National vs. International Postdoctorates in U.S. Biomedical Education and the Effects of Capping the Duration of Postdoctoral Careers

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ABSTRACT

In the past few years, the number of biological and medical researchers employed as post-doctoral associates has been rapidly increasing. However, the proportion of U.S. vs. non-U.S. scholars (national vs. international) in these positions has been declining. In this paper, we analyze these trends by building a differential equation-based model of postdoctoral training. We calibrate our model with data from the National Science Foundation (NSF) survey of doctoral recipients. Our model successfully replicates the observed trends in the data showing an increasing trends in both national and international researchers in U.S. biomedical fields. Using the model, we conduct several simulation-based analyses and study the effects of different policies on the population of postdoctoral researchers. Our model shows that capping the duration of a postdoctoral career, a policy proposed previously, actually favors foreign postdocs and decreases the ratio of national to international postdoctorates in the U.S. Furthermore, we find that hiring more faculty members does not affect the diversity, as many of these new jobs will be taken by international scholars. The analysis suggests that the leverage point to affect diversity in the system is in the K-graduate education area, and policies implemented at the postgraduate level have minimal effects on diversity, if any.

Keywords: Education policy, workforce development, postdoctoral researchers, diversity, national institutes of health

1. INTRODUCTION

Postdoctoral training in biology and medicine has become common practice for Ph.D. graduates. Over a 30-year period between 1978 and 2008, the number of postdoctoral researchers (postdocs) has more than tripled from around 11,000 to more than 35,000. The number and demographic characteristics of these researchers and the length of time they spend in such positions is of great policy interest to government funding agencies such as the National Institutes of Health (NIH) and the National Science Foundation (NSF).

The availability of funding for postdoc positions from multiple sources has made them attractive temporary research jobs and consequently attracted more international Ph.D.s. In 1979, 73 percent of biomedical postdocs were U.S. citizens, but this number dropped to 48 percent in 2008. This gap has been filled by international postdocs who help U.S. academics by generating high-quality research outcomes and serve as a source of high-quality experts who might stay in the U.S. However, as overseas research opportunities change, many international scholars might leave for better opportunities in their home country, which may affect the availability of highly trained researchers working in the U.S. Therefore, it is reasonable to examine the future trends of the number of national vs. international scholars in the U.S., and then analyze policies that can help maintain sustainable trends of national postdocs in U.S. academia.

In this paper, we report on a study to understand the dynamics of change in the number of national and international postdoctoral researchers in biomedicine over time and explore the consequences of changes in funding and other policy options. The primary purpose of the research reported here is to understand the dynamics of the growth in the number of national vs. international postdoctoral researchers over time and conduct counter-factual policy analyses. To

our knowledge, this is the first policy modeling effort to study the growing patterns of postdoctoral careers.

2. BACKGROUND

Postdoctoral researchers are broadly defined as individuals that hold a doctoral degree (or equivalent) and work in a *temporary* research role. A postdoctoral researcher is often distinguished from technicians, graduate students, or research scientists, but works very closely with these individuals. According to the National Postdoctoral Association, a membership organization of postdoctoral researchers, the purpose of a postdoctoral position is to "…acquir[e] the professional skills needed to pursue a career path of his or her choosing" (National Postdoctoral Association, 2012). University-based research laboratories are the primary employers of postdoctoral researchers.

In the past 30 years, scientific research in the United States has made dramatic progress and postdocs have played an essential role in the success of these efforts. For example, postdocs have worked in all fields of biomedical research and helped to foster discoveries in many biomedical domains.

From a workforce-development perspective, the nation's STEM postdoc workforce functions as a gateway to a scientific research career. Many research fields use postdoctoral opportunities as a key starting point for careers of new scholars. Usually, through these opportunities, young scholars learn to direct groups of research students, write grant proposals, and improve their own knowledge of the field. These postdoc opportunities have been increasingly attracting young scholars.

Figure 1 shows the trend of biomedical postdoctoral researchers in U.S. institutions for both national and international scholars over the past 25 years. The number of total postdocs has increased during the last 30 years, while the growth trend for international postdocs has been faster than for national postdocs. The number of international postdocs in this period has increased by about 400 percent.

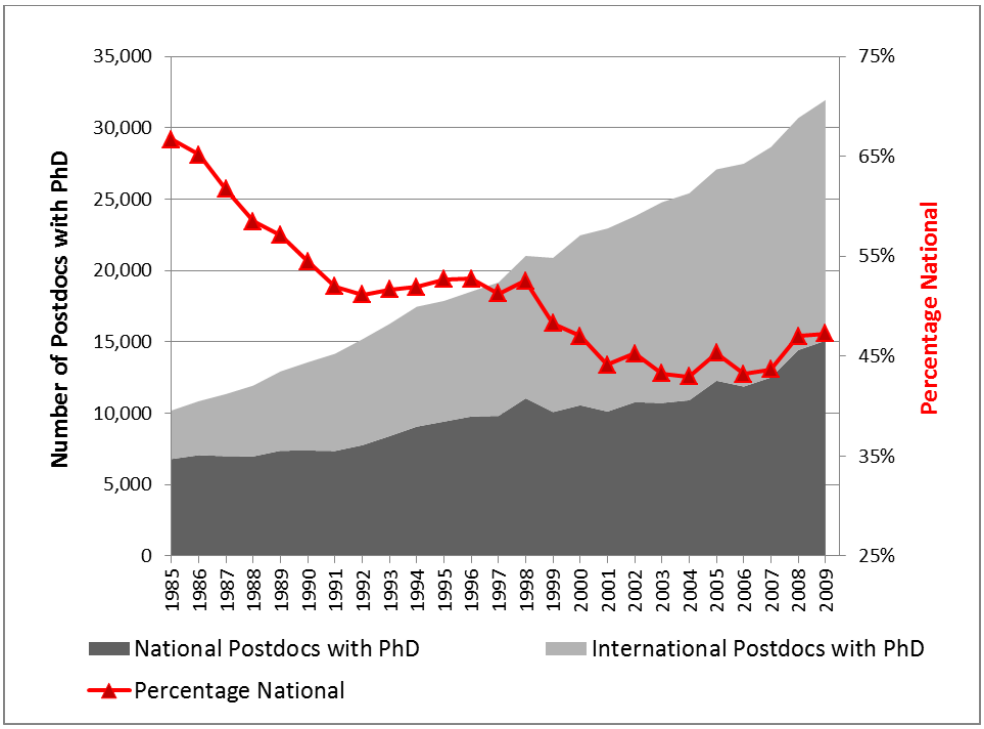


Figure (1): The trend of postdoc researchers in biology and medicine with PhD for national versus international scholars (Source: FASEB (Garrison and Ngo, 2011 and 2012))

We can list several possible explanations for this trend. One explanation is that the number of new graduates of Ph.D. programs in the U.S. has been increasing. In 1985, the number of Ph.D. graduates from U.S. universities in biomedical fields was 4,160 (501 of them were international), and in 2010, the number increased to 9,069 (2,331 international). More graduates require additional opportunities. Therefore, an increase in the availability of jobs is governed by

changes in the supply of graduate students. Another reason for the rise in the number of postdocs can be a relative decline in academic and industrial job opportunities. For example, the non-fixed retirement policy after 1995 has resulted in less position vacancies in academia (Larson and Gomez, 2012).

