Modelling the Swiss academic career pathway

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Abstract—Presented here is a first attempt to model the Swiss academic pathway. By using a system of time-discrete recursive equations, we illustrate the mechanism leading to a decline of the career prospects of postdocs in Switzerland. We also study the impact of an increase in the number of assistant professors with tenure-track (APTTs), and we present an overview of possible measures to help alleviate the bleak career prospects for early-stage researchers in Switzerland. All the code and the data are freely available on GitHub with the hopes that those who are interested will pick up and further expand this project.

1. Introduction

It is generally argued that academic careers have become unattractive for many talented young researchers due to poor career prospects and insufficient long-term contracts. This issue has been documented multiple times in recent years (TheEconomist 2010; Afonso 2013; Amrhein 2014; Nature 2014).

The 2012 Vision 2020 position paper (Fink et al. 2012), signed by six young researchers, was at the origin of a political debate in Switzerland. In addition to presenting figures for the Swiss academic system in 2011, the paper recommended the adoption of three measures to improve career perspectives for young researchers: 1. create 160 extra tenure track positions every year for 6 years; 2. increase PhD student stipends; and 3. provide extra support for women and families. Its figures point to almost 19'000 postdocs in Switzerland in 2011 (where postdocs are defined as research assistants holding a PhD and working on fixed-term contracts). This number corresponds to about 5 postdocs per professor, more than twice what is typically assumed (not more than 2 postdocs per professor, see the report of the Swiss Federal Council (SERI 2014)).

As the number of postdocs in Switzerland is poorly defined, we asked young researchers to fill out an on-line survey (see 5 Appendix) hoping to estimate their number more accurately. Using the results of this survey, we describe here the evolution of the numbers of researchers in each of the main stages of the Swiss academic system in terms of annual transition probabilities through a system of time-discrete recursive equations. By fixing the transition probabilities over time, we predict the outcome of the system for stable career perspectives, and we deduce to what extent the planned number of new professorships meets the need for a stable postdoctoral career scenario.

2. Current situation in Switzerland

A time series containing numbers and fluxes of individuals at different stages of an academic career in Switzerland was compiled from the Swiss Federal Statistical Office (FSO) website (link

1, link 2, link 3).[1] In it, the figures from 2014 to 2023 correspond to an FSO reference scenario forecast.

With regard to the postdoc stage, very little is known. According to our estimate (see 5 Appendix) we obtain an average of 3.02 postdocs per professor in Switzerland for 2013/2014. (Interestingly, this corresponds to a ratio professorsto postdocs to PhD students of approximately 1:3:5, respectively.)

