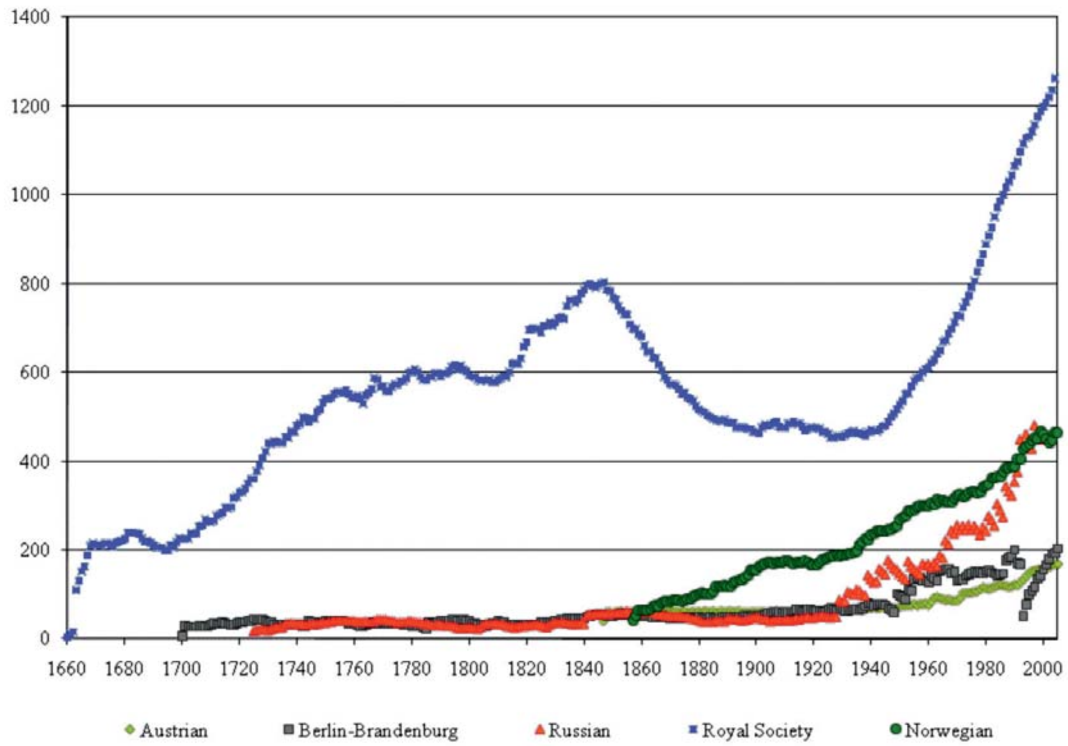
Table 2 – *Summary of history, policies, and membership and age structure (as of January 2005) of academies*

	Austrian	Berlin-Brandenburg	Russian	Royal Society	Norwegian
Year of foundation	1847	1700, 1993	1724	1660	1857
Data availability	1847-2005	1700-2005	1724-1999	1660-2006	1950- 005
Status previous to full member?	Yes	Until 1993	Yes	No	No
Current maximum intake	N/A	N/A	N/A	44	N/A
Statutory retirement (SR) age	70	68	N/A	N/A	67
Current maximum size	90	200	N/A	N/A	219
Current full membership	164	173	496	1,257	459
Per cent FMs above 'retirement' age	45.1	2.3	N/A	N/A	52.3

The Russian Academy of Sciences (RAS) lacks a statutory retirement age and does not have any clear limits for the number of elections, which take place every three years (unlike the other academies where elections occur annually). As of mid-2005, there were 496 FMs, by and large elected from a pool of corresponding members. Despite having one of the highest growth rates (Figure 3) and lowest life expectancies among academies (Andreev *et al*., 2011; Winkler-Dworak, 2012), the Russian academy has the oldest observed age structure: 68% of their members are above age 70. This is due to the fact that newly elected members tend to be much older than those in other academies: the mean age at election in the 15 years prior to 2005 was around 61, roughly 4 years older than in any of the other four academies (Figure 2).