In addition, the increase in funding opportunities has resulted in a higher demand for postdoc researchers. The NIH receives the biggest portion of government research spending (Semeniuk et al., 2011). The increase in research grants has provided more opportunities for research centers to hire postdocs and support graduate students in biomedicine (Teitelbaum, 2008; Gomez et al., 2012). More funding has also attracted international researchers with Ph.D. degrees from inside and outside the U.S. (Teitelbaum, 2008). Furthermore, due to recent communication and technological developments, more information is available about job opportunities in the U.S., and as more international researchers join U.S. academia, the environment has become friendlier to international scholars, which, in turn, attracts more international researchers.

Literature on the postdoctoral workforce has provided mixed evidence on the effects of postdoctoral training on education and research enterprises and on research workforce development. On the one hand, there are studies that argue about the positive effects of postdoctoral training. Gentile et al. (1989) and Levey et al. (1988) show that postdoctoral research is associated with more successful workforce development in academia. In one early study, Coggeshall et al. (1978) reported that individual postdoctoral recipients were more likely to pursue careers in research. Steiner et al. (2002) show that postdoctoral training increases productivity in terms of the number of publications. Completing a postdoctoral position is inversely related to the time it takes to secure the first grant after finishing training (Gentile et al.,

1989). In more recent studies, Su (2009, n.d.) has reported that postdoctoral training is associated with increases in productivity over the initial years of a scientist's career.

On the other hand, there is an extensive history of research that raises the question of long-term effects on the supply of researchers when an increasing number of scientists begin careers as postdocs. As early as 1976, Grodzins noted that as the number of postdoctoral positions increased and the number of faculty jobs declined, less-qualified applicants would complete Ph.D.s in sciences because they were being diverted to postdoctoral positions. In a series of studies, Zumeta (1984, 1985) raised questions about the patterns in the 1970s, when increasing numbers of postdoctoral recipients represented problems in the labor market for scientists. In this case, individuals who received postdoctoral positions did so because they had trouble finding employment.

The workforce-development literature has also argued that extended periods of postdoctoral employment are simply a diversion from long-term career advancement. Scholars such as Coggeshall et al. (1978) reported that continued employment as a postdoctoral associate (over two years) was due to individual inability to find suitable employment. In 1998, Regets reported that the length of time spent as a postdoctoral associate increased from 20 or fewer months in 1965 to 29 months for those completing degrees between 1989–91. In contrast, Xu (forthcoming) found that a longer postdoctoral position (three years or more) led to increased success in academic employment based on a survey of scientists' curriculum vitae.

It is also important to note that the citizenship of postdoctoral recipients has remained a public policy issue. In the recent Sigma Xi study, Wei et al. (2012) reported that over 50 percent of postdoctoral recipients were temporary visa holders. While there are significant differences across institutions in the percentage of postdoctoral recipients from other countries (which range

from 34–78 percent), overall postdocs from other countries are playing a critical role in the labs of many scientists. Bound, Turner, and Walsh (2009) analyzed the number of doctorate degrees awarded in the fields of science and technology and showed that there is an increasing trend in the number of international doctoral students. They offered several explanations, including the rise in the bachelor-level education in the home countries of the international students, as well as the expansion of federal funds for science and technology education in the U.S., which attracts more foreign students who can earn more in their home country by earning a doctorate degree.

While scholars report that foreign postdoctoral recipients make extensive efforts to contribute to innovations in science (Chellaraj et al., 2005; Stephan & Levin, 2001), governments in particular are concerned by the continuing reliance on foreign labor. There is the potential that restricting the entry to postdoctoral positions for foreigners will increase the risks to research enterprise as a whole. However, government must balance the need for skilled researchers with the need to create opportunity structures to increase jobs and education for U.S. citizens. Bound et al.'s explanations for the rise in international Ph.D. students might be insufficient to explain the rise in international postdoctoral researchers. The nature of Ph.D. studies is different from postdoctoral training—the former being a more planned and determined training than the latter. Furthermore, Ph.D. training is required to become a faculty member but postdoc training is not. This paper aims at filling the literature gap by investigating the dynamic trends of national vs. international scholars and providing a policy tool with which to analyze how government can affect these trends.

3. METHOD

We use the population-level NSF survey of biomedical doctorates, as reported by the Federation of American Societies for Experimental Biology (FASEB) (Garrison and Ngo, 2011 and 2012), to develop a differential equation (DE) model of the postdoctoral training for different characteristic-based groups.

Very few DE models have been developed to study the education pipeline, especially at the level of higher education and faculty positions. These models have mostly focused on the period after recruitment as a tenure-track professor or have not specifically considered the stage of postdoctoral training. Sterman (2000) developed a DE (system dynamics) model of the pipeline of faculty promotion (assistant professor to associate professor to full professor) and replicated the promotion and exit rate of faculties at MIT. In another study, Larson and Gomez (2012) built a small DE model of dynamics of recruitment in a university, and investigated the effects of faculty retirement on the number of hiring for faculty positions. In a follow-up study, Gomez, Ghaffarzadegan, and Larson (2012) modeled two stages of career development, young scholarship (defined as students, postdocs, and tenure-track professors), and established professors (after tenure), and studied the effects of increasing research funding on this pipeline. They did not disaggregate the young scholarship stage, and therefore did not provide any insights into the dynamics of a postdoctoral career. The current study addresses the gap and focuses on the postdoctoral career in the pipeline of workforce development.

Our DE model is consistent with the system-dynamics style of modeling (Forrester, 1967; Richardson, 1991; Sterman, 2000), which emphasizes the importance of feedback mechanisms and circular causality as well as the dynamics of accumulations (i.e., stocks and flows). In this paper, we provide a relatively small-system dynamics model for the policy problem on hand to

bring insight into the policy-making process as suggested by Ghaffarzadegan, Lyneis, and Richardson (2011).