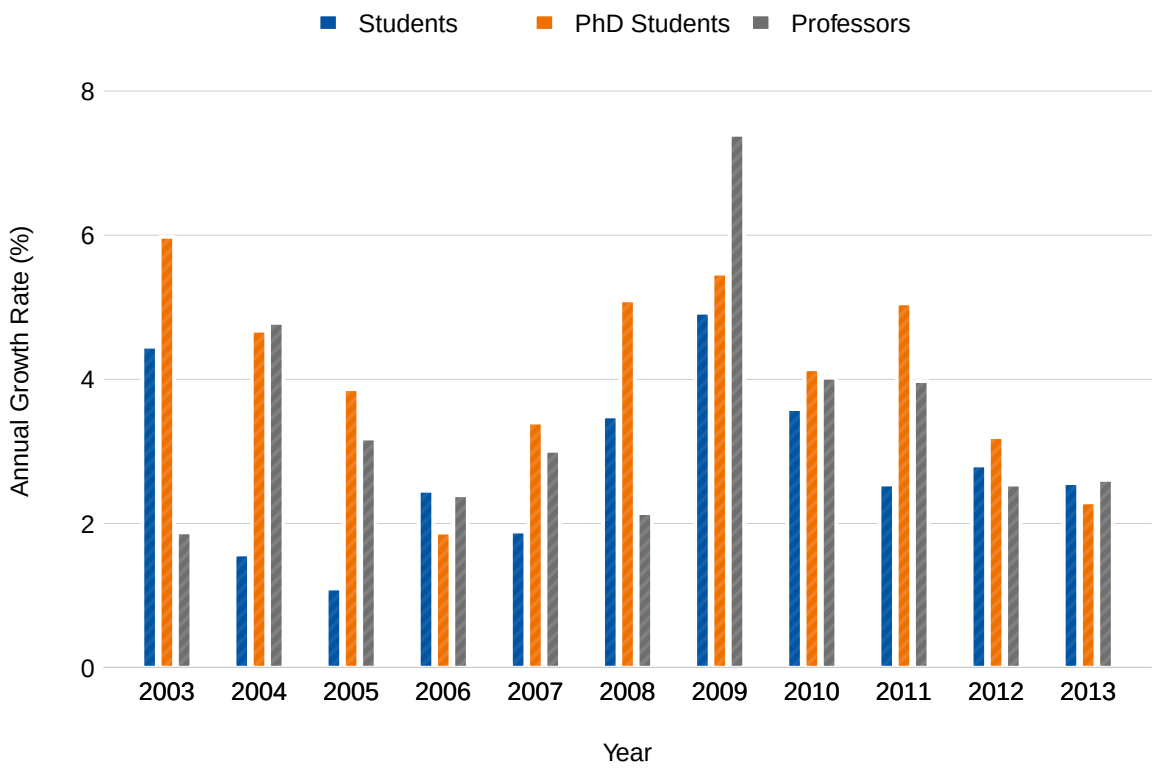

Figure 1: Annual growth rates of the number of undergraduate students, PhD students, and professors in Swiss universities since 2003.

From this data, we observe no significant differencies between the average growth rates of students, PhD students, and professors for the years 2002 to 2013 (see figure 1). This suggests that the different academic stages, from undergraduate students to professors (though we know nothing about the evolution of the number of postdocs), had comparable growth rates in the past decade.

It is also interesting to note that the number of professors is strongly correlated with the numbers of masters and PhD students. The Pearson correlation between the number of professors and the number of PhD students over the last 12 years is nearly 1 (1). The same applies to the correlation between the number of professors and the number of masters students.

[1] Oftentimes, the FSO presents the number of professors in full-time equivanlence (FTE). Although the are some small fluctuations in time, we approximated the number of professors in FTE to 88.5% of the number of professors working in both full and part time.

3. A model of the Swiss academic path

3.1 Fitting the model

To model the outcomes of different career scenarios based on the available data, we write a system of time-discrete recursive equations where we fix the annual transition probabilities over time. It is important to note that in a model with fixed transition probabilities, the values of all of the compartments following the masters students will reflect a time-lagged dynamic of the first stage (n_1): the masters student stage. In total, we consider the 6 following stages:

n_1	number of masters students
n_2	number of PhD students
n_3	number of postdocs
n_4	number of APTTs
n_5	number of full professors
n_6	number of ex-academics

We derive this system according to the flowchart provided in figure 2.

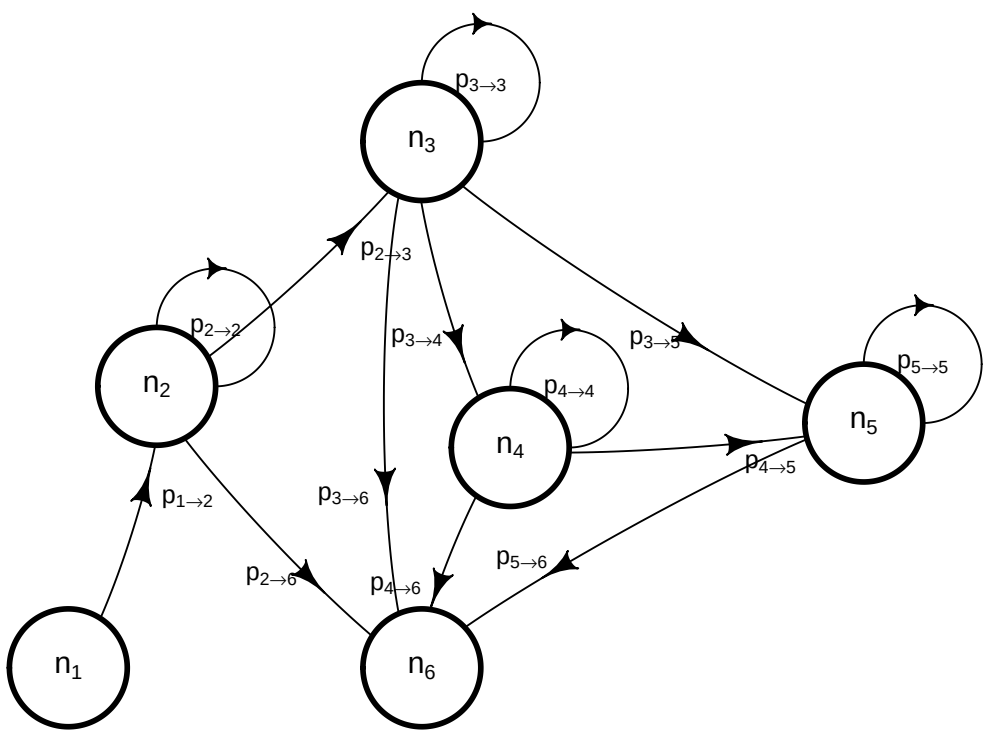

Figure 2: General diagram depicting the academic career path as a system of time-discrete recursive equations. Each level of the academic pathway is described as a separate stage, from n_1 to n_5. n_1 represents the number of masters students, n_2 the number of PhD students, n_3 the number of postdocs, n_4 the number of assistant professors with tenure-track (APTTs), n_5 the number of Full-Professors, and n_6 the number of ex-academics. Transition probabilities between stages are depicted with arrows and labeled $p_{x,y}$ according to the stages they link.

