POSTDOCTORAL APPOINTMENTS: MOTIVATIONS, MARKETS, AND EXPERIENCES

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ABSTRACT

JENNIFER M. MILLER: Postdoctoral Appointments: Motivations, Markets, and Experiences
(Under the direction of Maryann Feldman)

This dissertation considers three research questions. Why do scientists become postdoctoral scholars (postdocs)? What role do postdocs play relative to other categories of labor in research production? What factors are associated with a postdoc being dissatisfied?

The literature review in Chapter 2 summarizes findings about which scientists are most likely to become postdocs, considering characteristics of individual scientists and doctoral institutions. The role of individual motivations in determining which students plan to become postdocs is incorporated into a conceptual model based on the social psychological theory of planned behavior. The theory frames scientists' motivations for postdoc appointments in terms of behavioral attitudes, social norms, and perceived behavioral control, moderated by understanding that a postdoc is expected for a desired career.

Chapter 4 models universities' production of life sciences research as a function of capital and labor (doctoral research assistants, postdocs, and faculty). This analysis uses data about 145 research universities from the NSF Survey of Graduates and Postdoctorates, the 2006 NRC Assessment of Research Doctorate Programs, and other sources to estimate a translog production function using seemingly unrelated regression to calculate coefficients of

complementarity. Universities appear to utilize postdocs as complements to doctoral research assistants and faculty in research production.

In Chapter 5, survey data from 764 postdocs in physical and mathematical, biological, and health sciences are used in an ordered probit regression to estimate effects of individual and organizational factors on the probability that a postdoc will be dissatisfied with an appointment. Postdocs are less likely to be dissatisfied when they find their current research interesting, when the appointment is consistent with interest in a faculty research career, and when the research has an applied element. Surprisingly, being at an institution with a high-quality doctoral program does not seem to prevent dissatisfaction. Mediation analyses indicate that while postdocs in high-quality programs report greater freedom to shape research projects, they interact less frequently with advisors, possibly due to advisors' involvement in research commercialization.

Chapter 6 integrates findings with the literature and current topics in science and workforce policy; discusses implications for policymakers, institutions, and scientists; and suggests future research directions.

DEDICATION

To my husband, Andy, for his unconditional love, support, and patience.

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ARRA	American Recovery & Reinvestment Act
COSEPUP	Committee on Science, Engineering, and Public Policy
FTE	Full-time Equivalents
NAS	National Academy of Sciences
NIH	National Institutes of Health
NPA	National Postdoctoral Association
NRC	National Research Council
NRSA	National Research Scholars Award
NSB	National Science Board
NSF	National Science Foundation
SDR	Survey of Doctorate Recipients
SED	Survey of Earned Doctorates
S&T	Science & Technology

Chapter 1

Introduction

Postdoctoral appointments (postdocs) are an important concern for science and technology policy because of their large numbers and the significant contributions they make to research and innovation. The National Postdoctoral Association (NPA, 2009) provides the following definition of a postdoc: " … postdocs typically perform research under the supervision and mentorship of a more senior researcher, often called the postdoctoral advisor. The key characteristic of a postdoc position is that it is a temporary career-building step on the path to a more permanent position." Three aspects of this definition—the time-limited nature, mentored research, and career preparation—are consistently used to define postdoc appointments in the US (e.g., COSEPUP 2000).

A recent estimate places the number of postdocs in the US as high as 90,000 (National Science Board, 2010). According to the National Science Foundation's (NSF) 2006 Survey of Doctorate Recipients (SDR), there are a total of 488,860 science, engineering, and health doctorate holders employed in the US, with 226,400 employed in four-year institutions of higher education. 34,921 research doctoral degrees in science, engineering, and health were awarded in the US in 2008. In 2009, 67.32% of doctorate recipients in the life sciences, 55.48% in the physical sciences, and 36.72% in engineering took postdoc appointments—in each case an increase over prior years (Fiegener 2010; Stephan and Ma 2005). The number of foreign postdocs coming to the US with PhD in hand and the proportion of US doctorate recipients taking postdoc appointments have both contributed to the growth of the postdoc population (Stephan 2012). These postdocs include some of the most talented and productive early career scientists from doctoral programs in the US and around the world (Vogel 1999; Zumeta 1985).

There are concerns, however, that postdocs' scientific talent, developed at substantial public and private cost, may be underutilized in these time-limited appointments that lack the stability and autonomy that would allow scientists to tackle high-risk, high-reward research during the creative early stage of their careers when their research production should be high (Stephan and Ma 2005). From their historical origins as the privilege of a respite from the demands of teaching and administrative duties before embarking on a faculty research career, some critics assert that postdocs have become a holding pattern and a source of cheap labor (Mishagina 2009; Puljak and Sharif 2009).

In the life sciences, the US annually produces over 8,000 new doctorate recipients most of whom will have at least one postdoc appointment (NSF, 2009). When the National Institutes of Health (NIH) doubled its research funding between the years of 1998 and 2003, more students were attracted to life sciences doctoral programs. This effect lagged the funding increase by a few years, with the NSF Survey of Graduate Students and Postdoctorates reporting a 29% increase in life sciences graduate students between 2001 and 2006, compared to a 9% increase in other science and engineering fields over the same time period. However, as funding levels flattened, career appointments have not always been available for newly-trained scientists (Freeman and Van Reenen 2008). The approximately $10 billion of funding for life sciences research in the American Recovery and Reinvestment Act (ARRA) of 2009 represents another such sudden but temporary increase in funding. By subsidizing graduate education in response to sharp increases in demand, uneven funding levels are thought to be one contributor to the prevalence of postdoc appointments.

To better inform public policy related to the funding and management of postdocs, this dissertation takes a multidisciplinary and multilevel approach to investigate the roles of individuals and organizations in the prevalence of and problems with postdoc appointments.

The six-chapter dissertation has the following structure. Chapter 2 contains a review of the literature addressing individual and organizational factors affecting whether scientists take postdoc appointments. Chapter 3 elaborates a conceptual model of social psychological motivations behind individual decisions to pursue postdoc appointments. Chapter 4 draws on microeconomic theory to present a model of the role of postdocs in the production of university research. Chapter 5 presents an analysis of survey data revealing factors associated with dissatisfaction in postdoc appointments. Chapter 6 concludes with implications for policymakers, administrators, and early-career scientists and directions for further research on postdocs. Each chapter is summarized below.

The literature review in chapter two reviews and synthesizes the highly fragmented literature on postdoctoral appointments. It draws on the academic literature, government and professional association reports, and publicly available data to summarize what is known about who becomes a postdoc. One way to approach the question of who becomes a postdoc is by examining individual characteristics like personal motivation, human capital, and demographics. Another approach considers the role of characteristics of the doctoral institution. This review considers both approaches, as well as cross-level effects, to integrate knowledge of individual and institutional determinants of postdoctoral study. The review summarizes existing research on postdocs in a series of potentially testable propositions that suggest directions for future research.

Chapter 3 contributes to understanding of the influence of individual-level motivations on PhD students' intentions to pursue a postdoctoral appointment by placing the decision to become a postdoc in a theoretical framework based on Ajzen's (1988) theory of planned behavior. This chapter suggests an answer to the question of why students pursue graduate degrees that may not lead directly to related career positions by describing a model of the influence of behavioral attitudes, social norms, and perceived behavioral control on intention to pursue a faculty research position in the long term and a postdoc appointment in the near term. A theoretical rationale is considered for the effect of each component of the theory of planned behavior on intentions to pursue a faculty research position. The model also includes the effect of intentions to pursue a faculty research career on plans to seek a postdoc appointment after graduation, moderated by the belief that such an appointment is a career prerequisite. Policy implications suggest specific targets for improving access to information to improve scientists' career decisions.

The contributions of postdocs to the academic research enterprise are well established by prior research. However, the mechanism of this contribution is not well understood from an economic perspective. Chapter 4 presents an economic model of university research that treats doctoral research assistants, postdocs, faculty, and laboratory space (representing capital) as inputs in a production function. To answer the question of whether postdocs are substitutes for or complements to other inputs in the production of research, this analysis combines the extensive data gathered by the National Research Council (NRC) to assess research doctorate programs in 2006 with several publicly available data sources. Seemingly unrelated regression is used to estimate the effect of each input on postdocs′ factor share in production. The results of these estimates are used to calculate coefficients of complementarity.

Chapter 5 analyzes survey data to examine which factors are associated with a postdoc's dissatisfaction with an appointment. Dissatisfaction with postdoc appointments is a public concern because these appointments often represent a significant investment of public funds and dissatisfaction with postdoc appointments may deter the most talented scientists from continuing research careers. Dissatisfied postdocs are also a concern for universities and other organizations because they rely on postdocs' research productivity and have realized the need to incorporate postdocs more fully into the community of scholars. Individual scientists also have a particular interest in avoiding poor choices at the critical juncture in their early careers where they select a postdoc appointment. This chapter draws on survey data from 764 postdocs at major US universities to examine the factors associated with dissatisfaction. Results of an ordered probit regression indicate that the type of research conducted, its connection to career goals, supervision, and demographic characteristics affect the probability that a postdoc will be dissatisfied. The study also analyzes the mediating roles of autonomy, advisor interaction, and advisor involvement in commercialization activities on the relationship between program quality and dissatisfaction. The chapter concludes with implications for public and institutional policy and for early career scientists considering postdoc appointments.

The concluding chapter integrates these empirical findings with the literature and current topics in science and workforce policy to discuss implications for policymakers, the institutions that partner closely with government to implement these policies, and individual scientists. The conclusion summarizes the empirical findings to address the following questions. How do individual scientists make the decision to take a postdoc appointment? What determines whether a postdoc will be dissatisfied with the appointment? What is the economic function of postdocs in universities′ production of research? The conclusion also presents policy implications and directions for future research.

Chapter 2

Individual and Institutional Antecedents of Postdoc Appointments

As postdoctoral appointments have become more common and prolonged (Stephan and Ma 2005), policymakers seek to better understand who becomes a postdoc and why. This chapter reviews the literature and advances a series of propositions to guide future research on postdoc appointments. The review summarizes the academic literature, government and professional association publications, and publicly available data. The emphasis of the review is on US postdoc appointments. However, studies set in other countries are also included when relevant.

This review is organized in three sections. The first section reviews evidence about how individual-level factors such as motivation, ability, and demographics predict who becomes a postdoc. The second section discusses how university-level factors such as prestige of the university and features of the doctoral program predict who becomes a postdoc. The third section describes potential interactions between individual-level and university-level influences.

A great deal of descriptive information has been compiled about postdocs. Table 1 provides a chronology of key surveys and descriptive work on postdocs. Table 2 describes ongoing NSF surveys that include data about postdocs. The Survey of Earned Doctorates (SED) asks new graduates about their post-graduation career plans, which often involve taking a postdoc appointment. The SDR asks scientists about their post-graduation employment and training. In some years, the SDR includes more detailed questions about postdoc appointments.

Appendix A summarizes the empirical studies that are the main focus of this review, including methodology, key findings, and limitations. Note that many of the studies are cross-sectional or retrospective, based on secondary or archival data, reflect samples from earlier time periods, and/or are largely descriptive in nature. Several study postdocs outside the US.

INDIVIDUAL LEVEL

Prior research suggests that there are a number of individual-level factors that influence whether someone will become a postdoc. These factors, suggested by psychological, economic, and sociological theory, can be categorized as motivational, human capital, and demographic. The following section reviews the existing literature on these factors and motivates a series of potentially testable propositions.

Motivational Factors

Perhaps the most straightforward motivation for taking a postdoc appointment is the desire for an academic career. However, it might be useful to examine this motivation more carefully and distinguish it from other motivations such as interest in a research career that is not necessarily academic, belief that a postdoc appointment is a prerequisite for a desired career, or a motivation to change direction after completing the doctorate.

The SDR asks scientists who have taken postdoc appointments their reasons for becoming a postdoc. Trends in these survey responses from 1997-2003 are shown in figure 1. The most commonly reported reason for becoming a postdoc is that it is expected for one’s career. A lack of other employment opportunities is less frequently reported and has become less frequent over time.

Postdoc appointments have long been associated with the intention to pursue an academic career in the form of a tenure-track academic appointment (Curtis and National Research Council 1969). More recent studies have also found this association (Fox and Stephan 2001). Taking a *post hoc* view, those who become tenured faculty are more likely to have held a postdoc appointment than scientists who follow other career paths (Zumeta 1985).

Some new PhDs become postdocs because they feel that a postdoc appointment is required or expected in their field (Curtis and National Research Council 1969). In some fields, this belief accurately reflects the reality of scientists' career paths. Prior research suggests that doctoral students' beliefs about career prospects are influential even when they are only partially aligned with actual career paths typical in their field (Fox and Stephan 2001). As shown in figure 1, the expectation that a postdoc appointment is required or expected is the most commonly reported reason for becoming a postdoc among SDR respondents. The percentage of respondents citing this reason showed an upward trend between 1997 and 1999 and has decreased only slightly in the subsequent two surveys.