We use the data for three main purposes: (1) as input to the model, (2) for model calibration and parameter estimation, and (3) to test and examine the fidelity of the model results to observed behavior in the NSF data set. Our model simulations are used to examine the effects of different policies including a cap on the funding duration for postdocs, an increase in faculty hiring, a drop in the demand from international scholars, and the effects of change in the upstream of U.S. education, K-graduate.

Our research procedure is as follows: first we build a mathematical model of the problem, then run the model and calibrate it with the data set. After examining the model's ability in replicating the data set, we perform a counter-factual policy analysis (also known as a *what-if analysis* (Ghaffarzadegan and Andersen, 2012; Bardach, 2004; Zagonel et al., 2004; Stewart and Mumpower, 2004) and test the effects of different policies in the model.

4. MODELING

Figure 2 is a representation of research-workforce development that includes Ph.D. students, postdocs, and faculty members in a pipeline. People enter as they are admitted to a Ph.D. degree program, and move toward a faculty stage directly or through a postdoctoral career. Through this path, a considerable portion of people drop out of the pipeline, go into industry, or follow other types of careers.

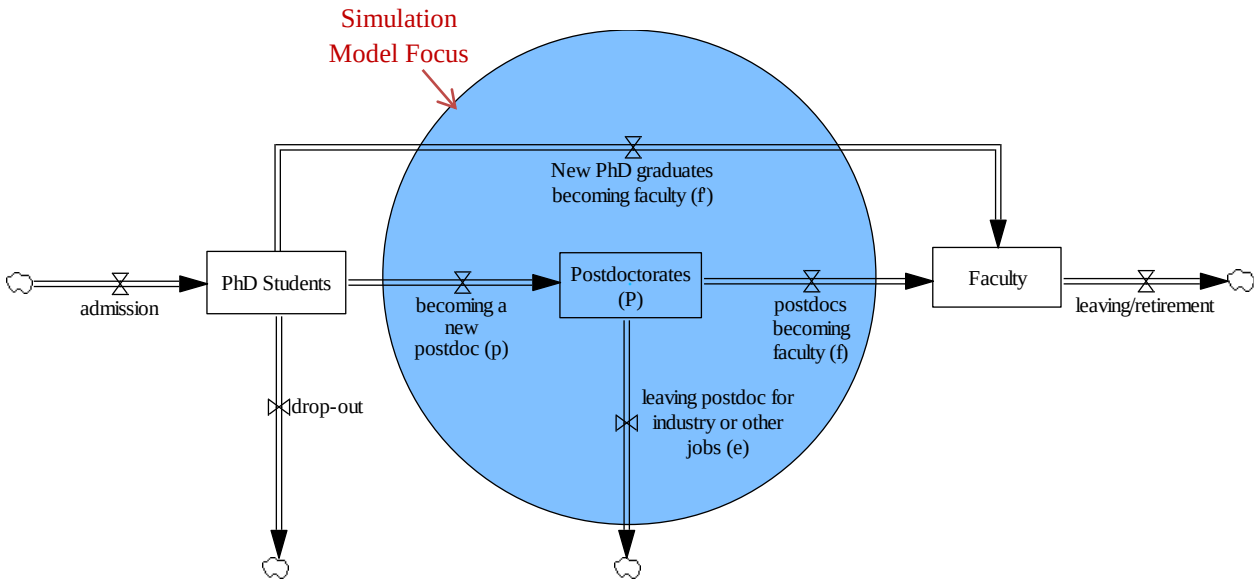


Figure 2: Research workforce pipeline and the modeling boundary

Note: Depending on how we divide scholars based on their characteristics, there can be several of these pipelines. For example, in this study we will use two to represent national vs. international researchers as they go through different stages of development.

As depicted in the figure, our focus will be on the postdoctoral period of the workforce development. We can divide postdoctoral researchers into different groups based on their characteristics. Let n be the number of groups. For example, if we divide postdocs to male vs. female postdocs, n will be 2; similarly if we divide postdocs to national vs. international. For more detailed categorizations, we will have a larger n. Let P_i represents the number of postdocs in group i, $1 \le i \le n$. P_i will increase as more people start a postdoc career and will decrease as people leave it. Equation 1 represents P_i where p_i is the rate of entrance of new people to the ith postdoc group (new hiring), f_i and e_i are the rates of leaving, with f_i being the rate of finding tenure-track faculty positions and e_i the rate of exiting the pipeline that may correspond to taking a job in industry or a non-tenure track position, etc.

$$\frac{dP_i}{dt} = p_i - (f_i + e_i) \quad (1)$$

In the following, we model each of the three variables on the right side of Equation 1.

4.1. Hiring for postdoc, p_i

If p is the total of new postdocs hired in each time period, Equation 2 represents the new postdoc rate in each group (p_i) proportional to total hiring ($p = \sum_{i=1}^{n} p_i$). In this equation, α_i is the proportion of new openings that is filled by group i,

$$p_i = \alpha_i \cdot p \quad (2)$$

The proportion, α_i, depends on the number of applicants from each group and the relative capabilities when compared to others. Equation 3 formulates α_i proportional to the population of each group ($\hat{G}_i$) and the relative weight in the market (ω_i), with the latter representing the relative quality of an average person of each group:

$$\alpha_i = \frac{\omega_i \cdot \hat{G}_i}{\sum_{j=1}^{n} \omega_j \cdot \hat{G}_j} \quad (3)$$

where $\hat{G}_i$ represents new Ph.D. graduates of group i that are in the postdoc job market. We assume that they are equal to the total of new graduates (G_i) in the job market minus the ones that find a faculty position immediately after graduation (G_i^*), as shown in Equation 4,

$$\hat{G}_i = G_i - G_i^* \quad (4)$$

4.2. Hiring for faculty positions, f_i

Similarly we can define f_i, the rate at which people in P_i find a faculty position. The main issue will be that not only postdocs compete to get a faculty position but new graduates can also compete for tenure-track positions. In other words, we have *2n* groups that compete. Let *f* represent the total number of tenure-track faculty hiring, and β_i and β_i' represent the ratio of openings that are taken by postdoctoral researchers and Ph.D. graduates in group *i*. Let f_i represent the number of postdocs from group *i* that get faculty positions and f_i' represent the number of Ph.D. graduates from group *i* that find a faculty position, where $f = \sum_{i=1}^{n} f_i + \sum_{i=1}^{n} f_i'$.