Like in the Russian case, the Royal Society (RS) lacks a statutory retirement age or any membership size limits per se (in addition, it lacks a corresponding member category). Although the RS does limit the number of elected fellows (to 44 per annum), this intake is large enough (relative to the total membership) to result in high growth in the latter half of the 20th century (Figure 3), making the RS the largest academy of the five societies hereby studied, with membership standing at 1,257 in mid-2005 (Table 2). Such high growth has indeed resulted in a younger age structure as compared to that of the Austrian and Russian academies, but not compared to the still young group of academicians from Berlin-Brandenburg (Figure 1).

Figure 3 – *Full membership size by academy and year*



The Norwegian Academy of Sciences and Letters, with a similar mean age as the Royal Society (Figure 1) does not have a corresponding member status either but does have a statutory retirement age of 67 (in line with Norwegian law for any member of the labour force). As in the Austrian and Berlin-Brandenburg cases, membership size below the SR age is limited (in this case to 219 members). However, the total size of the academy is 459, implying that 52% of its members are older than the SR age, a percentage similar to the one observed in the Austrian academy.

3.2 *Methods*

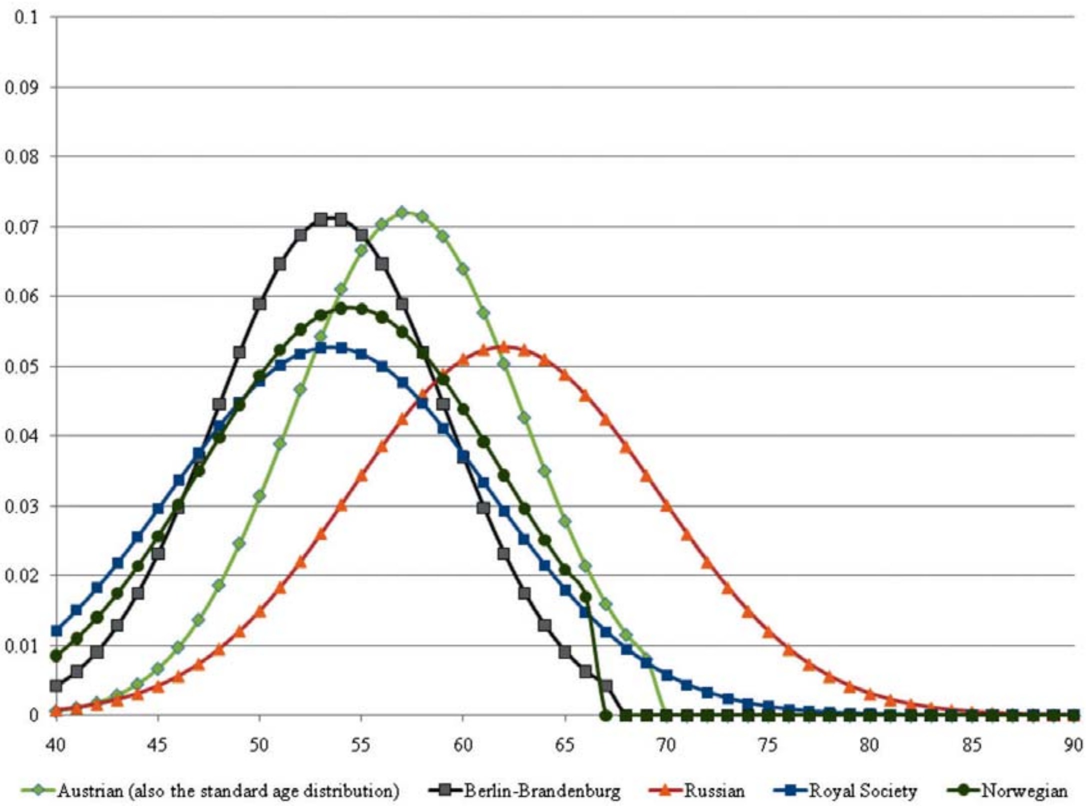
In order to understand the effect of different policies and practices regarding intake type and the age structure of elections on the academies' size and age structure, we project the population of each academy to 2070 using cohort-component projections (e.g., Preston *et al*., 2001, Chapter 6). While this allows us to study the steady-state age structure in each regime, we also compare the ultimate size of different scenarios for each academy in order to understand how pre-transitional dynamics (e.g. momentum) vary by scenario and according to initial conditions in each academy.