Taking a postdoc appointment may also be associated with the desire or perceived need to change fields (Curtis and National Research Council 1969; Libarkin and Finkelstein 2001). The desire to obtain training in another field was cited in one study as a motivating factor by over 40% of biochemists who had taken postdoc appointments (Nerad and Cerny 1999). Changing research interests could motivate a scientist to change fields. Speculatively, those scientists who found themselves in a less engaging area of study during the doctoral program may use the postdoc appointment as a way to transfer their skills to a more interesting type of research, assuming that they are still interested in a research career.

Taste for science. Postdoc appointments may also attract those who aspire to a research career, rather than the traditional faculty career including teaching and research. Akerlind (2005, 2009) found that Australian postgraduate researchers often described their career aspirations in terms of research rather than faculty appointments. Recent work has found that an intrinsic motivation or taste for science can have a strong influence on scientists' career choices (Roach and Sauermann 2010; Stern 2004). Such intrinsic motivations were found to be stronger in fields where postdoc appointments are common, such as the life sciences (Zumeta 1985).

Career theory suggests that value motivation, such as taste for science, along with self-direction, may differentiate between those who persist in careers in science and research from those who are more likely to pursue careers in education and health fields (Briscoe and Hall 2006; Segers et al. 2008). The role of taste for science may also be interpreted from the perspective of needs-supplies fit, in that scientific careers fulfill a perceived need for a work environment consistent with scientific values (Edwards 1991). While work on values congruence has usually focused on person-organization fit (Edwards and Cable 2009), the concept could potentially be applied to occupational choice (Blau et al. 1956). Scientists may be willing to make financial and other sacrifices to be scientists because the scientific occupation, rather than the employing organization, is congruent with their values. While prior studies have not addressed this question specifically, these considerations suggest that those with an intrinsic motivation or taste for scientific research are more likely to become postdocs.

Proposition 1: Taste for science will be positively associated with becoming a postdoc.

Human Capital

Human capital may play a role in the motivation to become a postdoc in three ways. First, scientists' levels of human capital upon completion of the doctorate may influence employers' selection decisions. These selection decisions may in turn influence who becomes a postdoc. Second, scientists may perceive the postdoc appointment as an opportunity to further develop their human capital. Third, scientists may see the postdoc appointment as an opportunity to signal the human capital they have already developed.

Human capital theory initially focused on the additional knowledge and skills gained through education (Becker 1975). In the extension of this theory to the concept of science and technology (S&T) human capital, knowledge and skills are supplemented with tacit knowledge, social capital, and connections to scientific networks to better explain the role of research experiences in developing scientific capacity (Bozeman, Dietz, and Gaughan 2001). Human capital is thought to be more successfully developed when the person is well-matched to the position or occupation (Jovanovic 1979; McCall 1990) and this results in increased productivity and other positive labor market outcomes (Allen and van der Velden 2001; Bender and Heywood 2009).

Level of human capital. One implication of human capital theory is that the scientists with the most human capital upon completion of the doctorate will be able to secure the most desirable positions. Relatively low pay and low job security imply that postdoc appointments would be less desirable positions. Some scientists, generally considered to be of lesser ability, may find themselves in postdoc appointments for an extended period of time and unable to secure a career position (Puljak and Sharif 2009).

However, the further implication that the most capable scientists are more likely to find career positions and avoid postdoc appointments is generally not supported and may be overly simplistic. It is not at all uncommon for scientists of high ability to take postdoc appointments (Hornbostel et al. 2009; Zumeta 1985; Bohmer and Von Ins 2009). The role of mobility and networks in development of S&T human capital may make postdoc appointments desirable, especially to those high-ability scientists who expect high productivity in an appointment that is a close fit to their research interests.

Several previous studies using measures that would seem to be good proxies for ability, such as pre-doctoral publications, have failed to find an effect on the probability of becoming a postdoc (McGinnis, Allison, and Long 1981; Reskin 1976; Su 2011). There are four possible interpretations. First, prior studies may not have had adequate ability measures. Second, ability may play no significant role in determining who becomes a postdoc. A third, related interpretation is that the effect of ability depends on time period, discipline, or other factors; prior studies examined widely varied contexts. Finally, it is possible that this relationship is nonlinear, with high ability doctorate recipients becoming postdocs by choice for the opportunity to develop S&T human capital and lower ability doctorate recipients becoming postdocs by necessity (Zumeta 1985). Despite the failure of prior empirical work to demonstrate a consistent relationship between ability and becoming a postdoc, the literature suggests the following speculative proposition.

> *Proposition 2: Relative to doctorate recipients of average ability, both high and low ability recipients will be more likely to become postdocs.*

Development of human capital. The literature has discussed development of generalist skills more than the types of specific scientific capabilities or technical skills that would be signaled through academic publications. This is somewhat surprising, since scientists themselves report subject matter knowledge as the greatest benefit from their postdoc appointments (See figure 2). Concerns have been expressed about knowledge and skill development. Postgraduate researchers in Australia reported that the skills they were developing were targeted toward faculty positions that combined research and teaching, but that these positions were scarce and the postdocs were often more interested in pure research positions (Akerlind 2009). Some of these Australian postdocs did not consider themselves to be in training at all. It is also not clear whether postdoc appointments serve the purpose of further developing scientists' abilities. If postdoc appointments are holding patterns or signals (Mishagina 2009; Recotillet 2007), graduates have no rational reason to become postdocs for skill development.

In practice there has been a significant effort to improve skill development opportunities for postdocs, especially in the areas of generalist skills such as project management, communication, and proposal writing (Davis 2009). Studies have also found that those who complete a PhD quickly may be more likely to become postdocs (Recotillet 2007; National Research Council 1981; Laudel and Gläser 2008). If postdoc appointments have value for skill development, they may have greater appeal to students with less developed skill levels. Here skill does not refer to research achievement measures, such as publications, or inherent scientific ability, but to skills such as teamwork, project management, and communication usually acquired through professional experience. Although there are other possible explanations, the finding that increasing age reduces the chance of becoming a postdoc is consistent with this line of reasoning (Zumeta 1985; Recotillet 2007; McGinnis, Allison, and Long 1981). Alternatively, students without these skills may not be competitive for career positions, and so may find themselves in postdoc appointments by default.

The postdoc appointment may also be an important stage in the transition from student to independent researcher (Laudel and Gläser 2008). Two aspects of becoming an independent researcher are selecting research topics and obtaining grant funding. Although the sample was small, one study found that PhD students whose advisors had assigned their dissertation topics were more likely to become postdocs (Curtis and National Research Council 1969). Surveys of postdocs reveal that proposal-writing is a key skill they hope to develop during their appointments (Davis 2009; Chang et al. 2005; Helbing, Verhoef, and Wellington 1998). These findings suggest that doctoral students who have had experiences with selecting research topics and obtaining funding may be less likely to become postdocs, as they will perceive fewer new skills to be gained from the experience.

Stephan and Ma (2005) express concern that human capital is not put to its highest use during the extended postdoctoral periods that have become typical. In combination with the emphasis on generalist skills, this concern suggests that the first postdoc appointment may be the most valuable to augmenting human capital. Mishagina (2009) found that scientists who had multiple postdoc appointments were more likely to leave science and engineering, indicating that these subsequent positions served as waiting lists rather than skill-developing opportunities. It may make sense to differentiate between postdocs in their first appointment, when they are likely to be developing new generalist skills, from those in subsequent appointments. Generalist skills receive a lot of attention in qualitative and practitioner-oriented work, but there appears to be little known about their specific place in scientific training and careers.

The following proposition could be tested to increase understanding of the role of generalist skills.[1]

> *Proposition 3: Opportunities to develop generalist skills during or prior to the doctoral program will be negatively associated with becoming a postdoc.*

Signalling human capital. New doctorate recipients may see postdoc appointments as not only a way to acquire human capital, but also a valuable way to signal their ability through the norms of open science (Dasgupta and David 1994). This explanation is consistent with the high level of academic publishing achieved by many postdocs (Cheung 2008; Corley and Sabharwal 2007; Kyvik and Olsen 2008). Dasgupta and David suggest that even scientists who eventually want to work in industrial settings where proprietary research is the norm may seek postdoc appointments that allow them to establish a track record of publications. The potential to use the postdoc appointment to signal human capital already developed suggests the following proposition.

> *Proposition 4: New doctorate recipients with a high proportion of research in the pre-publication stage relative to their number of publications will be more likely to take postdoc appointments.*

Demographic Characteristics

Postdoc appointments have been used to examine the extent to which universal and meritocratic norms prevail in science, as opposed to particularistic norms that judge scientists and their work based on personal characteristics (Reskin 1976; Long and Fox 1995). Demographic factors that have been studied with regard to their relationship to postdoc appointments include gender, race, nationality, age, and discipline. Nationality may also

[1] This proposition could also be explored at the university level from the perspective of Laudel and Gläser's (2008) hypothesis that some universities act as free riders in the training of doctoral students and utilization of postdocs.

moderate the effects of gender and discipline. While the relationship between a demographic characteristic and an outcome is not usually interpreted causally, it can be seen as an indication that particularist norms or social roles influence outcomes.

Gender. Of these demographic characteristics, the most extensively studied has been gender, consistent with the expectation of social role theory that men and women will behave differently base on their distribution into different social roles, especially in the contexts of work and family life (Eagly, Wood, and Diekman 2000). Many studies fail to find significant differences between women and men in the probability of becoming a postdoc (Zumeta 1985; Recotillet 2007; National Research Council 1981; Helbing, Verhoef, and Wellington 1998). Nolan, Buckner, Marzabadi, and Kuck (2008) found that women chemists were less likely to become postdocs. However, many studies do indicate that gender has an effect through interaction with marriage (Zumeta 1985; Curtis and National Research Council 1969; National Research Council 1981), children (Martinez et al. 2007), and spousal employment (Helbing, Verhoef, and Wellington 1998). These interaction effects may be stronger for foreign-born scientists, since social roles vary across cultures (Martinez et al. 2007; Mukhopadhyay and Higgins 1988). Even the interaction effects are sometimes ambiguous in direction. One possible explanation is that in some cases women who have family constraints take postdoc appointments instead of career jobs. In other cases, they may forego postdoc appointments due to family constraints. Women of higher scientific ability might be more likely to find themselves in the first situation and women of lesser ability in the second. It seems prudent for future studies to control for gender and its interactions with marriage and children. Studies that aim to explain the role of gender in postdoctoral appointments should include other variables that are likely to be relevant, such as marital status and parenthood.

US native male scientists may be particularly unlikely to become postdocs due to motivation or opportunity to pursue more highly paid opportunities within and outside of academic science (Black and Stephan 2010; Stephan 2012). Martinez et al. (2007) also found an interaction between nationality, gender, and marriage, with married men from the US being less likely to make accommodations for a spouse's career. This somewhat surprising finding may relate to cultural differences, the fact that non-US respondents had already made the decision to study in a foreign country, or possibly non-US respondents not being sure how to answer the question if the spouse did not have a career. It seems likely that the findings by Martinez et al. would generalize beyond the NIH sample they studied and to the postdoctoral career stage.

> *Proposition 5: Gender* per se *will not have a direct effect on the probability of becoming a postdoc; nationality, gender, and marital status will interact such that married men from the US are least likely to become postdocs, other factors being equal.*

Nationality. For the many graduate students from outside the US, there are also motivations related to the opportunities, incentives, and institutions surrounding scientific career paths in their home countries. Existing research in this area has focused on broad classifications, such as visa status and developing country origins. Students from developing countries have been found to be more motivated to stay in the US because their earnings potential, even as a postdoc, is much higher in the US than in the home country (Lan 2009). Developing countries may also have other undesirable characteristics, such as lack of facilities, isolation, and undesirable political and social conditions (Commitee on Policy

Implications of International Graduate Students and Postdoctoral Scholars in the United States and Board on Higher Education and Workforce 2005).

Doctoral students from some regions and countries are more likely to stay in the US after completing their degree (Thurgood, Golladay, and Hill 2006; Finn 2010). The NSF data analyzed by Thurgood and his colleagues show that doctoral scientists from Europe and Asia are more likely to stay than those from other regions. Within those regions, graduate students from China, India, and Russia are most likely to stay in the US. Since postdoc appointments take place primarily in the US, it seems likely that those who are more likely to stay are also more likely to become postdocs.

On the other hand, some scientists who have opportunities for attractive scientific careers at home may be less likely to become postdocs in the US. This may be especially true if, as described by Holzinger (2007), the opportunities in their home country are tied to native-language publications and national professional associations, as is common in continental Europe. Graduate study in the US may fulfill a home country expectation for international study and preclude the need for or benefit from being a postdoc in the US.

Figures 3-6 present stay rates for doctorate recipients by country grouped to illustrate regional patterns, which may correspond to career incentives. Figure 3 illustrates the considerably higher stay rates for new PhDs from the large, rapidly developing Asian nations of China and India compared to the lower stay rates for those from smaller Asian nations.