Equations 5a and 5b show the relation:

$$f_i = \beta_i \cdot f \,, \qquad (5a)$$

$$f_i' = \beta_i' \cdot f \,. \qquad (5b)$$

Similar to how we defined hiring proportions for postdoc (α_i), we can define hiring proportions for faculty positions (β_i and β_i') as shown in Equations 6a and 6b,

$$\beta_i = \frac{\theta_i^+ \cdot P_i}{\sum_{j=1}^{n} \theta_j^- \cdot G_j + \sum_{j=1}^{n} \theta_j^+ \cdot P_j} \qquad (6a)$$

$$\beta_i' = \frac{\theta_i^- \cdot G_i}{\sum_{j=1}^{n} \theta_j^- \cdot G_j + \sum_{j=1}^{n} \theta_j^+ \cdot P_j} \,, \qquad (6b)$$

where θ_i^- and θ_i^+ are the relative weight of group *i* in the faculty job market before and after the postdoc period, respectively. In other words, the difference between θ_i^+ and θ_i^- is what an average person in group *i* gains by becoming a postdoc. It is expected that as people stay for a

longer time period they will produce more papers, develop a better CV, and attain higher capabilities, which would make them more competitive in the market. We assume a simple linear function to model the gain as shown in equation 7.

$$\theta_i^+ = \theta_i^- + b \cdot T_{Average,i} \ , \qquad (7)$$

where $T_{Average,i}$ represents *years as postdoc* and *b* is gain in relative quality for each year of staying in a postdoc. *b* will be estimated through calibration.

4.3. Leaving the pipeline, e_i

It is likely that not all postdoctoral researchers in group *i* will find a tenure-track position. Some of them will stay in postdocs and some might leave to pursue other opportunities. Assuming k_i is the proportion of postdocs that do not take an academic job and want to leave the pipeline, we have

$$e_i = k_i \cdot (P_i - f_i) \ . \qquad (8)$$

In equation 8, k_i is not necessarily a constant parameter. It is reasonable to assume that people will not remain in postdocs forever, but as they stay longer they might lose hope in the job market. Mathematically, we can say $k_i = k_i(T_{Average,i})$.

We estimate *years as postdoc* ($T_{Average,i}$) in the simulation model by defining the total years of experience of people in postdocs (E_i) divided by number people (P_i),[1]

$$T_{Average,i} = \frac{E_i}{P_i} \ . \qquad (9)$$

Total experience of all members of a postdoc group is the sum of all postdoc experience in the group (e.g., if 100 international postdocs exit, and each one has 3 years of postdoc

[1] This formulation is mathematically similar to what is known as "co-flows" in system dynamics.

experience, total experience in this group is 300 person-years). In each time period, total experience increases as people stay as postdocs (in this example, if all 100 people stay as postdocs, 100 additional person-years of experience will be added), and decreases as people exit. The relation is shown in equation 10:

$$\frac{dE_i}{dt} = P_i - (f_i + e_i) \cdot T_{exit,i} \quad (10)$$

.

$T_{exit,i}$ is the average time people stay as a postdoc. In a uniform distribution of experience, $T_{exit,i} = 2T_{Average,i}$. In reality, we will have $T_{Average,i} \leq T_{exit,i} \leq 2T_{Average,i}$.

4.4. Calibration and application to the case of national vs. international postdocs

The current model is generic and can represent different segmentations of the academic community, and *n* can be any number based on how detailed our segmentation is. For example, the model can be calibrated to study race/gender disparities in higher education and postdoc positions. For the interests of this paper, we categorize the scholars into two groups of national (i=1) and international (i=2) and run the model for *n=2*, and $i \in \{1,2\}$.

We use data on the following variables as input to the model: *P* and *f*, the total number of postdocs and total number of faculty hiring each year, and G_1, the number of new U.S.-citizen Ph.D. graduates. While an ideal approach is to have a model that can simulate and create these variables endogenously, we set the model boundary around the higher education purposefully for our stakeholders' interests, which helps us to concentrate on the diversity of the population in *p* and *f* while keeping the model as simple as possible.

For G_2, the number of international Ph.D. graduates who are interested in becoming postdocs in the U.S., we can consider two components: one is the number of new international Ph.D. graduates that get their degree inside the U.S., for which we have data, and second, the

number of new international Ph.D. graduates with degrees from outside of the U.S. that are considering the U.S. postdoc market. Estimating the second component can be difficult and we model it by assuming it is proportional to the number of current international postdocs as shown in Equation 11,

$$G_2 = G_{2,US\,\deg} + G_{2,Frgn\deg} = G_{2,US\,\deg} + h.P_2 \ . \qquad (11)$$

The inherent assumption is that as more international postdocs come to the U.S., they will generate even greater numbers of potential international postdocs. There are several reasons for this reinforcement, including the fact that the academic environment is becoming more internationally friendly, and more international graduates are hearing about opportunities in the U.S. (by word of mouth). We estimate *h* through calibration of the model.[2]

We use the Vensim DSS software package for model calibration. Vensim DSS uses the Powell hill-climbing algorithm for optimization, and minimizes the mean-squared error by selecting parameters in the boundary that is provided by the modeler. We conduct calibration from 100 different initial points to avoid local sub-optimal solutions. The Vensim file with detailed parameter values is available from the authors.

5. ANALYSIS

5.1. Base run simulation

Figure (3) shows simulation results and compares them with the historical trends from the NSF data. The model is quite successful in replicating the observed data. In Figs. 3a and 3b, the simulation outputs for the number of international and national postdocs closely follow the observed trends in the data set (dashed lines). The figures show that the number of international

[2] This formulation is transferable to other contexts—for example, when we want to study male vs. female postdocs, or majority vs. minority (the environment becomes more minority friendly if there are more minorities in the school, encouraging more minorities to apply).

postdocs increases much more rapidly than national postdocs, which is consistent with the data. Figs. 3c and 3d depict simulation results for the inflows to and outflows from national and international postdocs: new postdoc rate (p_i), postdocs becoming professors (f_i), and postdoc exit rate from the pipeline (e_i) over time.