Such a model does not account for positive feedback loops (when additional professor positions result in extra PhD and postdoc positions, for instance). It also does not account for the cases of PhD students who bypass the postdoc stage or non academics who join the academic career pathway at different stages. And it does not account for other important factors such as immigration, price of education, economic performance of the country, and demographic changes.

We write the number of masters students for year t as $n_1(t)$ and endeavor to fit a curve through the data. As can be seen in the figure below, the data takes on a sigmoid-like shape, and so we fit to it a logistic function using nonlinear least-squares. For our data the logistic fit implies a saturation term of $41'174(\pm 4\%)$ masters students in the long term, and the best fit is found from the equation:

$$\hat{n}_1(t) = \frac{41174}{1 + exp\left(\frac{41174-t}{2.15}\right)}.$$

The temporal data on the number of entering PhD students $n_{1,2}(t)$ are also known, but their shape does not conform to standard functions typically used in the analysis of the dynamics of ODE's. However, if we calculate the annual transition probability from masters to PhD students $\hat{p}_{1,2}(t) = \frac{n_{1,2}(t)}{n_1(t)}$, then its shape corresponds to another (flipped) logistic curve, which can be fit to our data with the following equation:

$$p_{1,2}(t) = 1 - \frac{0.86}{1 + exp\left(\frac{2004.76-t}{1.81}\right)}.$$

The number of PhD students $n_2(t)$ is given by the number of entering PhD students $n_{1,2}(t) = p_{1,2} \cdot n_1(t)$ plus the number of remaining PhD students $n_{2,2}(t)$. To calculate $n_{2,2}(t)$, we assume that the duration of a PhD degree is distributed geometrically (follows a geometric waiting time occupancy) with an expected value $E[T_2] = 1/(1 - p_{2,2})$ (as we see later, we find $E[T_2] = 4.6$ years, in line with the figures given by the FSO), where $p_{2,2}$ is the probability that a PhD student is still a PhD student the following year.

Thus we have the following equation for $n_2(t)$:

$$n_2(t) = p_{1,2}(t) \cdot n_1(t) + (1 - \frac{1}{E[T_2]}) \cdot n_2(t-1).$$

We then assume that both the number of PhD students and the number of professors contribute to the number of postdocs in equal amounts, with a constant rate of 3.02 postdocs per professor and 0.53 postdocs per PhD student in Switzerland. (3.02 postdocs per professor includes a correction factor for the fact that our survey was more likely to sample from larger research groups, see 5.)

As with PhD students, the number of postdocs $n_3(t)$ is given by the number of entering postdocs $n_{2,3}(t)$ plus the number of remaining postdocs $n_{3,3}(t)$.

To calculate $n_{2,3}(t)$, we assume a constant rate of PhD students opting to stay in academia ($c_{2,3}(t)$). According to an earlier FSO report (FSO 2010) only 30% of Swiss PhD graduates stay in academia.\footnote {In the US, 65% of PhD graduates continue into a postdoc (Powell 2015)} Due to lack of data on how many of these stay in the country and how many postdocs immigrate to Switzerland, we make a very rough estimate that half of the graduating PhDs continue in academia $c_{2,3}(t) = 0.5$.

Thus, for $n_3(t)$ we can write the following equation:

$$n_3(t) = p_{2,3}(t) \cdot n_2(t) + (1 - \frac{1}{E[T_3]}) \cdot n_3(t-1),$$

$$\text{where} \quad p_{2,3}(t) = \frac{c_{2,3}(t)}{E[T_2]}.$$

Similarly, if we want to predict how the number of professors would evolve in a stable career scenario, we obtain a similar equation to $n_3(t)$:

$$n_{4+5}(t) = p_{3,4+5}(t) \cdot n_3(t) + (1 - \frac{1}{E[T_{4+5}]}) \cdot n_{4+5}(t-1).$$

The derived equations are plotted with the available data in figure 3.