Figure 4 shows the stay rates for new PhDs from Anglo-Saxon and other European nations. The stay rates appear noticeably higher for Eastern Europe, but the pattern for Anglo-Saxon and continental nations is not clear. Figure 5 shows only the UK, Australia, Canada, and the continental European nations. Consistent with Holzinger's (2007) distinction between Anglo-Saxon and continental European models, France, Germany, and Spain do have lower stay rates. Greece, which might be expected to follow the same pattern, starts out with a higher stay rate but has decreased to a low rate within four years. Italy's higher stay rates may reflect barriers to reintegration into the Italian science community (Gill 2005). The UK, Canada, and Australia all have high initial stay rates, but Canadian and Australian stay rates drop sharply after the second or third year. This pattern is consistent with a postdoctoral appointment in the US followed by return to the home country or relocation to a third country. Disaggregated data for The Netherlands and Scandinavian nations, hypothesized to follow the Anglo-Saxon model, would help confirm the pattern. Qualitative and policy research would be useful to understand apparent outliers like Italy and Greece.

Figure 6 shows stay rates for Latin American countries. New PhDs from Argentina and Peru have higher stay rates than those from other parts of Latin America. Disaggregated data on more Latin American and developing nations as well as qualitative research could lead to a better understanding of the career incentives and institutions shaping the decisions of Latin American scientists.

The relationship between staying in the US and becoming a postdoc is likely to be endogenous, with those who stay more likely to become postdocs and those who become postdocs more likely to stay. The more interesting question is about how the underlying structure of national innovation systems and scientific and academic careers in the home country influences the decision of foreign scientists to pursue a career in the US. Quantitative data document national patterns of immigration and economic motivations have been demonstrated empirically. However, little is known about qualitative and institutional aspects of international postdocs and the approach to such questions is largely speculative at this time.

Foreign students from different disciplines vary in their likelihood of remaining in the US after completing the PhD (Commitee on Policy Implications of International Graduate Students and Postdoctoral Scholars in the United States and Board on Higher Education and Workforce 2005). This finding can be attributed to the demand for specific expertise and the quality of science in those disciplines in the US. Conversely, demand for specific skills in foreign students' home countries will also play a role. Since the US is the primary location of postdoctoral appointments, it seems likely that foreign students in disciplines that are in greater demand in the US will be more likely to become postdocs.

Empirical evidence supports the role of temporary visa status as an indicator associated with postdoctoral study, independent of the effect of nationality (Lan 2009). Permanent visa status confers a number of advantages to a job seeker that increase the probability of receiving a career position rather than a time-limited postdoc appointment.

> *Proposition 6: Regional patterns of institutions and incentives associated with scientific careers and other home-country political, cultural, and economic characteristics will be systematically associated with the probability of becoming a postdoc, with students from small Asian, continental European, and most Latin American nations being less likely to become postdocs.*

Other demographic characteristics. Although one study found that US underrepresented minorities (African-Americans, Hispanics, and Native Americans) were less likely to become postdocs, possibly due to the greater availability of alternative employment at higher pay (Zumeta 1985), more studies conducted over 30 years have failed to find an effect by race (National Research Council 1981; Fiegener 2009; Thurgood, Golladay, and Hill 2006). The most common finding, especially in more recent studies, has been that race does not influence the probability of becoming a postdoc for underrepresented minorities earning a doctoral degree. However, analysis of racial effects is limited by the small number of minority postdocs identified in even large surveys.

Older doctorate recipients have been found to be less likely to become postdocs (Zumeta 1985; Recotillet 2007), usually interpreted to indicate that older PhDs are more likely to have financial obligations that motivate them to take higher-paying positions. However, one study found this relationship to apply only to fellowships and not to research associate postdocs hired with grant funding (McGinnis, Allison, and Long 1981).

As discussed earlier, opportunities to develop generalizable skills may be negatively related to becoming a postdoc. New PhDs who had work experience before entering their doctoral program or who spent more time as doctoral students may have had more opportunities to develop these skills. Since work experience and additional years of study both take time, they are likely to be correlated with age and may mediate the effect of age, at least partially. Although age has been found to be negatively associated with becoming a postdoc, the mechanism of its effect is not yet clear.

Discipline. The most straightforward way discipline has been related to the probability of becoming a postdoc is through labor market conditions. Postdoc appointments are frequently interpreted as a response to a lack of career opportunities, especially in academia (Stephan and Ma 2005). Graduate students who perceive a lack of career opportunities might be more likely to plan to become postdocs, and graduates who actually encounter a lack of career opportunities might be more likely to in fact become postdocs. The relationship between perceived and actual career opportunities was explored by Fox and Stephan (2001). While the most obvious way to study labor market effects would be to observe longitudinal trends, it might also be possible to observe this effect by discipline, if there is variation in the labor markets for different disciplines. Such differences in job opportunities may be observable at the level of specific fields within broad disciplinary groupings like life sciences.

Proposition 7: A large number of new doctorate recipients relative to the number of academic positions available will be positively associated with becoming a postdoc.

Postdoc appointments are more likely in some fields than in others. In addition to labor market factors, this may also be due to the type of knowledge involved in that specific field. At the most basic level, this has been attributed to some fields having more material to master (Curtis and National Research Council 1969). More specifically, postdoc appointments may be more likely in more highly specialized fields or those closely tied to biological systems (National Research Council 1981). Biochemistry has long had a particularly high prevalence of postdoc appointments (Nerad and Cerny 1999), possibly due to its inherent connection to two disciplines. Postdocs may also be more common in pure sciences like chemistry or physics than in transfer fields where basic and applied work are integrated, such as computer science and mechanical engineering (Zubieta 2009).

There have been numerous attempts to create conceptual maps of science. It might be possible to use such a map to predict the effect of scientific discipline on the paths of scientific careers, including the prevalence of a postdoctoral career stage. Klavans and Boyack (2009) have synthesized prior approaches to create a consensus map of science. They place biochemistry at one end and mathematics and computer science at the other. This configuration is consistent with the relative prevalence of postdoc appointments in those fields—with high prevalence in biochemistry and low prevalence in math and computer science.

It is also possible that the timing of specific scientific discoveries could make postdoc appointments particularly desirable (Kuhn 1962; Stephan and Levin 1992). Breakthroughs or paradigm shifts within a field could make a postdoc appointment an opportunity for a scientist to become one of the first in a new regime rather than one of the last trained under an old regime. This is a speculative area of inquiry, but could potentially lead to rich models of how knowledge structures relate to the structures of careers and professions.

Proposition 8: The knowledge content of scientific disciplines will be related to the prevalence of postdoc appointments in that discipline in a predictable way, such as through complexity, specialization, or change.

Alternatively and more concretely, postdoc appointments could address a mismatch between doctoral training and existing job opportunities. For example, a biochemist might seek a postdoc appointment that develops skills in biomedical engineering. This situation could be more likely to result when training takes place in disciplinary departments but job opportunities are in interdisciplinary settings (Chang et al. 2005). Motivation to change fields may therefore be rationally motivated by labor market conditions. Data about career patterns of recent graduates would allow for a test of the following proposition.

Proposition 9: Being in a field where recent doctoral graduates have frequently changed fields will be positively associated with becoming a postdoc.

UNIVERSITY LEVEL

Studies of university-level factors influencing postdoc appointments have most frequently emphasized the role of prestige. However, other features of the doctoral institution, such as location, may also influence the likelihood of becoming a postdoc.

Prestige. Perhaps because the scientific enterprise is highly stratified, prestige is the most widely studied university-level characteristic associated with postdoc appointments. In this context, stratification means the structure of the scientific enterprise and the relative prestige and influence of its parts. One of the most fundamental ideas in the study of stratification of science is the theory of cumulative advantage, often referred to as the "Matthew effect" (Merton 1968). Cumulative advantage refers to the tendency for scientists who have already achieved recognition to have an advantage over unknown scientists in achieving future recognition. This leads to a concentration of prestige in a small number of scientists and institutions.

Psychological, cultural, and structural mechanisms of cumulative advantage were proposed by Cole and Cole (1973). Rosen (1981) proposed an alternative model of stratification based on high returns to small increments in ability at the top of the ability range. While different mechanisms have been proposed, all of these models address the observation that science is highly stratified with prestige and influence concentrated among a few top individual and institutional contributors.

Several studies have found that new PhDs from more prestigious universities were more likely to become postdocs (Zumeta 1985; Curtis and National Research Council 1969; Zumeta 1984). However, Curtis found that the relationship with prestige was weaker in biological sciences and Zumeta found that the relationship grew weaker over time. It is possible that this relationship will not hold for a life sciences sample today, but the relationship has been common enough in other studies that the hypothesis should be tested. Further, while prestige may be found not to be a strong predictor of which life sciences doctorates become postdocs, prestige of the doctoral institution is known to have strong effects on other career outcomes for scientists (Su 2011; Zubieta 2009; Bedeian et al. 2010;

Burris 2004). Burris suggests that a more prestigious postdoctoral institution may take the place of the doctoral institution in explaining future career outcomes.

A strong role for prestige is also supported by the finding that predoctoral publication productivity typically does not predict whether a graduate takes a postdoc appointment (Hornbostel et al. 2009; McGinnis, Allison, and Long 1981; Su 2011), although Reskin (1976) found it predicted prestigious postdoctoral fellowships for men only. Productivity is one of the most plausible alternative explanations to prestige, but evidence for its effect is weak. A direct effect of prestige on funding decisions does not seem to be the mechanism through which prestige influences later outcomes. Like many other studies of peer review cited by Bornmann and Daniel (2006), Viner, Powell, and Green (2004) do not find that prestige of the doctoral or proposed postdoctoral institution had an effect on funding decisions. While the mechanism is uncertain, prior research has generally supported the idea that graduates from prestigious universities will be more likely to become postdocs.

Features of the doctoral institution. There has been considerably less attention paid to the role of features of the doctoral institution other than prestige. For example, the current literature does not seem to address the effect that interaction with postdocs as a graduate student might have on the probability of becoming a postdoc. It is common for doctoral students and postdocs to work together in labs and for postdocs to play a role in training and supervising graduate students (Akerlind 2005; Vogel 1999). The nature of doctoral student-postdoc interactions as well as their frequency may influence attitudes toward postdoc appointments. Conditions for postdocs vary a great deal from campus to campus (COSEPUP 2000). It seems likely that doctoral students at universities where postdocs are generally satisfied with their appointments would be more likely to become postdocs themselves. This is a potentially interesting question in particular because universities are putting structures in place to improve conditions for postdocs and to incorporate them into the university community, sometimes as a result of postdocs' organizing activity (Gerwin 2010). Such structures might further institutionalize the postdoctoral career stage by increasing interest in postdoc appointments among these institutions' own graduates. Postdoctoral organizing activity and administrative oversight are relatively new phenomena, so there is not yet empirical support for specific hypotheses about their effects. Institutions that make extensive use of postdocs themselves might produce graduates who are more aware of opportunities for postdoc appointments or to consider such appointments an expected part of the research career.

However, Stephan (2012) interprets the high frequency with which graduates of small liberal arts colleges pursue graduate training in science as perhaps resulting from their lack of familiarity with the sometimes unpleasant realities of scientific careers. This phenomenon might also carry over to doctoral students' familiarity with the realities of postdoc appointments, with the following implication.

> *Proposition 10: Graduate students at universities where there are many postdocs may be more likely to become postdocs themselves, moderated by the level of satisfaction of the postdocs.*

Location. Postdocs are highly concentrated in prestigious universities that receive large amounts of research funding (NSF, 2007, 2010). These universities are in turn geographically concentrated, especially in Boston and the Bay Area.

Postdoc appointments can play different roles in scientific careers. For some, they may expand networks beyond the doctoral program. For others, they may provide an opportunity to work in one's field of study that is compatible with personal obligations, such as a spouse's career (Martinez et al. 2007). New PhDs from universities in metro areas with many postdocs at multiple institutions may be able to accomplish both of these goals at the same time. On the other hand, graduates of universities that are not located in college clusters would need to relocate, perhaps half-way across the country, for a time-limited position. These geographic considerations imply that postdoc appointments may be more common for students when there are many such opportunities available at other institutions in the local area.

> *Proposition 11: The likelihood of becoming a postdoc will be positively related to the number of postdoctoral appointments available in the local area.*

CROSS-LEVEL INTERACTIONS

Individual-level factors may interact with university-level factors to make a postdoc position more or less likely. While research on such interactions has been limited, the literature does suggest some likely possibilities. This section briefly considers three such potential interactions.

Ability and Prestige

Scientific careers are characterized by cumulative advantage (Merton, 1968). This implies that outcomes will be better for those who combine multiple advantages, such as ability and affiliation with prestigious institutions. In discussing the hypothesized relationship between ability and the likelihood of becoming a postdoc, a nonlinear relationship seemed likely, with those of highest and lowest ability most likely to become postdocs. Prior research has identified non-linear institutional patterns in the careers of life scientists (Smith-Doerr 2006). Perhaps those students who combine high ability with high prestige doctoral institutions will be especially likely to become postdocs, as will those of low ability at low prestige universities. In studying a sample of mid-to-high prestige institutions, high ability students at high prestige schools might be expected to be the most likely to become postdocs, as they may be well positioned to persist to the eventual goal of a faculty position. Cumulative advantage, well-established in the sociology of science, implies that those who have already benefitted from high ability and the many advantages of a prestigious doctoral program will continue to accrue advantages throughout their careers, lending support to the following proposition (Merton 1968).