The cohort-component method is a discrete-time model of population dynamics, where the number of persons by age and sex are projected forward stepwise, based on the assumptions on fertility, mortality, and migration: first, the number of persons surviving to the beginning of the next time interval according to the postulated age and sex-specific death rates is computed. Secondly, the number of births, implied by the assumed age-specific fertility rates, is derived, and then, the number of those births surviving to the beginning of the next time interval is computed. Next, the number of emigrants is subtracted from the population, and then the number of births to immigrants is computed. Finally, the number of immigrants and their births surviving to the beginning of the next time interval are added to the population. In the case of academy members, the method simplifies because 1) membership is lifelong, and thus there is no emigration apart from voluntary exits, which are negligible, and 2) members are appointed only by election (comparable to immigration) rather than by birth. Hence, only the members surviving to the next time interval and the number of newly elected members for each age group need to be calculated.

To avoid conflating the effects of policies (or initial conditions) and those of differential mortality across academies (Andreev *et al*., 2011; Winkler-Dworak, 2012), we standardise longevity conditions by using a mortality Scenario for all academies used previously by Feichtinger *et al*. (2007, p. 23). This standard Scenario assumes the same mortality development as in the latest forecast of death probabilities by Statistics Austria (Hanika and Klotz, 2005), which were derived using the Lee-Carter method (Lee and Carter, 1992). As academicians show a significantly lower mortality than the general population, the forecasted death rates were adjusted according to the standardised mortality ratio for the most recent period (for more details see Feichtinger *et al*., 2007). This Scenario produces mortality estimates until 2050, after which we fixed mortality conditions (at 2050 levels) until 2070.

We manipulate two main policies in our Scenarios: intake type (linked vs. fixed) and the age distribution of elections (*status quo* vs. standard). We present results from three scenarios for each academy (except the Austrian, as is explained below). First, the *status quo* scenario assumes academies to have followed the same intake type they currently practice with an age structure of elections based upon a smoothed version of the academy-specific age distribution of election in the 1990-2004 period (the number of elections is based on recent numbers for fixed-intake academies as well). Figure 4 shows the smoothed *status quo* age distribution of election in each.

Figure 4 – *Full membership size by academy and age*



The second Scenario uses the same *status quo* age structure of elections but the opposite intake policy to the one currently observed (i.e. from fixed to linked intake or vice versa). The third Scenario uses the status-quo intake policy while *standardising* the age structure of elections. We use the Austrian Academy of Sciences' age distribution as our standard given that it is close to an average for these academies (except it has slightly lower variance than all but the Berlin-Brandenburg) and as it has been found to be a good approximation to an optimal election policy (under linked intake) that maximizes the number of elections while minimizes its aging effects (Feichtinger *et al*., 2007). As the standard chosen is that of the Austrian academy, we do not present the latter Scenario for this academy as it is of course exactly the same as the *status quo* projection.

Note that some of these policy Scenarios required additional assumptions. First, although the Russian Academy of Sciences has no clear limits on the number of elections in recent years, we specified the number of elections in its *status quo* scenario to 42 elections per year (the average on the 15 years prior to our baseline) to facilitate comparisons with other academies and policies. Second, when going from fixed to linked intake, we chose a SR age of 70 and fixed the size below this age to 750 in the case of the Royal Society and 300 in the case of the Russian Academy of Sciences.[6] The number of vacancies (elections) under the new linked regime is not fixed but corresponds to the number of members that turned 70 that year plus the number of deaths occurring before age 70 (an only minor figure due to the low mortality of academicians). Moreover, when changing the intake policy from fixed to linked elections, we also had to truncate and rescale the *status quo* distribution of age at elections so no FM elections take place after 70 in the *status quo* calculations. Finally, going from linked to fixed intake requires specifying the annual number of elections: we set the number of elections for these academies (Austrian, Norwegian and BBAW) to the average number of elections in the 15 years prior to our initial year (i.e. in the 1990-2004 period). That value was equal to 7 in the Austrian Academy of Sciences, 15 in the Berlin-Brandenburg Academy of Sciences and 17 in the Norwegian Academy of Sciences and Letters.