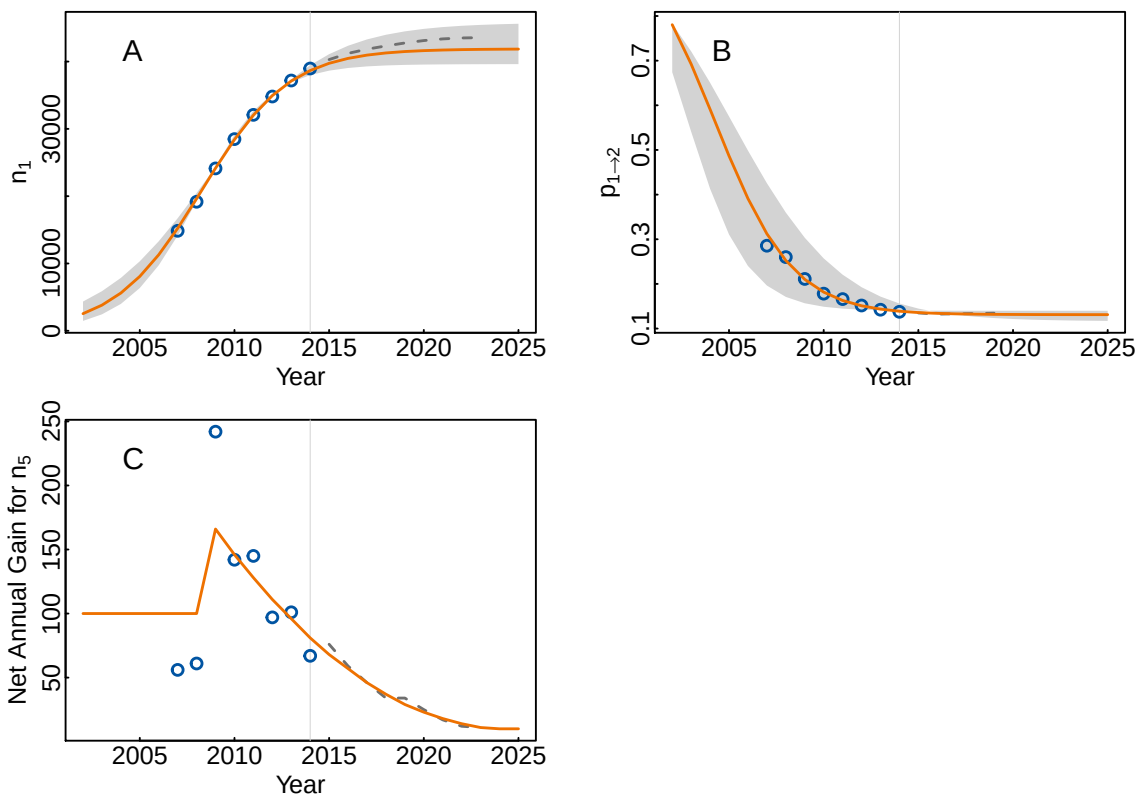

Figure 3: Fits for $n_1(t)$, $p_1(t)$, and $n_{3,4+5} - n_{4+5,6}$ for the time range between 2002 and 2025. Blue circles show the available data. Dotted gray lines show the predicted values for the next years according to the Swiss Federal Statistical Office neutral scenario. Orange lines show the derived empirical fits to the available data points. Although 95% confidence intervals are shown in light gray for panels A and B, in panel C the choice of a fit for $n_{3,4+5} - n_{4+5,6}$ is unreliable due to the lack of data.

We observe how the system of equations fit the data and adjust $E[T_2]$, $E[T_3]$, and $E[T_{4+5}]$ accordingly to obtain the best possible fit for the most recent years, see figure 4.

A fixed transition probability model shows that the growth of the number of professors (n_{4+5}) reaches the intermediate phase of a sigmoid after the growth curves of the number of masters