> *Proposition 12: Individual ability and institutional prestige will interact such that high ability individuals at high prestige institutions are most likely to become postdocs.*

Citizenship and Location

Foreign graduate students are at a disadvantage in their ability to tap into informal labor markets in the US (Wei, Levin, and Sabik 2009). In discussing the relationship between location of the doctoral institution and the likelihood of becoming a postdoc, it seemed plausible that proximity to postdoctoral opportunities would increase the probability of becoming a postdoc. This effect may be stronger for non-US students. The concentration of postdocs on the coasts, where immigrant populations are also concentrated, may also contribute to this effect. While postdocs are clearly concentrated on the coasts, there is empirical evidence of their disadvantage in the labor market, so at this point propositions about the interactions of those factors are speculative.

> *Proposition 13: Location of doctoral institution and citizenship will interact in such a way that non-US students in doctoral programs far from other postdoc opportunities will be least likely to become postdocs.*

Gender and Location

Postdoc appointments may be especially desirable when they combine the ability to affiliate with a new institution with the ability to stay in the same geographic location. This effect may be stronger for women, since they are more likely to seek an appointment that is compatible with a spouse's career (Nerad and Cerny 1999). Prior research has identified the greater propensity for women scientists to concentrate in college clusters, in comparison to their male colleagues (Kulis and Sicotte 2002). It may be possible to generalize from these factors known about women's careers to the context of postdoc appointments, anticipating that doctoral university location will have different effects on male and female scientists.

> *Proposition 14: Location of doctoral institution and gender will interact such that women in locations where there are many postdoc appointments will be most likely to become postdocs.*

SUMMARY

Research about why new doctorate recipients become postdocs identifies influences at the individual and university levels. A better understanding of which graduate students become postdocs would be of value to those who employ, fund, and organize postdocs.

While there is information about trends in certain key motivations for postdoc appointments (see figure 1), the information about motivations is still fairly superficial. Because the demographic variables that have been the focus of most prior research about why people become postdocs serve as indicators but do not explain mechanisms, it would be beneficial for future research to explore some potential mechanisms behind this career choice. For example, future research could examine the relative importance of knowledge acquisition and network development in the choice of a postdoctoral appointment. Further, it would be useful to advance understanding of the role that home country career incentives and institutions play in the decisions of international graduate students about whether to become postdocs in the US. While higher earning potential in the US explains many developing-country nationals' decisions to stay, less is known about why some choose to return and the decisions made by scientists from developed countries. A third individual perspective to consider for future studies is the influence of personal characteristics such as taste for science, disposition, and knowledge of career options.

Another potentially interesting direction for individual-level research would be to examine which scientists benefit from becoming postdocs. Scientists report many benefits from postdoc appointments (see figure 2), but these self-reported benefits, primarily in specialized knowledge, are not clearly tied to outcomes. It would be useful to test outcomes explicitly. The concept of taste for science could potentially be employed to assess the benefits of becoming a postdoc. By providing a way to approximate the value of the non-monetary rewards of scientific careers in monetary terms, both monetary and non-monetary benefits could be considered in evaluating career outcomes from postdoc appointments.

University-level influences beyond prestige are also a fruitful area for future study. Little is known about how characteristics of doctoral programs influence who becomes a postdoc. Factors such as location, teaching and mentoring of doctoral students, interaction with current postdocs, and career placement services may influence who becomes a postdoc.

The choice of research questions at both the individual level and the university level should be guided by a consideration of how policy instruments could influence the nature of postdoc appointments. Policy interventions could be designed to encourage those most likely to benefit from postdoc appointments to pursue them and to do so with accurate information about how to seek an appropriate appointment and maximize the opportunity it provides. Targeted interventions to provide the right information to doctoral students at the right time could improve decision making and utilization of resources during the doctoral and postdoctoral years.

Chapter 3

Conceptual Model of Individual Motivations for Postdoc Appointments

Both individual and institutional factors are believed to influence which scientists take postdoc appointments. This chapter presents a conceptual model of individual decision making with regards to the choice to take a postdoc appointment, an area that is not yet well understood. Prior empirical work provides limited information about why individual doctorate recipients become postdocs based primarily on demographics (Helbing, Verhoef, and Wellington 1998; McGinnis, Allison, and Long 1981; Nolan et al. 2004; Nerad and Cerny 1999) and ability measures (Reskin 1976; Su 2011; Zumeta 1985, 1984).

This chapter frames the question of why people take postdoc appointments as one of individual motivation. Motivational factors associated with the decision to take a postdoc appointment in prior research include interest in an academic career, typically understood to mean a tenure-track faculty position with an emphasis on research, and perception that a postdoc appointment is a career prerequisite (Fox and Stephan 2001). Long term career goals appear to motivate the decision to pursue a postdoc appointment after graduation. The most frequently cited motivation for taking a postdoc appointment has long been pursuit of a career for which a postdoc appointment is understood to be a prerequisite (Foley 2008). The postdoc appointment may be a prerequisite to further develop S&T human capital (Davis 2009; Bozeman, Dietz, and Gaughan 2001) or to signal human capital that has already been developed through scholarly publications (Dasgupta and David 1994).

Taking a postdoc appointment because of interest in a faculty research career can be problematic, however, because few faculty positions are available. Tenure may be achieved by fewer than 30% of even a select group of postdocs in the life sciences (Levitt 2010).

By placing the decision to pursue a postdoc appointment in a framework based on the social psychological theory of planned behavior, the current chapter contributes to understanding how this decision is influenced by individual-level motivations (Fishbein and Ajzen 2010; Ajzen 1991). In the theory of planned behavior, demographic and ability factors previously associated with postdoc appointments are expected to exert their effect through these attitudes, norms, and perceptions.

This chapter is organized in two sections. The first section describes Ajzen′s (1991) theory of planned behavior and evaluates its consistency with economic rationality. The second section applies the theory of planned behavior to the context of scientists′ postdoc appointments and advances four specific propositions about applying the model in this context. The third section concludes with discussion and directions for future research.

THEORY OF PLANNED BEHAVIOR

Ajzen′s (1991) theory of planned behavior integrates behavioral attitudes, social norms, and perceived behavioral control to explain intentional behavior. The behavioral attitudes variable incorporates beliefs about the consequences of engaging in a behavior. The social norms variable includes the individual′s perceptions of influential others′ beliefs about the behavior. The perceived behavioral control variable represents the extent to which an individual feels confident in the ability to engage in the behavior.

The theory of planned behavior rests on considerable support for the finding that intention is a reliable antecedent to behavior (Ajzen 1988; Ajzen and Fishbein 1980;

Sheppard, Jon, and Warshaw 1988). While past behavior is often the best predictor of behaviors that are repeated and frequent, behaviors that take place infrequently are often predicted by intention. Intention is useful to predict preparatory activities as well as the outcome of interest when the behavior is not completely under the individual′s control. The incorporation of perceived behavioral control into the earlier theory of reasoned action better accounts for behaviors that are not completely under the individual′s control, such as labor market activity (Ajzen 1991).

The theory of planned behavior has been applied to a wide range of intentional behaviors, including many studies of career-related intentions. In contexts similar to scientific careers and postdoc appointments, the theory has been found to explain intentions to work for the National Health Service as an allied health professional (Arnold et al. 2006), to seek temporary employment (Van Hooft and De Jong 2009), to enlist in the military (Schreurs et al. 2009), and to remain in the US after graduation (Baruch, Budhwar, and Khatri 2007). Occupational intentions have also been studied using the theory of planned behavior by Giles and Larmour (2000), Giles and Rea (1999), Norman and Bonnett (1995), and Song et al. (2006). Other relevant planned behavior studies include those focused on education (Davis et al. 2002; Meyer 2002; Archer et al. 2008), entrepreneurship (von Graevenitz, Harhoff, and Weber 2010; Engle et al. 2010; Krueger and Carsrud 1993; Krueger, Reilly, and Carsrud 2000; Carr and Sequeira 2007), and investment (East 1993).

Relationship to Economic Rationality

Science policymakers have often approached research about the scientific labor force from the perspective of economic rationality (e.g., Freeman and Goroff 2009). Excessive rationality has been one criticism of the theory of planned behavior (Reyna and Farley 2006;

Gibbons et al. 1998), leading to considerable debate (Fishbein and Ajzen 2010). In response to these criticisms, Fishbein and Ajzen qualify their model as rational only in the sense that attitudes, norms, and perceived behavioral control follow logically from a person′s beliefs. They also acknowledge, however, that these beliefs can be intuitive, biased, or erroneous. Even the theory′s critics acknowledge its appropriateness for deliberative decisionmaking. Fishbein & Ajzen defend the application of their theory to both rational behavior and a wide variety of spontaneous behaviors, while acknowledging limitations for behaviors like reflexes and addiction.

Intentions formed according to the theory of planned behavior have been compared to an individual conducting a personal cost-benefit analysis and formulating an appropriate intention based on the result (Conner and Armitage 1998). Similarities between the theory of planned behavior and economic rationality can be seen by examining the decision to pursue a doctoral degree from both perspectives. An economically rational explanation of the decision to pursue a doctoral degree has been provided by Breneman, Jamison, and Radner (1976), who assumed that the student made the decision like an investor interested in both monetary and non-monetary returns from acquiring a necessary occupational credential. Breneman and colleagues also acknowledged, however, that the student based the assessment of costs and benefits on limited information (cf. Mangematin 2000).

This economic model of the decision to pursue a doctoral degree shares several characteristics with a model based on the attitude, norm, and perception components of the theory of planned behavior. Individuals′ attitudes toward a behavior can include both monetary and non-monetary preferences. These attitudes also include beliefs, potentially based on imperfect information, about the consequences of pursuing the degree. Perceived behavioral control further incorporates the prospective student's limited available information about resources and opportunities to complete the degree. In economic terms, the individual is making a decision with some degree of risk based on incomplete and possibly inaccurate information. For example, students are often unaware of the labor market they will encounter upon completion of the degree. Fox and Stephan (2001) have observed a complex relationship among reality, perceptions, and preferences in scientific labor markets, concluding that new doctorate recipients' perceptions were only partially accurate. The theory of planned behavior further implies that some information comes from the social norms observed in influential others. With its emphasis on beliefs and perceptions, the theory of planned behavior integrates the individual's lived experience with economic rationality.

Application to Postdoctoral Appointments

An explanation of the decision to pursue faculty research careers and postdoc appointments based on the theory of planned behavior's attitudes, norms, and perceptions draws support from the theory's applicability in employment, education, and other related contexts. The theory suggests a model in which the intention to pursue a faculty research career leads to the intention to pursue a postdoc appointment (see figure 7). The intention to pursue a faculty research career is expected to depend on behavioral attitudes, social norms, and perceptions of control over obtaining a university research position. Intention to pursue a faculty research position is the model's key determinant of intention to pursue a postdoc appointment.

A near-term intention to pursue a postdoc appointment upon graduation arises from the intention to seek a faculty research position. Of course, the student's ultimate success in attaining a faculty position will depend not only on intentions but on the conditions of the labor market. During the doctoral program, these long- and short-term intentions may influence preparatory behavior such as completion of the doctorate, publication of findings, and exploration of alternate careers. This preparatory behavior is one reason to study intentions regardless of whether the student eventually obtains a faculty research position.

The remainder of this section examines the decision to pursue a faculty research career and a postdoc appointment in relation to each of the three components of the theory of planned behavior: behavioral attitudes, social norms, and perceived behavioral control.

Behavioral attitudes. Behavioral attitudes arise from beliefs through an expectancy-value model with two components: belief strength and outcome evaluation (Fishbein and Ajzen 2010). An attitude reflects a person's expectation that a behavior will lead to an outcome and the value a person places on that outcome. More formally, an attitude is "a latent disposition or tendency to respond with some degree of favorableness or unfavorableness to a psychological object [such as a behavior]," (Fishbein and Ajzen 2010, 76). A behavioral attitude arises from a belief, "the subjective probability that an object has a certain attribute" (Fishbein and Ajzen 2010, 96). The beliefs that shape behavioral attitudes do not need to be accurate or rational to be influential. However, attitudes are more rational than the related but more emotional concept of affect, which a person often experiences more generally rather than with respect to a specific object or behavior (Fishbein and Ajzen 2010).

The attitudes most relevant to a particular behavior being studied should be compatible with the target, action, time, and context of the behavior (Fishbein and Ajzen 2010). In the case of doctoral students' career intentions, the relevant behavioral attitudes include the qualities doctoral students prefer in their future careers and their beliefs about whether faculty research positions have those qualities.