4. COMPARING ACADEMIES' TRANSIENT AND ULTIMATE SIZE AND AGE STRUCTURE UNDER DIFFERENT POLICIES

4.1 *Effect of intake policy*

Table 3 shows results for each Scenario in terms of (A) academy size, (B) number of elections per year, (C) mean age of academy members, (D) the standard deviation in the mean age of the members of the academy and (E) the proportion of members below age 70. We present these figures at initial, medium-run and steady-state conditions as reflected by the values of these quantities in 2006, 2025 and 2070. Regarding size (Panel A), going from linked to fixed intake (that corresponds to levels equal to the average number of elections per period in 1990-2004) in the Austrian, Norwegian and Berlin-Brandenburg cases implies growing stronger in the pre-transitional period (ultimate size is 6.6% higher in the first two academies and 14% higher in the latter) than in the *status quo* scenario. The number of elections (which are equal to the number of open vacancies below the SR age, see Panel B) are higher in the short run in the status-quo than in the fixed-intake Scenarios but then stabilise to a similar or slightly lower level than the average number of elections in 1990-2004 used in the fixed-intake Scenario. Note that the short-run growth is exceptionally high in the Berlin-Brandenburg academy as they had not met its stipulated limit of 200 members below age 68 by 2005.

[6] In the case of the Royal Society, this number is close to the number of members below age 70 at baseline thereby tying its future growth to its pace of aging. In the case of the Russian Academy of Sciences, we allowed it to grow from its baseline membership below age 70 of ~200 to 300 as fixing it at 200 would have implied a very sizable dip in the number of academicians of *all ages* in the steady state given that the academy age structure is considerably older than that of the other academies (and as such, the implied number of elections in the linked-intake scenario would have plummeted relative to the status-quo scenario). Note, however, that even setting this number to 300 implied a moderate amount of negative momentum for the Russian Academy. We discuss this below.

Table 3 – *Membership size, intake, and age structure of full membership according to different Scenarios by academy*

	Austrian		Berlin-Brandenburg			Russian		
Status quo Intake type Mean age (sd) at election scenario	Linked 57.7 (5.4)		Linked 53.5 (5.4)			Fixed 62.5 (7.5)		
	1 *Status quo*	2 Δ intake policy	1 *Status quo*	2 Δ intake policy	3 Δ age structure	1 *Status quo*	2 Δ intake policy	3 Δ age structure
				A. Full membership				
2006	167	166	204	187	204	524	625	524
2025	197	201	390	420	437	913	738	955
2070	216	231	476	544	559	1191	829	1383
				B. Number of elections				
2006	8	7	32	15	32	42	143	42
2025	6	7	14	15	18	42	27	42
2070	7	7	13	15	17	42	27	42
				C. Mean age of regular members				
2006	70.9	70.9	59.3	59.8	59.9	73.0	70.8	72.6
2025	72.9	72.6	68.6	68.0	70.1	73.7	74.1	70.1
2070	74.2	74.2	72.4	72.3	74.2	76.4	75.6	74.2
				D. Standard deviation of age of regular members				
2006	10.1	10.1	6.5	6.4	6.1	9.0	9.9	9.5
2025	11.1	11.1	10.3	10.2	9.3	10.5	10.7	10.8
2070	11.6	11.6	12.5	12.5	11.6	11.0	11.1	11.6
				E. Proportion of regular members above age 70				
2006	0.461	0.462	0.010	0.011	0.010	0.631	0.520	0.620
2025	0.543	0.526	0.423	0.392	0.469	0.585	0.594	0.415
2070	0.584	0.583	0.527	0.526	0.584	0.673	0.638	0.583

A. Full membership

2006	1274	1296	1274	472	466	472
2025	1431	1471	1424	519	537	571
2070	1571	1596	1449	568	609	665

...Cont'd...

Table 3 – *Cont'd*

Status quo Intake type Mean age (sd) at election scenario	Royal Society Fixed 54.6 (7.2)			Norwegian Linked 54.5 (6.2)		
	1 *Status quo*	2 Δ intake policy	3 Δ age structure	1 *Status quo*	2 Δ intake policy	3 Δ age structure
	B. Number of elections					
2006	44	66	44	23	17	23
2025	44	45	44	17	17	22
2070	44	44	44	16	17	20
	C. Mean age of regular members					
2006	68.9	68.6	69.0	69.1	69.2	69.2
2025	71.0	70.7	72.8	71.4	70.9	72.2
2070	72.4	72.3	74.2	72.5	72.5	74.2
	D. Standard deviation of age of regular members					
2006	10.9	11.1	10.8	11.0	10.9	10.8
2025	12.2	12.2	10.6	12.1	12.1	10.9
2070	12.7	12.7	11.6	12.5	12.5	11.6
	E. Proportion of regular members above age 70					
2006	0.429	0.421	0.429	0.416	0.422	0.416
2025	0.505	0.490	0.556	0.491	0.472	0.514
2070	0.535	0.530	0.583	0.534	0.534	0.584