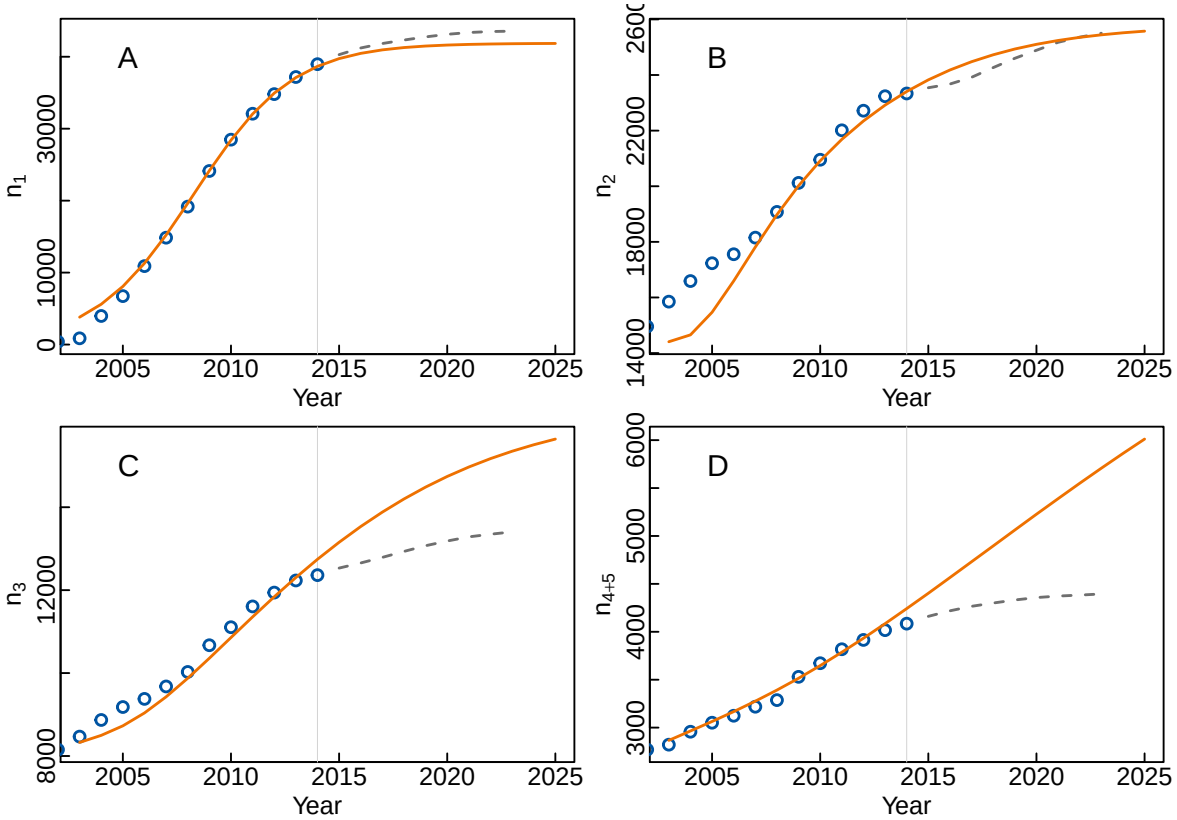

Figure 4: Fits for $n_1(t)$, $n_2(t)$, $n_3(t)$, and $n_{4+5}(t)$ for the time range between and 2002 and 2025. $E[T_2] = 4.6$ years, $E[T_3] = 5$ years, and $E[T_{4+5}] = 20$. Blue circles show the available data points. Dotted gray lines show the predicted values for the next years, according to the Swiss Federal Statistical Office neutral scenario. Orange lines show the empirical fits to the data points.

students, PhD students, and postdocs have reached (or are about to reach) the final (stationary) phase of a logistic growth (see the figure 4). Interestingly, stable career perspectives entail a change in the relative proportions of the numbers of individuals at the different stages. This is somewhat counterintuitive. The main reason being that the expected duration of a professorship is about 20 years whereas PhDs and postodcs typically last 4 to 6 years. Hence, at present, if relative proportions are maintained as stable over time, early career researchers' perspectives are doomed to deteriorate.

3.2 Probing different scenarios

Without yet considering the subclass of APTTs, the number of professors n_{4+5} is given by:

$$n_{4+5}(t) = n_{4+5}(t-1) + n_{3,4+5} - n_{4+5,6}.$$

If we write $g(t)$ as the net gain in new professorships (for both APTTs and full professors) per year, then we have $n_{3,4+5}(t) = g(t) + n_{4,6}(t) + n_{5,6}(t)$.

There are little temporal data regarding the number of APTT positions in Switzerland. One single data point has been reported: 240 APTTs in 2011 (SERI 2014). As with the number of postdocs, we assume that the number of APTT positions is a fixed fraction of the total number of professors. We also assume that APTT positions have a 6 year duration ($E[T_4] = 6$) and we take $p_{4,5}$ as the probability of getting tenured in a given year. Last, we write the number of new APTT positions $n_{3,4}(t)$ as a fraction c of the number of full professors leaving academia $n_{3,4}(t) = c \cdot \frac{n_5(t-1)}{E[T_5]}$.

Thus, the number of APTTs is given by:

$$n_4(t) = \frac{c \cdot n_5(t-1)}{E[T_5]} + \left(1 - \frac{1}{E[T_4]}\right) \cdot n_4(t-1).$$

And with $n_5(t+1) = n_{3,5}(t) + n_{4,5}(t) + n_{5,5}(t)$ we arrive at the following equation:

$$n_5(t) = g(t) + \frac{n_4(t)}{E[T_4]} + \left(1 - \frac{c}{E[T_5]}\right) n_5(t-1).$$

The inclusion of an APTT subclass does not have an impact on the previous earlier stages of the academic pathway. Thus, we can focus on the effects that different scenarios have on the composition of the two professor-level stages of this model ($n_4(t)$ and $n_5(t)$, see figure 5).

To compare the impact of the scenarios shown in the figure above on the career perspective of postdocs, we can divide the number of predicted entering professors $n_{3,4+5}$ by the number of predicted exiting postdocs ($n_3(t)/E[T_3]$). We call this fraction "postdoc success rate", and it is plotted in figure 6, which shows that the career prospects of postdocs has diminished drastically in recent years.