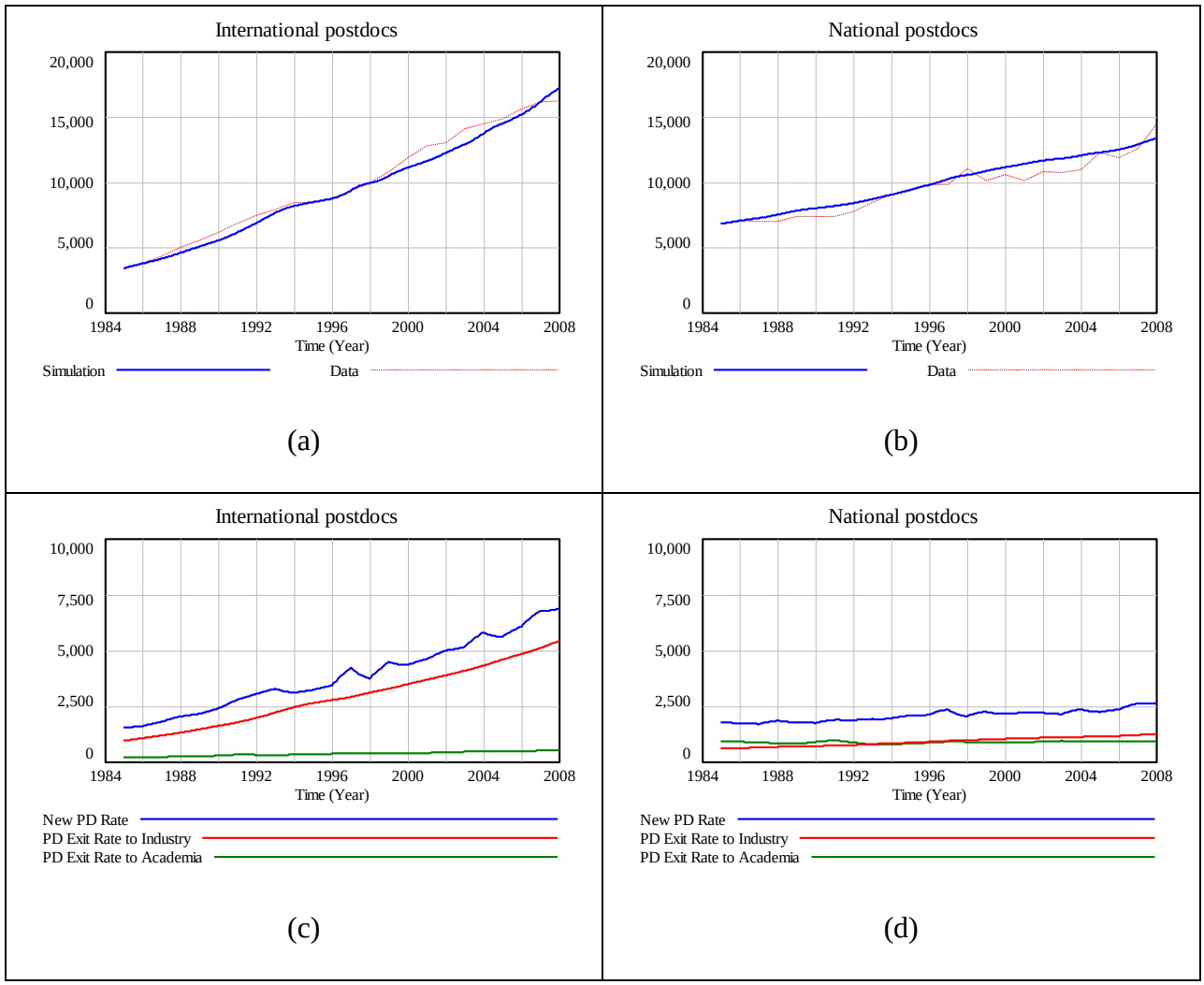


Figure (3): Simulation results for the base run and comparison with the data.

One of the first points that is observable from comparing Figs. 3c and 3d is that on average, the rate of entrance and exit for international postdocs is larger than for national postdocs, i.e., on average, internationals come at a faster pace and leave at a faster pace. Furthermore, as we also

see in both graphs, the number of postdocs that find a faculty position is relatively steady for internationals and declining for nationals, while the number of postdocs that choose to exit the pipeline to presumably go into industry is increasing for both groups. These trends become more meaningful when we compare them with the entrance rate to a postdoc career in each graph. Now, we conduct a few experiments with the model and examine the simulation results under different policies. The goal is to see how the proposed policies by NIH and other related constituencies can affect the number of national and international postdocs.

5.2. Policy Analysis

The model is used to examine the effects of five different policies as listed in Table 1: (1) capping the duration of funding for postdocs at four years, (2) capping the duration of funding for postdoc at two years, (3) more faculty hiring in the U.S., (4) a drop in the demand from internationals to pursue postdoc training in the U.S., and (5) an increase in the quality of U.S. high school graduates.

These tests are implemented as counter-factual tests—i.e., we compare what in reality happened (base run) with what could have happened if the policies were implemented. We pick 1995 as the base year of testing changes. Table 1 also summarizes the results of simulation runs, which we will discuss in this section in detail.

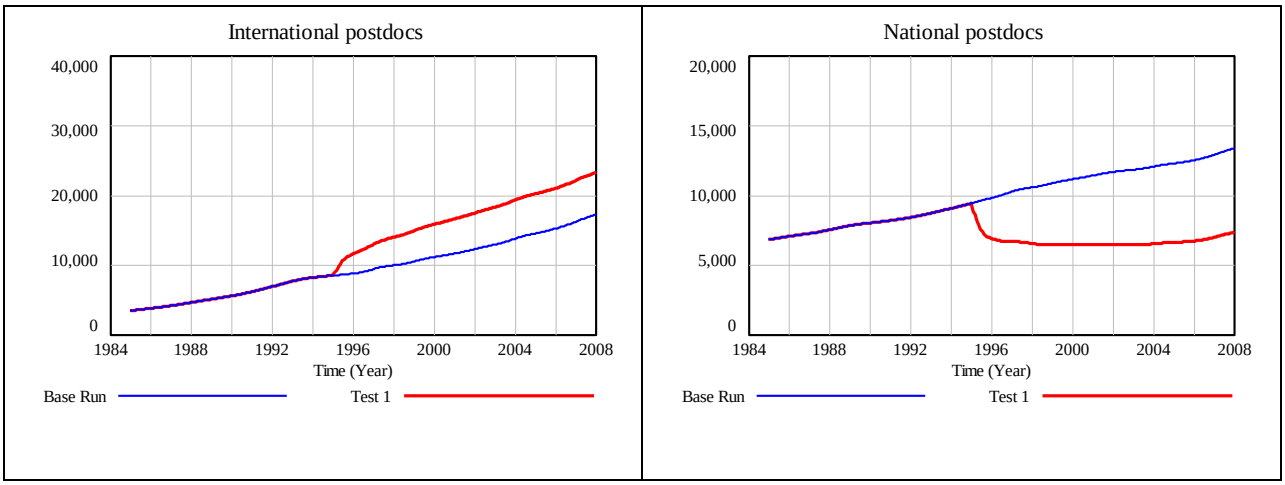
Simulation Experiments	Policy Measures			
	International Postdocs	***National Postdocs***	***Ratio of National to International Postdocs***	***Faculty Hiring Ratio of National to International Scholars***
(1): Capping duration of postdoc at 4 years	↑	↓	↓↓↓	↓↓↓
(2): Capping duration of postdoc at 2 years	↓	↓↓	↓↓	↓
(3): More faculty hiring in the U.S.	↑	↓	↓	↓
(4): Drop in the demand for postdocs outside the U.S.	↓	↑	↑	↑
(5): Increase in the quality of U.S. high school graduates	↓	↑	↑↑	↑↑

Table (1): Five Model Simulation Experiments and Their Effect on Different Policy Measures

Figures 4–8 show simulation outcomes for each test, respectively. Figure 4 depicts the results of Test 1: the effect of capping the duration of postdoc at four years. The results are counter-intuitive and contrary to the initial expectation. As a result of the policy, the number of international postdocs increases (Fig. 4a: red line), but the number of national postdocs declines (Fig. 4b: red line). This behavior is very interesting as one might expect that capping the duration should at least affect both international and national postdocs in the same way.