Legend: sd ... Standard deviation

Transitioning from a fixed to a linked-intake type of election (Scenario 2 in Table 3) implies a lower average number of elections in the projection period and thus a smaller membership size for the Russian Academy of Sciences: its steady-state size under fixed intake would be 1,191 members while under linked intake the stationary size would be only 829. While one would expect that a relatively old age structure of intake, such as the status-quo distribution of elections in the Russian Academy of Sciences, implied a large number of elections given the trade-off between number of elections and age structure of members at election under linked intake (Dawid *et al*., 2009), the large difference in ultimate size between these two scenarios is the result of negative momentum (Rowland, 1996). That means, as the percentage of Russian academicians who are above age 70 is rather large (63 per cent, see Panel E), the projected number of deaths is *well* above the projected number of newly-elected members. Note that this is true even though, in the linked-intake Scenario, we set the number of academicians below the SR age to 300, a number well above the number of members below age 70 at baseline (158). As such, our estimate of negative momentum is quite conservative relative to that of enacting a policy setting the number of members below the SR age close to the *status quo* at baseline (as we do in the case of the Royal Society). Only if we increased the maximum size of the academy under age 70 to almost triple the number of members below 70 in 2006 (results not shown) would these differences vanish.

In contrast, the Royal Society would grow slightly less rapidly under its current policy of fixed intake, projected to be 1,571 by 2070 than by linking the number of elections to those reaching age 70, projected to 1,596. This is due to the fact that the recent past of a large number of elections under a young age structure of intake resulted in a favourable age structure of members in 2006 allowing a considerable amount of growth in the short run as these relatively large cohorts come close to 'retirement' age. Coincidentally, the ultimate number of elections under the linked intake is the same as the fixed-intake number of elections.

Remarkably, changing intake policies while keeping the age structure of elections constant has no consequences regarding the aging prospects of academies in the long run: regardless of initial conditions, academy size and intake type, the same age-specific distribution of intake and mortality schedules results in the same age structure for all (i.e. one with a mean age of 74.2 years and a standard deviation of 11.6 years around the mean, where 58.35% of members are above age 70; see Panels C, D, and E for Scenario 3 in all academies, Table 3). Hence, choosing between a policy that fixes or anchors the number of elections with the *same age* distribution will affect the stationary *size* but not the stationary age structure of an academy. As we base our parameter assumptions on the recent past history of the academies in terms of number of elections and age structure of members, the growth rates under fixed or linked type do not differ substantially. As long as the latter holds, the stationary age structure is independent of the type of intake because of ergodicity (Lopez, 1967). Nevertheless, the number of elections could vary considerably during the pre-transitional period due to momentum (Keyfitz, 1971).

4.2 *Effect of age structure at election*

Scenario 3 in Table 3 presents the results for each academy with the status-quo type of election but standardising for the age structure at election. Obviously, an older (younger) age structure of intake implies that the steady-state age structure of the academy will be older (younger). That means that using the standard age distribution at election implies a younger ultimate age structure of members for the Russian Academy of Sciences and an older age structure of members for the other learned societies (see Panels C, D and E in Table 3, Scenario 3). Again, the ultimate age structure is solely determined by the age distribution at election, regardless of initial conditions or intake type. Standardising for the age distribution at election, the age structure of members for all academies eventually converges to the same age structure, which is characterised by a mean age of full members of 74.2 years, a standard deviation of 11.6 years around the mean and a proportion of members below age 70 equal to 58.4 per cent.