4. Discussion

As in the Vision 2020 paper (Fink et al. 2012), this study uncovers a lack of data regarding the postdoc stage. It is also shown that career perspectives for postdocs have decreased roughly by

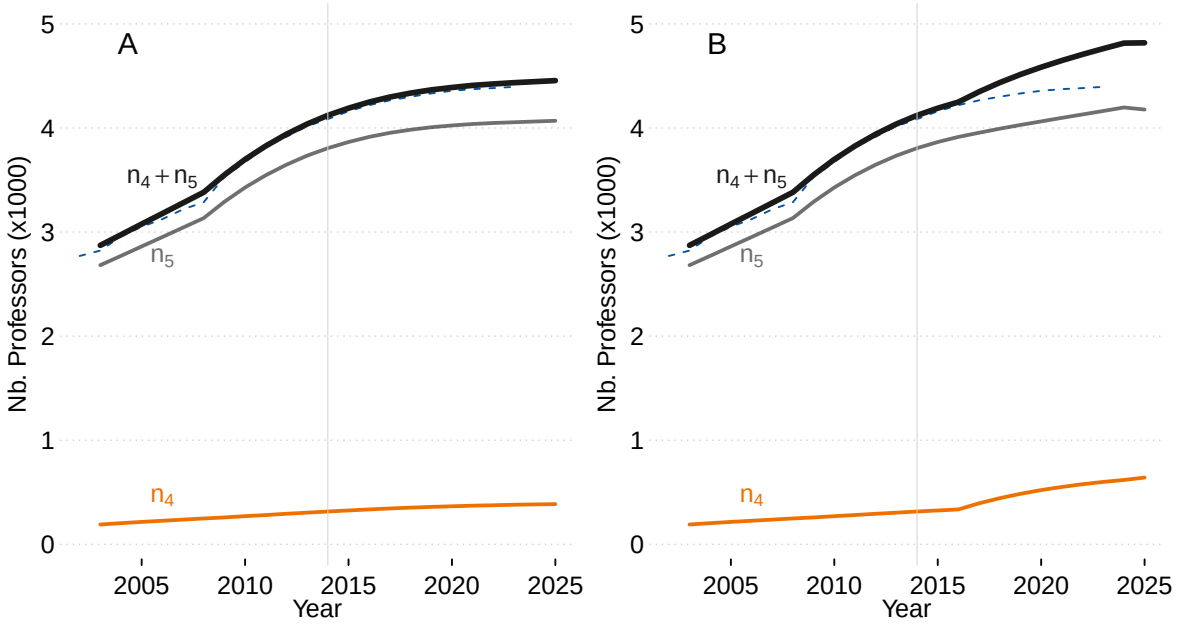

Figure 5: Two proposed scenarios showing the number of professors over time. Blue dotted lines: FSO neutral scenario; black thick line: total number of professors. A: current situation, no intervention, approx. 40 APTT positions are opened each year. B: Scenario A with an additional 50 APTT positions per year for a time period of 8 years. Probability of getting tenured $p_{4,5} = 0.9$.

half in ten years. This is mainly due to two factors. On the one hand, it is a result of the logistic growth phase of the number of both masters and PhD students in the last 6-8 years. On the other hand, is stems from a shortage of new professorships, due to a much lower turnover rate at the professor stage as compared to all the previous stages.

The FSO predicts that the ratio between the number of PhD students and the number of professors should stay constant in the years to come. This, unfortunately, implies ever more limited career perspectives for young researchers, specially at the postdoc stage. Moreover, even if there would be no bottleneck between the postdoc and the professor stages, there would always be the likelihood of a "snowball effect", meaning that newly created professorships would also translate in new PhD and postdoc positions. Therefore, adding extra funds on the top without a longitudinal restructuring of the academic pathway would not solve the problem. On this note, our study shows that even though an increase in the number of APTTs would raise the turnover rate of the professor stage, its implementation would reduce the postdoc problem only slightly, with the tenuring probability having little effect (results not shown).

Our results therefore support additional measures previously suggested in the literature, which address earlier stages of the academic career: 1. introduce constraints on the number of postdocs and PhDs themselves, and not only at the professor level. An example of this change of rules at the postdoc level is the above-mentioned reduction of funding at the postdoc and PhD levels, while at the same time increasing APTT positions at the top. This is the only way to change the steepness of the so called "academic pyramid" and prevent a "snowball effect"; 2. constrain the postdoc level and prevent further expansion at this stage by limiting the number of postdoc years, as mentioned in (Alberts et al. 2014). This measure can and should, of course, be accompanied by an increase of APTT positions, and ideally no increase in budget; 3. introduce more long-term stable research positions at a lower career level in addition to the measures above. This could help