Qualities identified as influential by prior work include the norms and lifestyle that attract scientists to academic careers. Scientists have expressed preferences for work consistent with the Mertonian norms: universalism, communitarianism, organized skepticism, and objectivity (Anderson et al. 2010; Merton 1973). Challenge, freedom, autonomy, and a role in social change have been found to motivate people to pursue academic careers (Lindholm 2004). Preferences for challenge, freedom, and the ability to participate in the scientific community are associated with the concept of taste for science, which implies that a scientist will accept lower compensation to work in an environment consistent with scientific norms (Roach and Sauermann 2010; Stern 2004). Freedom and autonomy, ability to do science for its own sake, free dissemination of knowledge, and interaction with broader scientific community are norms doctoral students associate with academic careers (Mendoza 2007).[2]

In addition to scientific norms, general features of job quality, such as job security and compensation, are lifestyle factors that often attract people to academic careers (Jencks, Perman, and Rainwater 1988; Finkelstein 1984). The importance students place on these aspects of job quality and their beliefs about the quality of faculty research positions are also relevant to behavioral attitudes.

The following proposition summarizes the role behavioral attitudes are thought to play in doctoral students' career intentions.

> *Proposition 1: Doctoral students who perceive that the characteristics of faculty research positions match their own career preferences will express a stronger intention to pursue faculty research careers.*

[2] Although academic scientists also engage in commercial activities with their corresponding norms, the graduate students studied by Mendoza (2007) put greater emphasis on the traditional norms.

Social norms. Ajzen (1991) describes his social norms variable as "[t]he likelihood that important referent individuals or groups approve or disapprove of performing a given behavior" (p. 195). These norms can be injunctive, expressing influential others' approval or disapproval, or descriptive, expressing influential others' actions with respect to the target behavior (Fishbein & Azjen 2010). Both injunctive and descriptive norms are applied subjectively, that is, as perceived by the person whose intentions are being studied. Injunctive norms are believed to influence intentions directly. Descriptive norms are believed to influence intentions directly and indirectly through both injunctive norms and perceived behavioral control.

From a rational choice perspective, social norms can be seen as a check on self-interest potentially enforced by sanctions (Boudon 2003). Information, reward, coercion, legitimacy, expertise, and referent power are six bases of power thought to motivate compliance with social norms (Raven 2008). Social norms' influence on intention has generally been assumed to depend on the subject's motivation to comply. However, the role of motivation to comply does not receive strong support from empirical evidence. In practice, range restriction may result from subjects inherently choosing people who motivate them to comply with social norms when identifying influential others as referents (Fishbein and Ajzen 2010).

Doctoral students are believed to acquire social norms through two forms of socialization. First, they are socialized into their role as graduate students within an academic department. Socialization into the graduate student role includes the tasks of intellectual mastery, developing a realistic sense of departmental activities, and integration into the department (Golde 1998). Second, students begin a stage of anticipatory socialization into their profession, usually conceived as an academic career (Mendoza 2007). Anticipatory socialization into the academic career gains momentum once the student has achieved doctoral candidacy and is focused on completion of dissertation research (Tierney and Rhoads 1994). At the dissertation stage, students become more aware of the academic department′s core functions of publishing and basic research (Mendoza 2007). Awareness of social norms does not necessarily lead to their adoption (Antony 2002), which may depend on motivation to comply. Referent others promoting the socialization of doctoral students into academic norms and careers include influential professors (Finkelstein 1984), graduate advisors and faculty (Lindholm 2004), and faculty and other students (Weidman and Stein 2003).

Some of the social norms observed during this socialization process relate to differences between industry careers and academic careers (Mendoza 2007). A qualitative study of science and engineering doctoral students and postdocs at three universities on the West Coast of the US described students′ socialization as a combination of three cultures: strongly noncommercial, overlapping commercial and noncommercial, and strongly commercial (Szelenyi 2007). Noncommercial culture is associated with the Mertonian norms presented earlier (Merton 1973). Noncommercial norms can be contrasted with counternorms of emotional commitment, particularism, secrecy, self-interest, and organized dogmatism (Mitroff 1974) and with commercial norms of academic capitalism (Slaughter and Rhoades 2004) and academic entrepreneurship (Shane 2004).

Social norms and the extent to which doctoral students are motivated to comply with them are expected to influence career intentions. The socializing influences surrounding doctoral students lead to the following proposition:

Proposition 2: Doctoral students who perceive that social norms in their lab favor faculty research careers will express a stronger intention to pursue such careers.

Perceived behavioral control. Perceived behavioral control refers to "... the extent to which people believe that they are capable of performing a given behavior" (Fishbein and Ajzen 2010, 154). Perceived behavioral control helps explain planned behavior because people rarely form intentions to do something if they believe it to be impossible. Perceived behavioral control consists of two factors, capacity and autonomy.[3] Capacity refers to capability or power to perform a behavior and autonomy refers to the extent to which the behavior is under the subject's control (Fishbein and Ajzen 2010). Again, capacity and autonomy are applied subjectively based on the subject's perceptions. With the addition of perceived behavioral control to the earlier theory of reasoned action based on attitudes and norms, the theory of planned behavior more effectively models behavior not fully under the subject's control (Ajzen 1991). Intention to engage in a behavior completely under the subject's control could potentially be explained by attitudes and norms alone. When a subject does not have complete control over a behavior, perceived behavioral control is more important for prediction of the subject's behavioral intention.

Control's influence on behavior has been described using a wide variety of terms. Two of the most widely known terms are locus of control (Rotter 1990) and self-efficacy (Bandura 1997, 1977). Locus of control has its conceptual origins in social learning theory and refers to an individual's generalized expectation that events are under his own control (internal locus of control) or determined by influences beyond his control (external locus of control) (Rotter 1990). Locus of control is stable within individuals and across contexts. Self-

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[3] This use of the word autonomy should not be confused with its use earlier to refer to a desirable characteristic of a scientific career.

efficacy, or “beliefs in one′s capabilities to organize and execute the courses of action required to produce given attainments” (Bandura 1997, 3), was originally considered to be a similarly generalized concept (Bandura 1977). However, more recent work has considered self-efficacy to be specific to a given context (Bandura 1997). Thus, self-efficacy and perceived behavioral control are conceptually similar, although they are often operationalized differently (Fishbein and Ajzen 2010).

Perceived behavioral control also differs from actual control. Perceptions of capacity and autonomy are often influenced by actual levels of ability, resources, and opportunity, but intentions are believed to be formed based on perceptions—accurate or not—rather than actual conditions (Ajzen 1991). When the theory of planned behavior is applied in studies where both behavioral intentions and behavioral outcomes are measured, perceived behavioral control affects behavior indirectly through intentions and directly, to the extent that perceptions reflect reality.

To apply the concept of perceived behavioral control to doctoral students′ career plans, it makes sense to consider students′ perceptions of their capacity to obtain a faculty research position and the extent to which they perceive that obtaining one is under their control. It is at this point in the model where structural concerns, such as labor market conditions, enter the model, albeit mediated by the student′s perceptions. Perceptions about the scientific labor market seem to matter even when they only partially reflect reality (Fox and Stephan 2001). The model predicts that students who perceive more opportunities to obtain a faculty research position will be more likely to pursue such a position.

Applicants are generally understood to exert lower levels of control over obtaining faculty positions than over obtaining postdoc appointments (Fox and Stephan 2001; Zubieta

2009). Faculty positions are generally scarce, highly competitive, and filled through a complex formal selection process, resulting in a low level of control (Vick and Furlong 2008). Postdoc positions are more widely available and often filled informally (Wei, Levin, and Sabik 2009). Because obtaining a postdoc appointment is assumed to be within most students′ control, perceived behavioral control is expected to be less relevant to understanding pursuit of postdoc appointments than it is to faculty appointments. Career intentions are therefore thought to depend on perceived behavioral control in the following way:

> *Proposition 3: Doctoral students′ perceived control will be positively associated with intention to pursue a faculty research career.*

Postdoc appointments are often described as prerequisites for faculty research careers. When asked their reasons for taking postdoc appointments, scientists have long reported that they saw the appointment as expected for their intended career (Foley 2008). While postdoc appointments are also available in industry, government, and non-profit organizations, most take place at universities (National Science Board 2010). Postdoc appointments as prerequisites for faculty research careers can be understood through human capital development, human capital signaling, and labor market surplus perspectives (Bozeman, Dietz, and Gaughan 2001; Dasgupta and David 1994; Mishagina 2009).

From a human capital development perspective, individuals invest in training because of the potential for future returns (Becker 1975). The concept of human capital is often applied to scientists as S&T human capital, incorporating tacit knowledge and social capital in addition to the more concrete aspects of skill development (Bozeman, Dietz, and Gaughan 2001). Returns to the investment in human capital can be either monetary or non-monetary, such as an agreeable work environment (Breneman, Jamison, and Radner 1976). The S&T

human capital development explanation gains support from scientists who report that they have benefitted from their postdoc appointments through gains in field-specific skills (Foley 2008) and from survey data where postdocs describe the value they place on opportunities to develop generalizable skills such as proposal writing and project management (Davis 2009). Doctorate recipients seek postdoc appointments because they do not yet have the skills or social capital to compete for, or possibly even to perform, their desired career position. Such a skill deficit is sometimes seen as a deficiency in the doctoral program (Laudel and Gläser 2008). In any case, the human capital development theory holds that postdoc appointments are prerequisites because they serve a legitimate developmental purpose.

Postdoc appointments may also be an opportunity to signal existing human capital to potential employers. The publication of research results that is a central feature of academic science provides an opportunity for postdocs to establish a publicly available track record of achievement (Dasgupta and David 1994). Dasgupta and David speculate that this human capital signaling is valuable even if the scientist eventually wants to work in industry, where publication of research findings is less common. Postdocs′ high publication productivity supports the human capital signaling perspective (Corley and Sabharwal 2007; Vogel 1999). Human capital signaling theory considers the postdoc appointment to be an opportunity to resolve an information asymmetry; the postdoc knows the extent of her talent and uses this time to demonstrate it (Zubieta 2009).

Postdoc positions are treated as queues or holding patterns from a labor market surplus perspective (Mishagina 2009). This perspective, in which scientists in postdoc appointments await career positions, is supported by evidence from special situations, such as the periods following the Vietnam War, the Cold War (Regets 1998), and the doubling of

NIH funding between 1998 and 2003 (Freeman and Van Reenen 2008). Labor market surplus is not generally considered a complete explanation for the increasing prevalence of postdoc appointments (Regets 1998), although it has been identified as a contributing factor (Stephan and Ma 2005).

Human capital development, human capital signaling, and labor market surplus are not mutually exclusive. Each perspective may play a part in explaining the role of postdoc appointments as career prerequisites. Each perspective provides a potential explanation for the empirical evidence that postdoc appointments are considered prerequisites by many scientists. Thus, the intention to pursue a postdoc appointment is expected to depend on both intention to pursue a faculty research career and on the belief that a postdoc is a prerequisite for that career.

> *Proposition 4: Plans to pursue a postdoc appointment will be positively associated with intention to pursue a faculty research career and the belief that postdoc experience is required.*

DISCUSSION

The theory of planned behavior provides a useful model of doctoral students′ intentions to pursue faculty research careers. Models based on the theory of planned behavior often suggest targets for policy intervention. If the theory of planned behavior explains doctoral students′ decisionmaking regarding faculty research careers, it would suggest a number of policy interventions.

Science policymakers are often stymied by the seemingly contradictory problems of industry′s cry of a scientific talent shortage and scientists′ cries of a labor surplus (National Academy of Sciences 2007, 2010; Teitelbaum 2008). While some policy interventions aim to change the behavior of organizations through regulation and funding, policy interventions aimed at individual scientists-in-training may also address these concerns. Interventions to change behavior arise from four characteristics of the theory of planned behavior (Fishbein and Ajzen 2010). The theory clearly focuses on the target behavior's determinants. It is also parsimonious, explaining behavior using relatively few variables. By focusing on beliefs, it has a logical connection to changing behavior by providing information. Finally, its measurement methods adapt readily to monitoring policy effectiveness.

Policy interventions suggested by this model include identifying avenues to inform early-career scientists' choices, given the scarcity of faculty positions and the increasing prevalence of postdoc appointments. To the extent that students may hold erroneous, favorable beliefs about academic research positions, better information can improve their career decisions by changing behavioral attitudes.

Further investigation of the role of specific behavioral attitudes could also be useful for the development of new models of scientific employment. While behavioral attitudes are formed by comparing preferences with beliefs about the attributes of faculty research careers, it is possible that some of those attributes either exist or could be incorporated into other employment opportunities.

The influence of social norms could also improve career decisions. Departments, labs, and advisors transmit social norms to doctoral students. They may not always provide support for a broad range of scientific activity. For example, some labs may support activities narrowly focused on the advisor's academic career. Most students would benefit from support for a broader range of activities that correspond to the career opportunities currently available. Because opportunities currently available in the labor market respond to market demand, society also stands to benefit from scientists improved knowledge of career options.

For social norms to be influential, the student needs to adopt those norms. Some advisors and labs may be supportive of industry research, but not engage students in such a way that they adopt norms consistent with industry employment. Norms related to working with industry will be less appealing to students if they feel exploited as a source of "cheap labor," encounter barriers or perceive unfairness related to intellectual property issues, or fail to see a benefit to society from industry work (Mendoza 2007).