Two main explanations can be offered for the pattern. First, as we cap the duration of postdocs, national postdocs are affected more, as, on average, they stay for a longer time period in a postdoc career. International researchers naturally have many limitations regarding whether to stay or more incentives to leave (e.g., visa-related limitations, having alterative options in their home country), and they are more likely to leave the U.S. than national postdocs; therefore, the policy affects national postdocs more than international postdocs. Second, as long-time national postdocs meet the cap and leave, more empty slots become available for new postdocs. In the

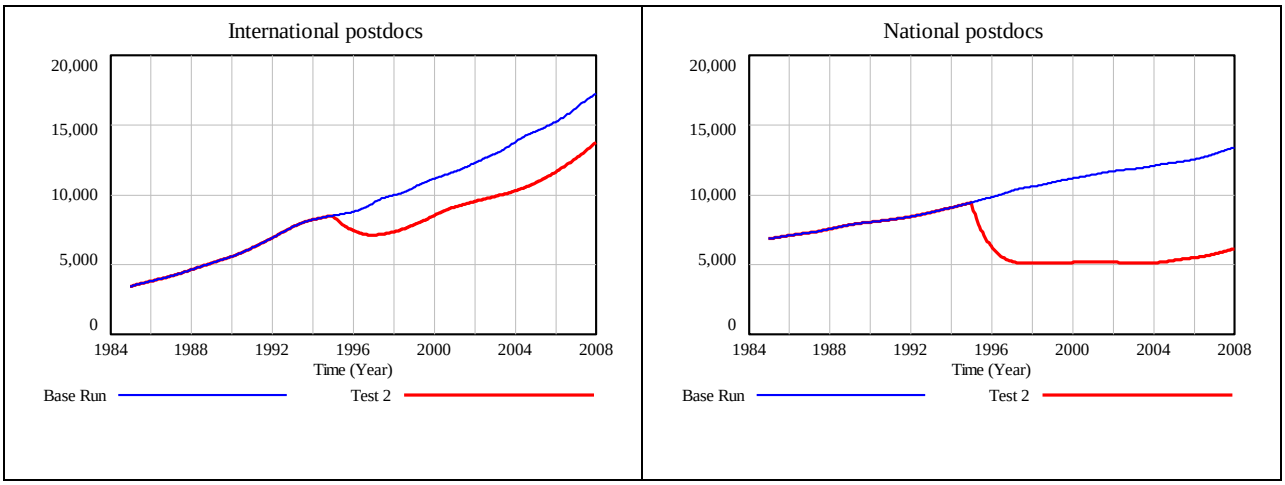
competitive market, international postdocs would take a considerable portion of the new positions. In other words, capping the duration forces national postdocs to leave sooner and give most of their positions to internationals. These two effects result in more international postdocs.



(a) (b)

Figure 4: Comparison of the Base Run with Test 1: Capping the duration of postdocs in 1995 at four years.

One might expect that the effect would change if the limit were, say, two or three years. Test 2 takes an extreme-condition approach by capping the duration at two years. The results are depicted in Fig 5. In an extreme condition, both groups would be affected. But as the figure shows, overall, the effect on national postdocs is much larger. As a result, the proportion of national vs. international postdocs and faculty members changes in favor of internationals.

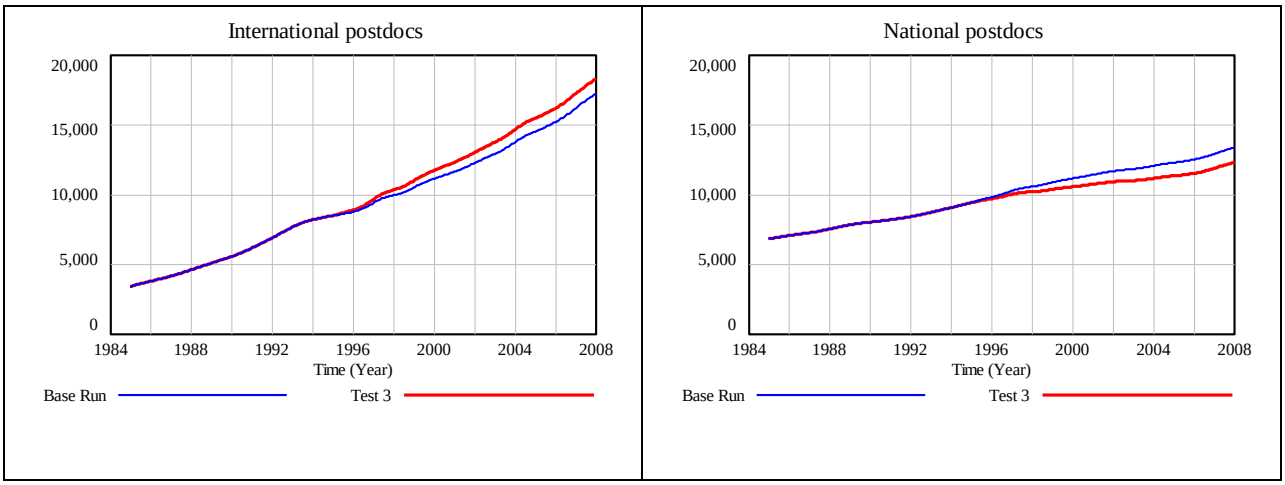


(a) (b)

Figure 5: Comparison of the Base Run with Test 2: Capping the duration of postdocs in 1995 at two years.

In summary, Tests 1 and 2 together suggest that capping the duration of postdocs results in a higher ratio of international to national postdocs, and more allocation of funding for international postdocs.

In Test 3, we analyze the effects of a change at the end of the pipeline. There is a common argument that most of the problems regarding postdoc careers concern the lack of sufficient faculty positions. We test the effects of more faculty openings on the number of international vs. national postdocs. Figure 6 shows the results. This policy has very little effect on the patterns, and the direction of the effect is in favor of international postdocs. The reason is similar to the first policy: more faculty openings increase the outflow from postdoc positions and the new positions are taken disproportionally by international scholars. Overall the policy results in more international postdocs.