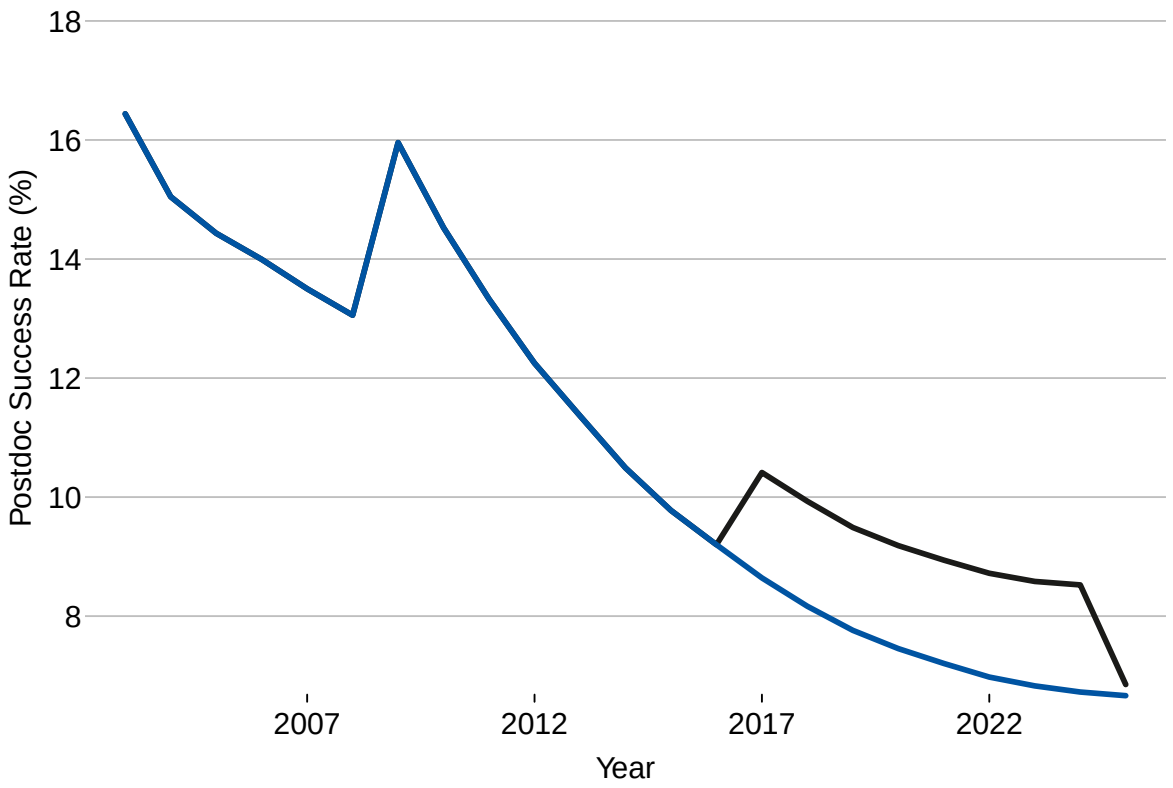

Figure 6: Postdoc success rates over time. To look at the impact of different scenarios on the career perspective of postdocs, we define the postdoc success rate. This measure is defined as the number of predicted number of postdocs who make it to the next stage (going from n_3 to either n_4 or n_5) by the number of total exiting postdocs (going from n_3 to n_4, n_5 or n_6). The blue solid line shows the case A from figure 5 whereas the black line corresponds to the scenario B.

many PIs continue to produce at a higher rate without relying on a constant turn-over of postdocs.

5. Appendix

5.1 On-line survey

In the first part of this study, we collected some data on the number of postdocs in Switzerland via an on-line questionnaire, see the figure 7.

In this questionnaire we considered the term postdoc in a broad sense, similar to the definition of the Vision 2020 position paper, as an individual who has completed a doctoral degree and is engaged on a fixed-term contract. Essentially, this definition corresponds to the NIH and NSF official definition (Ruiz Bravo and Olsen 2007). Note that this definition also includes individuals who have no intention of pursuing an academic career in Switzerland. The survey was on-line in February and March 2014. During these two months, 578 responses were collected from which we excluded all missing a link to a research group and duplicates.

More than half of the respondents worked in fields related to biology and medicine (BIO/MED). More than a quarter worked in the fields of mathematics, computer science, natural science and technology (MINT). The rest, almost a quarter, in the fields of social sciences and humanities (SSH). On average, research groups in the MINT domains have more postdocs.

In terms of institutions of higher education, the ETH-domain contributed with more than two-thirds of the replies. As expected, ETH Zurich and EPF Lausanne had, on average, research groups with higher numbers of postdocs.

From the survey, we estimate that there are 3.02 postdocs per professor. To estimate the average number of postdocs per professor we bootstrapped the number of postdocs by university and calculated the mean taking into account the relative number of professors of each university according to the numbers of the FSO (to account for the different university weights more accurately than in our survey). Finally, we found that our estimate for ETH Zurich was still 114% higher than the value derived from ETH's annual report of 2014 (ETHZ 2014). Hence, we made the assumption that our estimate is biased by this factor from the fact that it is easier to sample from larger research groups than from smaller ones.