Note that a lower dispersion of the age at election in the standard scenario compared to the *status quo* implies also a lower ultimate dispersion of age of members except for the Russian Academy of Sciences (see Panel D in Table 3). While the standard deviation of the status-quo age distribution of the Russian Academy is about two years larger than the standard deviation of the standard age distribution, the steady-state standard deviation of the *status quo* is actually slightly lower than the one of the standard age distribution for the Russian Academy of Sciences. The latter results can be explained by the higher ages of members in the *status-quo* scenario for the Russian Academy of Sciences and the fact that mortality increases with age, implying a more left-skewed age structure of members compared to the standard Scenario.

The implications of standardising the age structure at election on the size and number of elections do indeed hinge on the type of intake. Under fixed intake, the pre-transitional growth implications of standardising the age structure of elections (as reflected in the steady-state size of the academy) are contingent on whether the *status quo* distribution is older/younger than the standard of course: *ceteris paribus*, a younger distribution of elections will yield a larger steady-state academy than an older age distribution (see also Arthur and Espenshade, 1988). For the Russian Academy, where the *status quo* age structure of intake is older than the standard, electing 42 younger members per year with the younger standard age structure would result in a larger stationary size (1,383; see Scenario 3, Table 3) than electing 42 academicians with the older *status quo* age structure (1,191; see Scenario 1, Table 3). In the Royal Society, going from electing 44 members with a younger *status quo* age distribution to electing the same number of members with the older standard intake schedule (the opposite direction of the change in Russian academy) would imply attaining a slightly smaller academy in the steady state (1,571 vs. 1,449; Scenarios 3 and 1, respectively, Table 3). In both cases, this is a result of a higher pre-stationary transitional growth under a younger age structure as a result of lower crude death rates.

As mentioned before, the effect of a younger or older age structure of elections on the stationary size of academies with linked-intake regimes is not as straightforward as in fixed-intake academies where deaths are the only component of growth depending on how young or old the age structure of elections is. Under linked intake, pre-transitional dynamics of the academy are more complex as the transient and steady-state number of elections is also contingent on the age structure of intake. Moreover, unlike the number of deaths, which are directly proportional to the mean age at election, the number of vacancies is inversely proportional to the mean age at election (Feichtinger *et al*., 2007; Dawid *et al*, 2009). The reason for this is that a younger age structure of intake will extend the expected waiting time before statutory retirement, thus implying a lower number of vacancies in the medium and long run (Feichtinger *et al*., 2007). On the other hand, a younger age structure of elections will imply a lower death flow in the medium run.

Which of these two effects dominates (and thus, if a linked-intake policy implies a larger or a smaller stationary size than one of fixed intake) depends on *initial conditions*, as these will determine the transient election and death flow. In both linked-intake academies in which we modify the age structure of elections, the effect of the age structure of elections on the number of open vacancies in the future is stronger than its effects on the death flow. In the Norwegian Academy, the older standard schedule yields a *larger* number of elections (20 vs. 16) and a larger population size (665 vs. 568) than the *status quo* Scenario. Likewise, in the Berlin-Brandenburg Academy of Sciences, the older standard age structure of intake yields both a larger stationary number of elections (17 vs. 13) and a larger academy size (559 vs. 476) than in the *status quo* Scenario.

5. DISCUSSION AND CONCLUSION

In this paper, we have shown the importance of different intake policies on the intrinsic stationary size and age structure of academies of science using data from five academies with a mix of heterogeneous policies/practices. First and foremost, we have shown that the stationary age structure is solely determined by the age structure at election, independent of the type of intake. Most obviously, a younger age structure of inflow implies a younger stationary age structure in academies with either type of intake (for a mathematical exposition applied to the population of nation-states, and applicable for the most part to fixed-intake academies, see Schmertmann, 1992).

However, secondly, we have also found that both intake type and the age structure of intake do have an effect on the stationary size of an academy. Linked intake generally yields a smaller academy size than fixing the number of elections to the average number in recent times. Furthermore, in fixed-intake academies, a younger age structure led to a larger academy size whereas it did not necessarily lead to higher growth in linked-intake academies. As such, provided an academy is interested in curbing growth (or to maintain fixed its membership of scientists below a certain age, for whatever other purpose), a linked intake policy may be a more sensible approach to regulate such growth. Note that this decision would come "cost-free" in terms of any aging trade-offs given that, as mentioned before, the stationary age structure of an academy is solely governed by the age structure (and not the type or size) of intake.