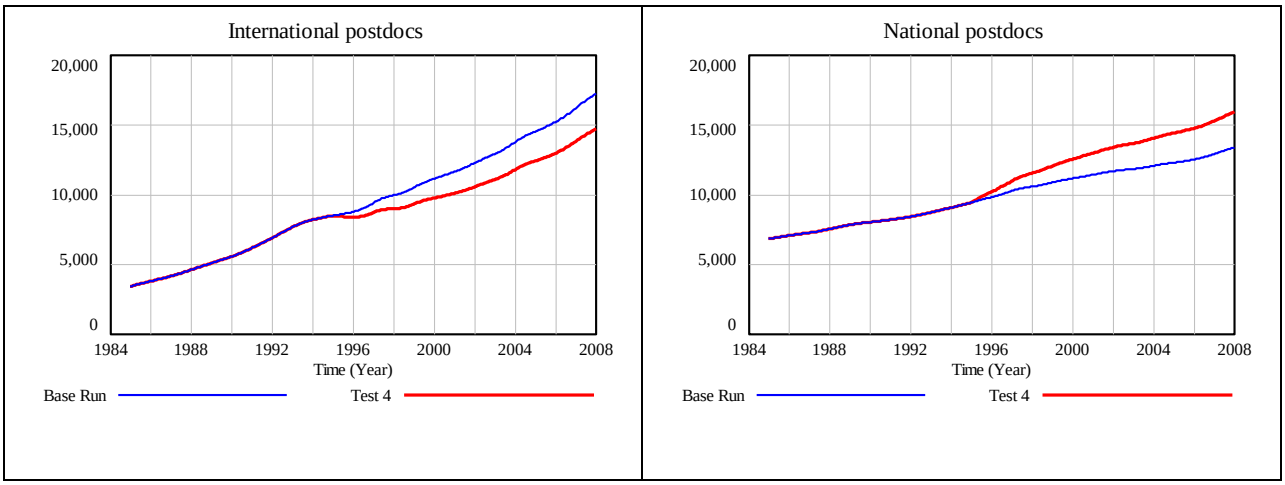


(a) (b)

Figure 6: Comparison of the Base Run with Test 3: what if more faculty jobs were available.

Next, in Test 4, we represent a drop in internationals' decision to stay in the U.S. In this test, we examine what would happen if international researchers became less interested in staying in the U.S. This could happen due to a wide range of reasons, which might include the political and economic conditions of their home country compared with those in the U.S. For example, if job opportunities in the home country of international postdocs improve, there might be more reasons for them to return to their home country.

Figure 7 shows the results. As expected, the number of international postdocs decreases (Fig. 7-a). Interestingly, such an external shock affects national postdocs as well, as Fig. 7b shows. As international postdocs leave the U.S. and show less interest in having a postdoc position, more positions are taken by U.S. researchers. The inherent dilemma is that a better economic condition in the home countries of international researchers can also improve workforce development in the U.S.



(a) (b)

Figure 7: Comparison of the Base Run with Test 4: what if a smaller portion of international students stay in US after graduation.

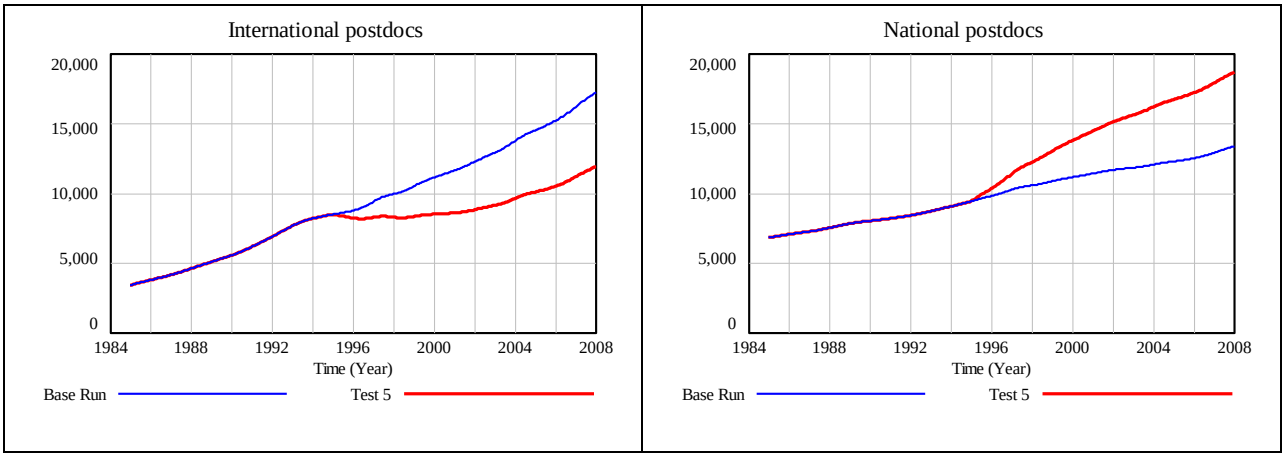
It is interesting to note that the tested effect can happen in the reverse as well, when there is a shock in the economy of the home countries of international researchers. Through the mechanism depicted above, the U.S. market for postdocs will be affected as if the economic shock in foreign countries is transferred to the U.S. market. The reason is that as more international postdocs enter the U.S. job market, the competition becomes more difficult and therefore affects national applicants. The number of national applicants that become successful in the postdoc job market decreases.

This simulation result is additional support for a previously documented argument by Teitelbaum (2008) in *Science* magazine that the research system in the U.S. is an open system, and political and economic conditions in other countries affect its research environment and workforce development.

All of these tests show that the system is resistant to the suggested policies and environmental changes and in many cases can backfire and act in an opposite way to what we

expect. It appears that there is no easy way to change the trend, or at least change is not possible by implementing policies at the postdoc-faculty pipeline.

The declining rate of national postdocs might relate to less competitive in the job market, which may be rooted in the K-12 education system or beyond—in universities and graduate schools. Our model does not look at the upstream part of the pipeline. However, to represent a change in the upstream, we can increase the competitiveness of U.S. graduates in contrast to international graduates. Such an increase, Test 5, will represent a rise in the output quality of the K-graduate pipeline, which is the input to the postdoc pipeline. Figure 8 shows the results.



(a) (b)

Figure 8: Comparison of the Base Run with Test 4: what if more faculty jobs were available.

To make a better sense of the effects Figure 9 compares the ratio of National vs. International postdocs under different policies, and Figure 10 compares the effects on the hiring ratio for faculty positions in Tests 1–5.