The effects of perceived behavioral control also suggest some potential interventions. A recent study of entrepreneurship education found that it was possible to improve sorting on intention to start a company by increasing students' knowledge of skill and resource requirements for entrepreneurs (von Graevenitz, Harhoff, and Weber 2010). Doctoral students might also modify their career plans based on additional information about the skill and resource requirements for faculty research positions.

Specifically with respect to the capacity aspect of control, students can make better career decisions if they have accurate information early on about their own ability levels. Initiatives such as the NPA's core competencies program and the promotion of individual development plans for doctoral students are both helpful for these decisions (Davis 2009). This study's findings support expansion of initiatives that help doctoral students better understand their abilities and limitations.

With respect to autonomy, students may also benefit from complete information about the labor market for doctoral scientists and the limited availability of faculty research positions. Students may overestimate the availability of these opportunities while remaining unaware of other career paths. Programs offering professional degrees in law and business conduct alumni surveys and use information about career outcomes to compete for students.

Academic departments offering degrees in science and engineering could adopt a similar practice. Government agencies and professional associations could also expand their role in providing labor market information.

While one obvious place to convey information about the labor market for doctoral scientists is in doctoral degree programs, other options should also be considered. For example, labor market information could be incorporated into the doctoral student recruitment process. Making the information available even earlier, such as during master's or even bachelor's degree programs, could help students make decisions about and prepare for scientific careers before making a commitment to doctoral study.

A final policy issue related to postdocs is the considerable debate about whether they are students or employees, a determination with significant policy and legal implications (Haak 2002). This model could be seen as providing support for treating postdocs as students, since it implies that postdoctoral appointments are undertaken in preparation for a future career.

The theory of planned behavior provides a useful model of how doctoral students in the sciences and engineering form intentions related to their career paths and the decision to pursue postdoc appointments after graduation. The model suggests several directions for future research on the role of postdoctoral appointments in the scientific workforce. The theory of planned behavior may also be useful for investigation of other behaviors relevant to science and technology policy.

A longitudinal study could establish a causal relationship between intention to pursue an appointment and actually seeking or obtaining one. Such a longitudinal study should include the moderating effects of labor market conditions and job search activity. If interventions are conducted to improve career decisions, program evaluation studies should evaluate their effectiveness. It would also be useful to determine whether graduates from some programs are more likely to become postdocs because of student or program characteristics.

The theory of planned behavior could also be used to study other examples of intentional behavior in scientific careers and technology commercialization. For example, it would be a useful framework for examining determinants of invention disclosure by university faculty. Other intentional behaviors of potential interest include migration, publication, patenting, and participation in university-industry partnerships.

Chapter 4

Postdocs and Production of University Research

The production of knowledge is one of universities' main contributions to economic development (Drucker and Goldstein 2007). With federal assessment initiatives such as the Government Performance and Results Act, the President's Management Agenda, and the Performance Assessment Rating Tool, universities are increasingly pressed to maximize this knowledge production under resource constraints (Michelson 2006). In *How Economics Shapes Science* (Stephan 2012), research is portrayed as a production process where knowledge results from labor and capital inputs. With respect to the labor inputs to knowledge production, Stephan poses the questions "Are certain inputs complements while others are substitutes for each other? Does a change in the cost of one input, such as the cost of employing a graduate research assistant, lead principal investigators (PIs) to hire more postdocs and cut the number of doctoral students they support?" (p. 63). As both postdocs and PhD students are employed in producing research, their relative prices may determine the precise mix. This chapter addresses the research question of postdocs' role in the production of academic research, examining whether they serve as substitutes or complements for faculty and doctoral research assistants.

This chapter proceeds in four sections. The first section reviews select literature on substitution and complementarity in relevant production contexts. The second section presents an analytical model of the production function. The third section describes the sample and data used in this study. The fourth section presents results.

Input Substitution and Complementarity in Production

Since the early twentieth century, the US has been in a period of technological change where new technologies have complemented skilled labor, rather than substituting for it as was the case in the nineteenth century (Acemoglu 2000). This complementarity has two implications for the role of postdocs in research production. First, technological advances in the sciences have increased demand for the skilled labor they complement. Postdocs, especially immigrants, and graduate students are relatively easy ways to increase a supply of skilled labor that would otherwise be rather inelastic. Second, postdoc appointments themselves can be thought of as a "technology," broadly defined (Rosenberg and Birdzell 1986). Postdocs may be a skill-biased technology that increases the productivity of faculty and graduate students. Alternatively, postdocs may be substitutes that crowd out faculty or graduate students, as foreign graduate students were found to crowd out native-born males (Borjas 2004). Literature examining substitution in four related contexts is reviewed below: research production, skill level, contingent employment, and immigration.

First, because this study is concerned with the production of research, the literature on the substitutability of other inputs, such as funding sources, in research productivity is reviewed. Table 3 summarizes selected studies of the substitutability of inputs in research production. Numerous studies have examined the phenomenon of government R&D funding potentially crowding out private funding, when it functions as a substitute, and leading to increased private funding, when it functions as a complement. David, Hall, and Toole (1999) reviewed studies of this type and found substitution in about one third of the studies, with substitution more common in US studies and in studies at the line of business or lab level. In a recent study of life sciences R&D, federal and non-federal funding were found to be complementary (Blume-Kohout, Kumar, and Sood 2009). Caloghirou, Kastelli, and Tsakanikas (2004) found that internal knowledge creation and external knowledge seeking contributed to innovation in a potentially complementary way. The substitutability of invention disclosures, licenses, patents, and materials transfer agreements did not appear to reduce commercialization activity (Mowery and Ziedonis 2007). The literature on R&D inputs provides evidence that both substitution and complementary relationships are possible and that context, such as national innovation system and level of analysis, may shape this phenomenon.

Second, because doctoral students, postdocs, and faculty possess different levels of skill in research, consideration is given to the literature on the substitution of workers with different skill levels. The research questions of whether low skilled workers substitute for or complement higher-skilled workers has long interested labor economists and has been summarized by Hamermesh (1987) and Hamermesh and Grant (1979). They identify four studies that examine substitution by level of education, with a focus on college graduates, high school graduates, and workers with less than a high school degree (Grant 1979; Welch 1970; Johnson 1970; Dougherty 1972). All find that the various categories of labor are substitutes, with less expensive unskilled labor taking the place of more expensive skilled labor. The implication of these studies for the research production context is that the less educated research assistants and postdocs would substitute for faculty, and research assistants would substitute for postdocs.

Third, the literature on substitution of contingent employees for core employees is reviewed. Although for some purposes postdocs and doctoral students are not considered to be employees, they are performing work on a time-limited basis similar to contingent employment. Table 4 summarizes selected studies of the substitution of contingent employees for core employees. These studies examine two contexts, on-shore and off-shore employment and temporary and regular employment. In a review of empirical studies of the effects of offshoring on developed country labor markets, domestic and offshore labor were found to be weak substitutes (Crinò 2009). The relationship may depend on the location of the offshore workers. In a study of US multinationals hiring offshore within their own firm, offshore workers in high-income countries were found to be complements to US workers while offshore workers in low-income countries were found to be substitutes (Harrison, McMillan, and Null 2007). Agency temporaries have been found to function as substitutes for regular employees (Houseman, Kalleberg, and Erickcek 2003). However, internal contingent employment systems were found to be complementary to regular employment (Ko 2003). Ko found this complementary relationship was strongest in organizations with strong internal labor markets. University faculty have one of the strongest internal labor markets in the US, characterized by high job stability, a role in governance, and generous benefits (Schuster 2006). If the most important feature of postdocs is their role as a system of contingent employment within universities' strong internal employment system, they would be expected to serve as complements to faculty and perhaps, due to their shorter terms of appointment, even to doctoral students.

Fourth, immigration is one of the most widely studied labor substitution contexts. It is also directly relevant to the postdoc and doctoral student populations, as over half of all postdocs, and over half of doctoral students in some fields, are foreign-born temporary visa holders (National Science Board 2010). Table 5 summarizes selected studies of the labor market effects of immigration. In a widely cited early study, Grossman (1982) finds that native workers, first generation immigrants, and new immigrants all function as substitutes. A recent review of this literature finds mixed results, with effects on native workers generally small (Okkerse 2008). Borjas (2003) finds the largest wage effects on workers with the highest and lowest levels of education, high school dropouts and college graduates. While much attention has been paid to the potential for immigrants to displace native workers at the lowest skill levels in the US, less is known about immigrants' displacement of high-skill workers. This study of academic scientists contributes insights about a particularly high-skill context. The Grossman and Borjas studies suggest that postdocs are likely to function as substitutes.

Two additional studies related to immigrants and natives also provide potentially relevant information. Borjas (2004) finds that immigrants crowd out native male graduate students, especially in elite programs. In their study of universities' patent productivity, on the other hand, Gurmu, Stephan, and Black (2010) find evidence that suggests immigrant and native graduate students are complements rather than substitutes. These studies have contradictory implications for the role of postdocs, who are even more likely than graduate students to be from outside the US, in the production of research.

Studies of substitution and complementarity in similar contexts reveal that both substitution and complementary relationships are both common. Whether a given pair of inputs exhibits substitution or complementarity appears to depend on context. A contextual factor important to this study is the difference between public and private universities. The subsidies public universities receive for education of in-state students may be the most relevant difference. These subsidies apply to many students at public universities because it is often possible for US citizen students to establish in-state status during the doctoral program. Because of these subsidies, the cost structure for doctoral student labor is different between public and private universities. Other differences between public and private universities are that faculty salaries at public universities are lower and public universities receive more budgetary scrutiny. Therefore, whether a university is public or private may moderate the substitutability of doctoral students for other inputs.

MODEL

It is possible to determine whether different types of labor are substitutes or complements using either production functions or cost functions, with production functions more suitable when exogenous shocks or policy interventions are expected to affect quantity rather than price, as is the case with immigration quotas and training programs (Hamermesh and Grant 1979). Grossman (1982) provides a production function model well-suited to the data available on the academic workforce. Borjas (2003) and Okkerse (2008) have endorsed this approach for estimating whether different types of labor—in their papers, immigrants and natives—are substitutes or complements in production.

Academic output is estimated using a translog production function (see equation 1). The translog functional form is suitable for modeling a system with more than two inputs, as it relaxes the assumptions of additivity and homogeneity (Christensen, Jorgenson, and Lau 1973).

(1) $$\ln Q = \ln\alpha_0+\Sigma\alpha_i\ln X_i+(\Sigma_i\Sigma_j\gamma_{ij}\ln X_i\ln X_j)/2$$

for *i=doctoral, postdoc, faculty* and *capital* and X_i=the quantity of *DOCTORAL, POSTDOC, FACULTY*, and *CAPITAL*.

Based on this functional form, factor shares are calculated based on the quantity of each input employed in the production of research. Equation 2 illustrates the factor share calculation.

(2) $$S_i = w_i * X_i/Q$$

In this equation, w_i represents the cost to employ an input, X_i is the quantity of that input employed, and Q represents the value of research produced. For example, equation 3 represents the labor share for doctoral research assistants.

(3) $$S_{\text{DOCTORAL}} = DOCTORAL \text{ share} = w_{\text{DOCTORAL}} * DOCTORAL/Q$$

Here, w_{DOCTORAL} represents the wage paid to employ a doctoral research assistant, *DOCTORAL* represents the number of research assistants employed, and Q represents the quantity of research produced.

Factor share equations are then estimated based on the translog production functions for doctoral research assistants, postdocs, faculty, and capital as shown in equation 4 (Grossman 1982; Okkerse 2008).

(4) $$S_i = \alpha_i + \gamma_{i,\text{doctoral}} \ln DOCTORAL + \gamma_{i,\text{postdoc}} \ln POSTDOC + \gamma_{i,\text{faculty}} \ln FACULTY + \gamma_{i,\text{capital}} \ln CAPITAL + e, \text{ where } i = doctoral, postdoc, faculty, capital.$$

Factor shares were scaled so that the sum of the four shares totaled one, ($S_{i(\text{scaled})} = S_i/\Sigma S_i$).

DATA

Reliance on postdocs is most prevalent in the life sciences and this study focuses on 145 university life sciences doctoral programs in the US. The life sciences were defined to include agricultural sciences, biological sciences, medical sciences, and other life sciences.

The analysis is based on data for 2006 because the NRC Assessment of Research Doctoral Programs provides an especially rich source of information for that year. The NSF Survey of Graduate Students and Postdoctorates for 2006 lists 193 institutions in the Carnegie classifications high research activity and very high research activity with life sciences programs. These research-intensive universities, identified as those with a high level of aggregate or per capita research activity relative to all institutions granting research doctorates in 20 or more programs (Carnegie Foundation for the Advancement of Teaching, n.d.), are most likely to have a sizable population of postdocs and form the base population for this analysis. 169 of these institutions were also included in the NRC Assessment. Those that were not included in the NRC Assessment were primarily schools whose graduate programs in the life sciences emphasized masters rather than doctoral programs (e.g., College of William and Mary).

In some cases, multiple institutions were consolidated into one reporting unit when some variables were only reported in aggregated form. For example, the NSF Survey reported the number of postdocs separately for the University of Wisconsin's Madison and Milwaukee campuses. However, the publication count was available for the University of Wisconsin as an aggregate. Therefore data are aggregated and analyzed at the University of Wisconsin level. This type of aggregation reduced the number of universities by an additional 13, to 156. One or more missing data elements removed an additional 11 units from the analysis, leaving N=145.