The choice of one intake policy over the other is then a matter of deciding (1) how large an academy should be in the long run and (2) what would be an acceptable set of conditions (e.g., number of elections, academy growth) in the medium run. Whether or not an academy cares about a more vs. a less limited amount of growth depends, of course, on its objectives and priorities, for instance in terms of how it views the relationship between aging, growth, and academy quality. Concerning the latter, the concern that age is negatively related to innovative ability and scientific achievement is often raised. The arguments are mostly based on the early age at which eminent researchers did their pioneering discoveries (e.g., Lehman, 1953). On the other hand, Stroebe (2010, p. 664) finds that "there is no universal age-related decline in cognitive ability. […]. To the extent that an age-related decline in scientific achievements exists, it is more likely to be due to changes in motivation or the availability of resources." In fact, academies of sciences offer their members, who had to retire due to age-related compulsory retirement regulations, opportunities and facilities for a continued scientific activity. As such, the concern with aging in academies seems more rooted in the continued support of innovative research and new disciplines rather than concerns about productivity *per se*.

Despite this, many academies do seem to have a certain degree of concern about their pace of aging (Van de Kaa and Roo, 2003; Leridon, 2004; Feichtinger *et al.*, 2007), and some about their size (Cohen 2009). In the case of academies that worry about both, a linked intake might be a better solution, as it yielded lower growth than all of our alternative fixed intake Scenarios. A younger age structure of intake yielded not only a lower mean age, but also lower growth in *some* of our Scenario (i.e., for the Norwegian and Berlin-Brandenburg academies).

Note, however, that the growth-limiting feature of a young age structure of elections under linked intake may entail additional complications given that it dictates the future number of vacancies in an academy. As such, academies may need to choose an age structure of elections that does not only rejuvenate the academy, but also maintains a "reasonable" number of elections. As other studies have formally demonstrated (Dawid *et al.*, 2009) and illustrated empirically (Feichtinger *et al.*, 2007), the optimal strategy for this particular trade-off is attained by using a bimodal age structure of elections that may include a mix of distinguished scholars close to the retirement age and of younger promising scientists.

Having said that, our projections of the Russian Academy of Sciences highlight the relevance of initial conditions in the pre-equilibrium dynamics of academies adopting a policy of linked intake. Linked intake only seems like a reasonable strategy if the recent history of the academy has not implied both high growth and aging by way of electing many older members. Otherwise, academies should be aware that the transient dynamics and ultimate size will be especially sensitive to enacting this policy. In the Russian case, interrupting the history of rapid growth (Figure 1) and an older election schedule (Figure 4) would imply a most dramatic drop in the ultimate stationary population to levels *well below* the initial size of the population (Table 3, Panel A) given that most members in the initial population are already above the assumed SR age (Table 1). In short, academies should thus consider their recent demographic history before deciding to enact specific policies as the *transient* growth and aging dynamics and ultimate size of the academy will also depend on them.

In addition to drawing useful lessons for academies and other age-structured organisations, particularly those with strict retirement policies or those wishing to remain at a relatively fixed size, our study also contributes to the literature of stable population models open to age-structured intake, and in particular on how age-structured intake may affect population aging and growth. For instance, as laid out in Section 2, our fixed intake scenarios are analogous to a stable population model open to migration commonly used to study the effect of immigration on aging in nation-states (e.g., Espenshade *et al.*, 1982; Arthur and Espenshade, 1988; Feichtinger and Steinman, 1992; Schmertmann, 1992).

In addition to the fact that our study is a (modified) application of these models, our use of linked intake Scenarios, which also yield stationary conditions in the long run, could be considered of potential use to study the implications of age-structured intake on the population of nation-states. Although the applicability of our study to less structured populations, such as those of nation-states, is indeed limited by the fact that academies only grow through age-structured intake (as opposed to fertility) and future intake is not directly, strictly linked to the current size of a generation (as in general populations, where the production of new population members is physically born by other members), an exploration of linked intake type immigration policies could prove fruitful from the perspective of both formal demography, and immigration and ageing policies. Only a few studies have considered linking the number of immigrants to a given population quantity or parameter (e.g. as a proportion of the number of births, see Alho, 2008). As such, future research should look at the potential effect of linking the number of immigrants to the size of other age groups (e.g., in order to keep the size of the labour force stable) and other kinds of age-structured intake on the aging and size of nation states at large.

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