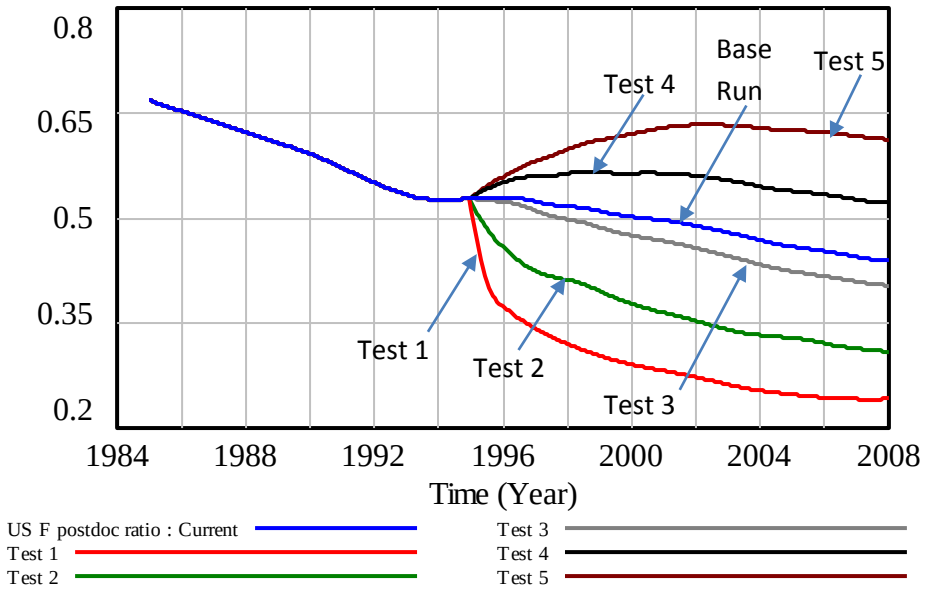


Figure 9: The Ratio of National to International Postdoc

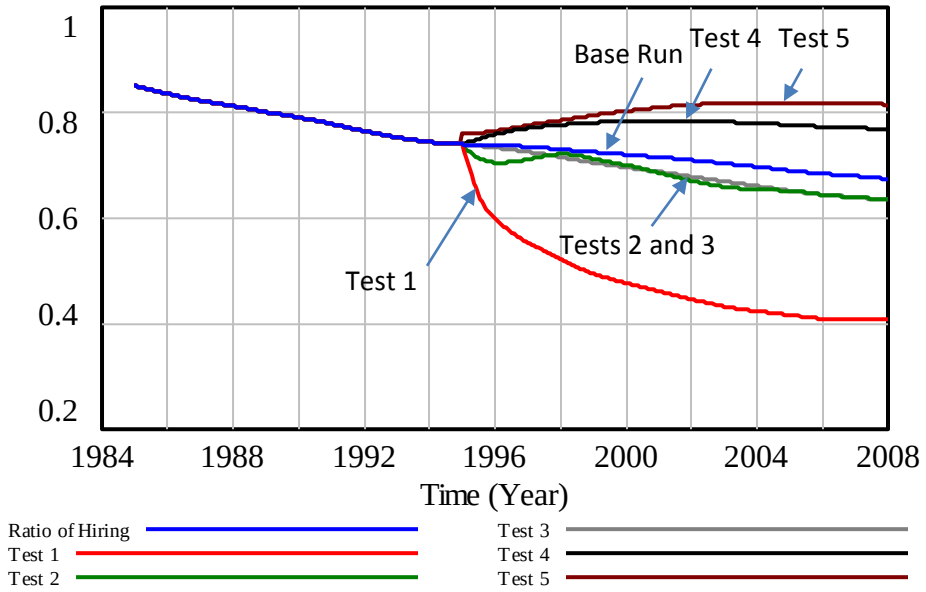


Figure 10: The Ratio of National to International Hiring for Faculty Positions

As these figures show and the results are summarized in Table 1, capping the duration of a postdoc does not produce the desired outcome. The system also gets easily affected by a change in the economic and political conditions of other countries. The policies implemented in the

upstream of the education pipeline (Test 5) can have much stronger effect than policies implemented at the downstream of the pipeline (Tests 1, 2, and 4).

6. DISCUSSION

In this paper, we analyzed the trends of national vs. international postdocs in the U.S. We built a differential equation-based model of postdoctoral training. Then, we calibrated the model with data from the NSF survey of doctoral recipients. Our model successfully replicates the observed trends in the data. Using the calibrated model we then conducted a set of simulation-based counterfactual analyses of the postdoc population and examined under what conditions the ratio of international to national postdocs changes.

This study offers two major contributions. First, the paper contributes to the study of postdoc population in academia. Building on past studies of diversity across postdoctoral researchers, this study offers the first simulation model of research workforce development that consists of postdoctoral training. We provide a framework within which to analyze the movement of postdoctoral participants through the academic workforce. Using an analysis of feedback mechanisms, the paper represents different decision rules in the system and the flow of researchers into a postdoc career and from postdoc into faculty positions. The model is formulated and could be applied to different segments of the postdoc population.

Second, using the model, we conduct several simulation-based analyses and offer managerial insights and policy implications for research workforce development. Our model shows that capping the duration of a postdoctoral career, a policy proposed previously, will likely have an unintended effect of favoring foreign postdocs and decreasing the ratio of national to international postdocs in the U.S. The reason is because international postdocs spend a shorter

time in postdoc positions than their U.S. counterparts. This is consistent with the data from NSF. Thus, capping the duration adversely affects U.S. researchers more than international researchers. In addition, if we cap the postdoc duration, more U.S. postdocs leave and are replaced by new international postdocs, leading to even more international researchers. No formal analyses prior to this study investigated the possible effects of these policies. Our model also explores the effects of economic changes in the home countries of the international postdocs, which are considerable.

Similar to all modeling efforts, the study faces some limitations. Our model boundary is defined around postdoc training, and does not consider the upstream part of the education pipeline such as the high school stage in details. We also try to keep the model as simple and compact as possible in order to make policy insights clearer and avoid unnecessary details (Ghaffarzadegan, Lynies, and Richardson, 2011). Of course, this approach imposes several limitations. For example, we do not differentiate between international countries although scholars from different countries might behave differently. In addition, there are other feedback loops that are interesting to analyze and can represent complex issues in this system. For example, the desired number and funding of postdocs might be affected as more experienced postdocs leave. While the simplifications are in line with the scope and goal of the current study, they also suggest future analyses.

In summary, our analyses shows that the leverage point to affect diversity in the research workforce development system is in the K-graduate education area and policies implemented at the postgraduate level have minimal effects on diversity, if any. Specifically capping the duration of postdocs could have unintended effects and result in decreasing the ratio of national to international postdocs in U.S. academia.

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