In addition to the NRC Assessment and the NSF Survey of Graduate Students and Postdoctorates, several other publicly available data sources are used as described in table 6..

Full-time equivalents were measured for each of the three categories of researcher. The number of *doctoral* student research assistants was taken from the NRC assessment. The percentage of students with teaching assistantships was subtracted from the percentage of first-year students receiving full support.[4] This percentage was multiplied by the number of enrolled students. Because a doctoral student's research assistantship is usually a part-time job, with the remaining time devoted to classes, exams, and the student's dissertation research, the number of doctoral research assistants was divided by two to calculate the full-time equivalents (FTE).

The number of *postdocs* came from the Survey of Graduate Students and Postdoctorates and total *faculty* from the NRC assessment.[5] Postdocs and faculty were assumed to work full-time.

Neither master's-level and undergraduate research assistants nor non-faculty research staff were included in the production function.

Capital was measured as net assignable square feet for life sciences laboratory space as reported for 2005 in the biennial NSF Survey of Science and Engineering Research Facilities.

Wage was measured in the following ways. For doctoral students and postdocs, the NIH Kirschstein National Research Scholars Assistantships were used as a baseline stipend amount. These stipend levels serve as a national benchmark for postdoc compensation

[4] The NRC Assessment includes a measure of the percentage of students with research assistantships. However, due to the complex grid-based data collection used for this variable, the summary data included in the publicly-available dataset appear to dramatically understate the number for several schools. For example, most programs at Yale list 0% because institutional fellowships are counted separately. For that reason, the NRC measure of students with research assistantships is not used in the calculation.

[5] The total faculty count was used for consistency with the 1996 NRC assessment.

(COSEPUP 2000). For doctoral student research assistants, wage was calculated as the sum of the NIH pre-doctoral stipend ($20,772 in 2006)[6] plus the university's tuition—in-state for US citizens and out-of-state for foreign students. This calculation was based on the assumption that US doctoral students typically apply for in-state tuition, but foreign students are rarely eligible for it. Further, it assumes that the student receives a tuition waiver, with the academic department reimbursing the university. This approach probably understates the cost of US students because some may not be eligible for in-state tuition, especially in their first year. The lower in-state tuition can be interpreted as a subsidy from the state government for the training of in-state doctoral students. This subsidy is unavailable at private universities. For postdocs, wage was calculated as the level 1 NIH postdoc stipend ($38,976 in 2006).

Each of these stipend amounts was multiplied by 1.25 to account for payroll taxes and employee benefits. These wage estimates do not take into account graduate students or postdocs with outside funding— approximately 12% of first-time postdocs in biochemistry, for example (Nerad and Cerny 1999).

For faculty, wage was measured as the average salary and benefits as reported for the institution in the Almanac of Higher Education (2006). Although faculty salaries vary considerably by field, the average salary for all fields appears to be a reasonable estimate for the life sciences. For example, of 26 fields ranked in order of 2001-2002 salaries for professors at doctoral institutions, biological sciences was ranked in 12th place (American Association of University Professors 2004). These salaries exclude faculty in medical

[6] A survey conducted by the Chronicle of Higher Education (June 2008) found that the average stipend paid to research assistants at 111 doctoral research universities was $18,200.

schools, although some of the research doctoral programs in the NRC Assessment are housed in medical schools.

The *rental rate* of lab space was estimated based on median construction costs for college laboratory space ($203 per square foot) and geographic cost adjustment factors from the R.S. Means directory of *Facilities Construction Cost Data* (R.S. Means Co. 2006). Based on a published account of the 2006 rental rate for Boston (Botelho 2008), the location with the most postdocs, the rental rate was assumed to be 24% of the construction cost.

Quantity was measured as the estimated number of citations of life sciences journal articles published by the institution in 2008, to allow a two-year lag time from the researchers' employment in 2006 (Stephan and Levin 1992).[7] The number of articles published in 2008 was multiplied by the average number of citations per article calculated from the NRC Assesssment. Such bibliometric measures have long been used to quantify research production (Thelwall 2008).

The factor share S_i for each type of labor was calculated based on the wage, full-time equivalent workers of each type, and value of output. The factor share of capital was calculated using square feet of lab space multiplied by an estimate of the local rental rate.

The independent variables in the factor share regression equations were the natural logs of FTE of *DOCTORAL*, *POSTDOCS*, and *FACULTY* and natural log of square feet of *CAPITAL*. To maintain the sample size, one was added to the values of doctoral and postdocs before taking the natural log to adjust for values of zero.

[7] An alternative specification used publications as the measure of quantity. With this measure, fewer effects reached the level of statistical significance.

Descriptive statistics for the variables used to calculate factor shares are provided in table 7. Correlations for the variables used in the regression are provided in table 8. As is common in production functions (Kennedy 2008), the quantities of input factors are highly correlated, with the highest correlation coefficient corresponding to the faculty and doctoral research assistants ($r=0.893$, $p<0.001$). Issues related to multicollinearity will be discussed along with the regression results.

Factor shares equations for doctoral research assistants, postdocs, faculty, and capital were estimated using seemingly unrelated regression using the four regression equations represented by equation 4 (see table 9). Consistent with demand theory, effects are assumed to be symmetrical. That is, the effect of postdocs on faculty's factor share is assumed to be the same as the effect of faculty on postdocs' factor share. The sum of the constant terms α_i for the system of equations is assumed to equal one.

The coefficients from the regressions were used to calculate coefficients of complementarity, $C_{ij}=(\gamma_{ij}+S_iS_j)/(S_iS_j)$ (Grossman 1982). A positive value for C_{ij} indicates that the factors are complements and a negative value for C_{ij} indicates that the factors are substitutes. More specifically, the factors are substitutes if the regression coefficient γ_{ij} is negative and of greater absolute value than the product of the factor shares of factors *i* and *j*.

RESULTS

Model 1 reveals that doctoral research assistants, faculty, and capital are all negatively associated with the size of postdocs' factor share ($\gamma_{\text{doctoral}} = -0.006$, p = 0.012; $\gamma_{\text{faculty}} = -0.018$, $p<0.001$; and $\gamma_{\text{capital}} = -0.029$, $p<0.001$). For example, the share of production attributed to faculty would increase by 1.8% (ln100=4.605; ln271=5.605) if the number of postdocs employed increased from 100 to 271. The statistically significant relationships between the labor inputs and capital indicate that capital and labor are not separable in the context of this study; it would be inappropriate to estimate the substitutability of labor factors without including a measure of capital (Berndt and Christensen 1973). Models 2 and 3 show similar relationships among factors and factor shares in the sample's 100 public institutions and 45 private institutions, respectively.

Because of the strong correlations among the quantities of input factors, potential issues related to multicollinearity should be considered (Kennedy 2008). One potential consequence of multicollinearity is a lack of statistically significant coefficients, but that is not the case here. The mean variance inflation factor (VIF) for model 1 is 5.68 and all VIFs are less than 10, cited by Kennedy as a customary level above which multicollinearity is considered problematic.

Calculating the coefficients of complementarity, $C_{ij} = (\gamma_{ij}\text{-}S_iS_j)/(S_iS_j)$ (Grossman, 1982), at the mean of the raw factor shares (*DOCTORAL* = 0.102, *POSTDOCS* = 0.064, *FACULTY* = 0.376, and *CAPITAL* = 0.304) reveals that the coefficients of all cross-elasticities for postdocs with other labor inputs are positive (see table 10). The coefficient of complementarity between postdocs and capital is -0.015, indicating that these factors function as substitutes. Thus, all types of workers appear to be complements to one another, with the possible exception of doctoral research assistants and faculty at private institutions. In any case, this analysis provides no evidence of postdocs substituting for other categories of labor. Postdocs did appear to be substitutes for capital at private institutions (C = -0.065, $p<0.001$).

Alternative specifications of the model, including the use of raw factor shares and Grossman's (1982) approach which scaled X_{CAPITAL} to equal 1-ΣL_i did not improve the model fit. The use of raw coefficients resulted in negative pseudo-r^2 values, indicating misspecification. Scaling *capital* to equal 1- ΣL_i yielded similar evidence of complementarity, but lower pseudo-r^2 values and fewer statistically significant effects.

DISCUSSION

This study's findings indicate that postdocs function as complements to other categories of labor in the production of research. This finding is contrary to the expectation that workers at different skill levels function as substitutes (Hamermesh and Grant 1979). However, finding a complementary relationship is more consistent with the idea that regular and contingent employment systems function as complements, especially in organizations where the regular employees participate in a strong internal labor market (Ko 2003).

Academia has been likened to a pyramid scheme in which faculty produce PhDs who go on to train yet more PhDs (Holden 1995; Sharom 2008; Stephan 2012). The problem is compounded as the doctoral students being trained also contribute to research and teaching, which provides an incentive to train them even when no career positions are available (Freeman and Van Reenen 2008). The increase in postdoctoral appointments is often attributed to this pyramidal structure (Stephan and Ma 2005). Most new doctorate recipients in the life sciences, especially those interested in academic careers, will take a postdoc appointment immediately after graduation (NSF, 2008). Yet the career academic positions they seek have become increasingly scarce, with tenure-track faculty positions increasing at a much slower rate than new doctorates (Fox and Stephan 2001). As with any pyramid scheme, disaster ensues when demand is quickly saturated by exponential growth.

A 2003 New York Times piece by author Daniel Duane, "Eggheads Unite," gives particularly incisive expression to this perspective:

> University fund-raising depends primarily on high-profile faculty publishing, so the smart money cuts the total number of professors in order to spend big on a few stars and give them enough free time to stay famous. Graduate students, serving as T.A.'s and even as lecturers, pick up the teaching slack. This makes for a great fiscal model -- tenure produces high fixed costs, while disposable T.A.'s work for peanuts. But it also creates an ever-greater oversupply of Ph.D.'s competing for ever-fewer tenured jobs. Back when graduate students could reasonably see themselves as apprentices bound for glorious lecture halls, the low pay was tolerable, but when T.A.-ships look like the university's way of balancing the budget at the expense of their graduate students' futures, it feels like an outrage (54).

While the passage above refers to teaching, a similar argument can be made about the laboratory grunt work of animal care, sample preparation, and routine data collection done by research assistants and postdocs. By delegating both lab work and undergraduate teaching to assistants and postdocs, faculty have more time to devote to publishing, training graduate students, designing research, and preparing grant applications (Lan 2009).

As more new PhDs find no career position available, many find themselves in a holding pattern of extended postdoc appointments (Stephan and Ma 2005; Mishagina 2008). If postdocs were substitutes for doctoral students in support of faculty-led research, this could potentially counteract the incentive to train a surplus of PhD students. However, if postdocs are complements to doctoral students, as indicated by the preceding analysis, the rise of the postdoc may perpetuate the training of scientists in excess of demand.

These findings also suggest a number of directions for further research. For example, it would be useful to understand whether these complementary relationships have changed over time, perhaps in response to changing funding levels or immigration policies. The model might also be extended to consider whether US and international research assistants and postdocs have similar or different roles in the production of research. Non-faculty research staff should perhaps be added to the model. It might also be beneficial to model the process as one of joint production of teaching and research outputs (Hanushek 1979; Johnson and Turner 2009). Finally, there may be factors that moderate this complementary relationship. For example, this analysis has been confined to the life sciences. Production functions in the life sciences may differ from those in engineering or the physical sciences where there are more career opportunities in industry.

One of the main concerns of the science of science and innovation policy is the application of theoretical models, often from economics, to improve understanding of the relevant policy issues (Marburger 2007). This study, which attempts to use publicly available data to answer a seemingly straightforward question based on economic theory, sheds light on the adequacy of existing data sources for such an effort. On the positive side, the data made available through the NRC assessment make it possible to at least estimate each variable that enters into the production function. On the other hand, in some cases these estimates involved significant assumptions. This was true especially with respect to understanding the contributions and costs associated with graduate student research assistants. Further, many of the data available through the NRC Assessment are not available on a more regular reporting schedule. For example, there appears to be no regular reporting of the number of faculty at a university by discipline. To apply economic and other social science theories to practical problems of science policy, data collection aligned with the constructs of prevailing theoretical models should be a priority.

Chapter 5

Dissatisfaction with the Postdoc Experience: Insights from a Survey

Science policymakers at the national level, institutional administrators, and individual scientists have all expressed concern about the nature of the postdoc experience. At the national level, policymakers are concerned because postdocs make significant contributions to scientific research (Vogel 1999; Black and Stephan 2010; Corley and Sabharwal 2007). Some argue that the postdoc career stage has deterred many of the most talented students, especially US-born men, from pursuing careers in science and technology (Stephan and Ma 2005; Butz et al. 2003). Lack of autonomy and stability during early careers—often a time of peak creativity—may reduce scientific productivity (Stephan and Ma 2005; Zubieta 2009). The NSF has identified the nature of the postdoc experience as one of the key remaining research questions about postdocs (Oliver and Rivers 2006).