6. Acknowledgments

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Number of postdocs in Switzerland

PostDoc? PhD?

There are serious discussions in Swiss politics about the careers of young scientists at the moment. However, no one really knows how many Postdocs there are in Switzerland. We would therefore like to have a rough estimate from you in order bring light to the problem and elucidate decision makers.

Please tell us how many PostDocs you have in your lab and then share the link with as many people as you know from other research groups. Thanks!

* Required

How many postdocs work in your research group? *

postdoc = person with a PhD on a fixed-term contract

The website of your research group?

In which field is your research group?

- Humanities
- Social Sciences
- Mathematics, Finance
- Engineering
- Biology
- Medicine
- Physics
- Other:

In which university is your research group?

Submit

Figure 7: A screenshot of the postdoc on-line questionnaire.

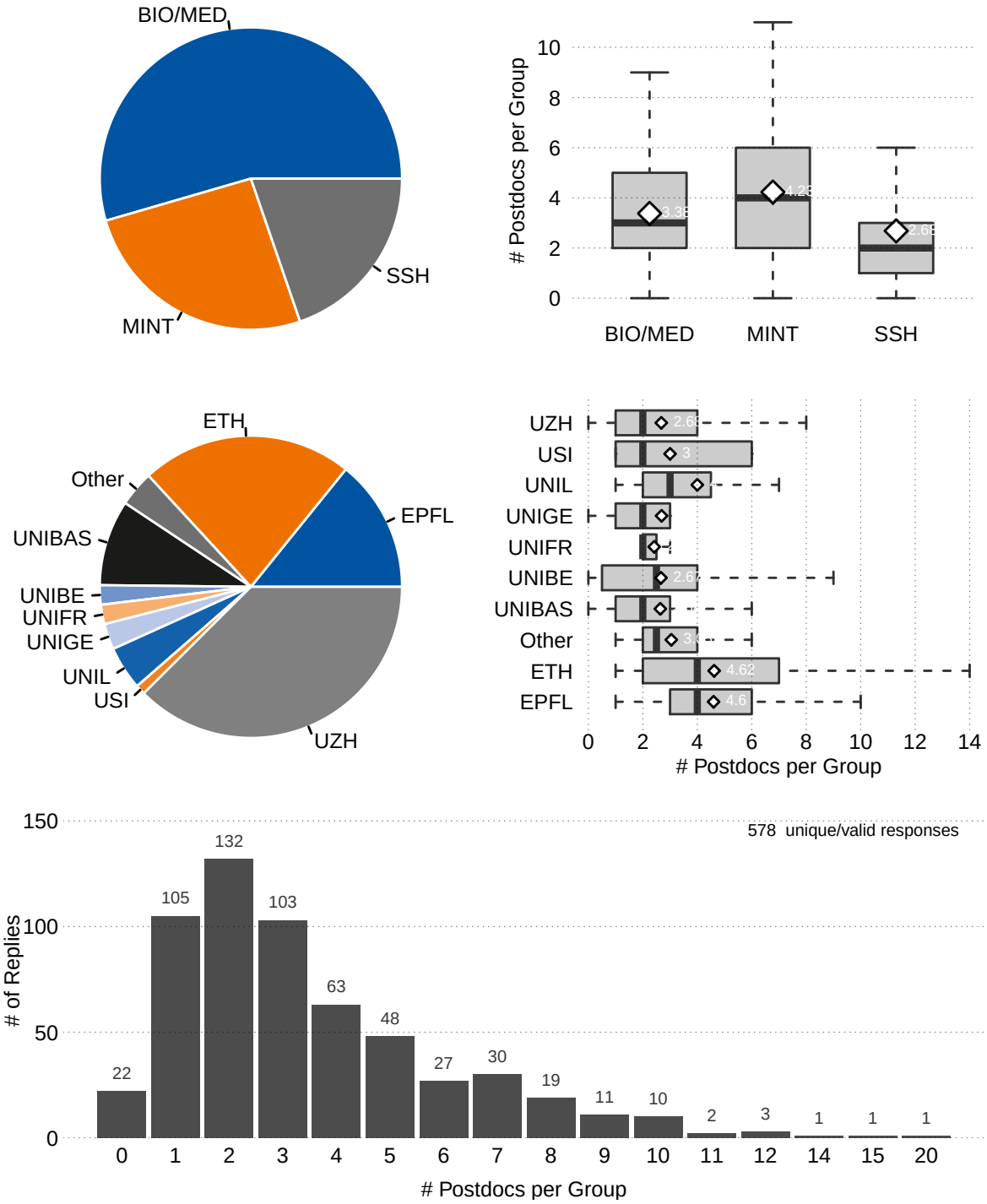

Figure 8: Distribution of responses to the on-line survey.

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