The effective management and inclusion of postdocs presents a challenge to the institutions where they are appointed. Although not readily classified as either students or employees, some postdocs have organized through labor unions (Gerwin 2010). Universities have responded by creating offices of postdoc affairs, perhaps as a form of nonunion employee representation, a common union avoidance strategy (Taras and Kaufman 2006). Postdocs have also engaged the political process, lobbying through the NPA and the American Association of Universities (AAU) (Scaffidi and Berman 2011). Collective action by postdocs in political and institutional contexts has often focused on increasing satisfaction by improving the quality of their developmental experiences.

The stresses facing postdocs are a frequent topic in the popular scientific press, with headlines like “Career Transitions: Panel Throws Lifeline to Struggling Postdocs,” “Postdoc Trail: Long and Filled With Pitfalls,” “The Postdoc’s Plight,” and “A Pressure Cooker for Postdocs?” (Survey Sciences Group 2008). In extreme cases, postdocs have been involved in workplace-related violence as victims (The Associated Press 2010) or alleged perpetrators (Postdoc Allegedly Attempts to Poison Lab Colleague 2008) or have succumbed to psychological stress, even to the point of suicide (Smaglik 2006; Krupnick 2011). Workplace violence, sometimes attributable to dissatisfied workers, is a widespread and costly problem in all sectors of the economy and has received particular attention in the healthcare and educational settings where postdocs are found (Flannery 1996). In the scientific community, a single incident can result in the loss of several talented scientists and their potential contributions to society (Obituaries, Huntsville Times, February 14 and 15, 2010).

Individual scientists, of course, also stand to benefit from a better understanding of how to avoid unsatisfactory postdoc appointments. New PhDs often obtain these positions in an *ad hoc* labor market with limited access to information (Wei, Levin, and Sabik 2009). A successful postdoc appointment with a prominent advisor at a prestigious institution can have a high payoff in the cumulative advantage that characterizes scientific careers (Su 2011; Merton 1968). The postdoc career stage has also been identified as a juncture where many women exit or reduce their commitment to the scientific workforce after significant personal and public investment in their training (Martinez et al. 2007).

These social, institutional, and individual concerns motivate this investigation of factors influencing postdocs’ dissatisfaction with their appointments. The analysis of these factors proceeds in four sections. First, findings from prior research about the postdoc experience are presented in support of propositions about dissatisfaction among postdocs. Second, the probability that a postdoc will be dissatisfied is modeled as a function of types of research, career goals, postdoc-advisor interaction, program quality, and demographics. Third, the study's data are described. Fourth, the ordered probit regression analysis is explained. Fifth, results of the ordered probit regression are presented and the mediating roles of autonomy, advisor interaction, and advisor activities in the relationship between program quality and dissatisfaction are tested. Sixth, the chapter then concludes with a discussion of results, policy implications, and directions for future research.

Dissatisfaction among Postdocs

A seminal work on the measurement of job satisfaction (Seashore and Taber 1975) describes it as "a result of fit between need and need fulfillment" (p. 339), emphasizing the importance of both individual and environmental factors in determining satisfaction. In summarizing the results of the Sigma Xi survey of postdocs, Davis (2005) paraphrased Tolstoy, observing that satisfactory postdoc experiences were uniformly good, but each unsatisfactory one was unhappy in its own way. However, the current study finds common threads in the experiences of the minority of postdocs (11% of sample) who express dissatisfaction with their appointments. The mean rating of postdoc satisfaction in this study's sample, 5.464 on a 7-point scale, is almost exactly equal to the 5.48 reported as the norm for an extensively validated global measure of job satisfaction, the Michigan Organizational Assessment Questionnaire Job Satisfaction Measure, indicating that this sample of postdocs has a similar level of satisfaction to that typically found in employee surveys (Bowling and Hammond 2008).

This is about half of the rate of dissatisfaction found in the Sigma Xi survey, possibly indicating improvements in conditions for postdocs since 2003 when those data were gathered. Table 11 summarizes survey findings about postdoc satisfaction from various sources. While comparisons are limited by differences in measurement approaches across these surveys, levels of satisfaction appear to have varied significantly over time. Reported levels of satisfaction range from nearly universal satisfaction (Curtis and National Research Council 1969) to widespread dissatisfaction (National Research Council 1981) to a more moderate 22% dissatisfaction in the Sigma Xi survey. Global satisfaction measures such as the one used by Sigma Xi and in this chapter tend to understate the level of dissatisfaction (Oshagbemi 1999).

University offices of postdoctoral affairs and postdoc-run associations have become more common and can address some potential sources of dissatisfaction by offering training, orientation, networking, and integration into the local community (Felfly 2011). Universities may have responded to the findings that nonmonetary aspects of the postdoc appointment—such as the postdoc and advisor jointly developing a research plan at the outset— increased postdoc satisfaction (Davis 2009). Also, the Sigma Xi sample included postdocs in a broader range of fields, including social sciences and humanities, and a broad range of settings. Postdocs in the major research universities included in this study may be less likely to be dissatisfied.

To identify potential causes of dissatisfaction, the job satisfaction literature has long emphasized the need to examine individual and environmental factors. “Prevailing conceptions view job satisfaction as a joint product of characteristics of job and job environment on the one hand, and the characteristics of the person on the other, with the effective set of relevant job characteristics and personal characteristics depending upon unspecified combinations and interactions between them" (Seashore and Taber 1975, p. 340). At the individual level, Seashore and Taber model the correlates of job satisfaction as demographics, stable personality traits, abilities, and situational aspects of personality, such as motivations and preferences. At the environmental level, they include characteristics of the job and job environment, the organizational environment, and the macroeconomic and political context.

Postdocs' motivations for taking the appointment often center on pursuit of an academic research career and a desire to further develop or signal their level of human capital, while being constrained by personal, institutional, and labor market circumstances (Miller 2011). Prior research on postdocs suggests that factors related to the research they are conducting, career goals, postdoc-advisor interaction, program quality, and demographics are likely to be associated with postdocs' dissatisfaction. The roles of these factors in the postdoc experience are described below.

Research. Because research is central to the postdoc experience, the influence of the type of research conducted on postdoc satisfaction is considered first. Scientists are thought to be motivated by an intrinsic interest in extending the boundaries of knowledge (Anderson et al. 2010; Merton 1973). One important difference between the careers of faculty at research universities and those of researchers in other settings is their greater opportunity to engage in basic research (Agarwal and Ohyama 2010; Sauermann and Stephan 2010). Postdocs are typically pursuing faculty research careers and, especially in academic settings, postdoc appointments often offer opportunities to engage in basic research. Postdocs engaged in interesting, basic research are expected to be less likely to experience dissatisfaction. Of course, scientists' levels of interest in basic and other types of research vary (Roach and Sauermann 2010). A mismatch between a postdoc's interest in basic research, applied research, and development and the current research project's emphasis on these activities may indicate poor fit, a potential source of dissatisfaction (Edwards 1991; Kristof-Brown, Zimmerman, and Johnson 2005).

Career goals. Postdocs' dissatisfaction may also be influenced by the extent to which their appointments support their career goals. In fact, 85% of the postdocs in the sample reported that increasing the likelihood of getting their desired job was an important factor in taking their current appointment. However, 20% of the sample reported taking the appointment because no other job was available (reasons were not mutually exclusive).

Postdoc appointments are most closely aligned with career goals in academic research, since they are practically required in many fields for a faculty appointment at a research university (Rudd et al. 2010; Nolan et al. 2004). Postdocs who intend to pursue faculty research careers and those with a strong interest in basic research may therefore be expected to be more satisfied with their appointments compared to postdocs with other career goals.

Postdoc-advisor interaction. Another factor believed to influence satisfaction with postdoc appointments is the structured oversight provided (Davis 2009; Scaffidi and Berman 2011). Davis's analysis of the Sigma Xi survey found structured oversight, defined as the postdoc's relationships with a lab and faculty advisor, to be more influential than compensation and benefits in determining postdoc satisfaction. Postdocs who are dissatisfied might be expected to be lacking in structured oversight, since not all postdoc advisors embrace the role of mentor (Fetzer 2008), or perhaps to be micromanaged in a way that does not facilitate the transition to an independent research career (Laudel and Gläser 2008). The NSF recognized the importance of this relationship by introducing a mandate in 2009 that required principal investigators to include a mentoring plan for postdocs funded through their grants (NSF, 2009). While prior research on postdocs has found benefits from structured oversight, the "paradox of autonomy" implies that such oversight should consist of a balance of direction and involvement (Trevelyan 2001).

Postdoc-advisor interaction should also be considered with regard to the postdoc's and advisor's levels of ability. Cumulative advantage, in which those who have an early advantage tend to accumulate future advantages, has long been identified as a characteristic of scientific careers (Merton 1968). Thus, postdocs with the highest research ability are expected to work with the advisors with the highest research ability and gain the most from those associations. Good mentoring relationships with highly regarded researchers are expected to be inversely related to dissatisfaction in postdocs.

Program quality. Program quality is also expected to influence postdocs' level of satisfaction. Quality can confer benefits in terms of reputation or access to specific resources. The prestige of a postdoc program has been found to be associated with the prestige of subsequent faculty appointments (Rudd et al. 2010; McGinnis, Allison, and Long 1981; Su 2011; Burris 2004). High quality departments are likely to provide more resources and affiliation with a prestigious program may send a stronger signal of the scientist's ability, supporting future career goals (Dasgupta and David 1994). Although these benefits might be countered by stress and pressure to perform, postdocs are believed to seek out the appointments that they believe will maximize their utility, constrained by their ability to signal their level of human capital (Zubieta 2009). Presumably those postdocs who were able to obtain appointments in high-quality departments would also have been able to get appointments in lower-quality departments (Spence 1973), so postdocs' presence in high quality departments is interpreted as a revealed preference for quality. For reasons of both reputation and resources, postdocs in high-quality departments are expected to be more satisfied.

Demographics. Earlier studies had found that several demographic characteristics were related to satisfaction as a postdoc. There is concern that native-born males may be leaving the scientific workforce, "crowded out" by immigrants or lured away by higher earnings in finance, law, and other careers (Black and Stephan 2010). If native-born males tend to leave science for better opportunities, perhaps they are more likely be dissatisfied as postdocs. However, another study found that noncitizen postdocs were less satisfied (Corley and Sabharwal 2007). Thus, the direction of the expected relationship between citizenship and satisfaction is ambiguous, especially keeping in mind the potential for higher attrition among the dissatisfied.

Prior studies have found that older doctorate recipients were less likely to take postdoc appointments, possibly due to financial obligations (Zumeta 1985; McGinnis, Allison, and Long 1981; Recotillet 2007). Financial concerns may also be greater for married postdocs or those with children, and the effects of family obligations have been found to be different for men and women (Helbing, Verhoef, and Wellington 1998; National Research Council 1981; Martinez et al. 2007). Prior research also indicates that satisfaction will decline as scientists spend more years as postdocs or take multiple appointments (Akerlind 2005). This effect may be independent of age, as postdocs feel less valued the longer they remain in an appointment (Helbing, Verhoef, and Wellington 1998). Although decreasing satisfaction over time as a postdoc has been a consistent finding, it may potentially be countered by attrition of postdocs who are especially dissatisfied.

Prior work has demonstrated that parenthood plays a different role in the academic careers of men and women (Mason and Goulden 2004). Qualitative and survey research on postdocs has previously found family to be a greater barrier to women's careers (Martinez et al. 2007). While prior research has identified no clear direct relationship between gender and satisfaction as a postdoc, gender may have an effect mediated by parental or marital status. Gender and discipline were found to be related to job satisfaction in science and social science faculty (Sabharwal and Corley 2009).

Returning to the Seashore and Taber (1975) model, the independent variables above include demographic characteristics, stable personality traits such as research interests, a self-assessment of ability, and situational variables such as motivations. They also include job characteristics such as interesting research, the type of research involved, and freedom to shape a research project and factors related to the organizational environment, including interaction with the advisor and program quality. In a sense occupation is held constant, since all subjects are postdocs, and as a cross-sectional study the political and economic context does not vary. To the extent occupational and economic conditions vary by scientific field, these are controlled for by fixed effects.

MODEL

Dissatisfaction among postdocs may be explained by examining the influence of the type of research they are conducting, career goals, postdoc-advisor interaction, program quality, and demographics. These factors are incorporated into an ordered probit model of postdoc dissatisfaction.

The following equation (5) represents the ordered probit model:

(5) $Pr(\textit{dissatisfaction}) = y = \beta_0 + \beta_1[\textit{research}] + \beta_2[\textit{career goals}] + \beta_3[\textit{postdoc-advisor interaction}] + \beta_4[\textit{program quality}] + \beta_5[\textit{demographics}] + e$

The error term *e* is clustered by university to account for shared variance among postdocs at the same institution.

DATA

Survey Sample

This analysis is based on data from 764 postdocs at major research universities in the US. Web surveys were sent to approximately 30,000 graduate students and postdocs whose names and email addresses were gathered from the websites of biological and health sciences, engineering, and physical and mathematical sciences departments at 39 large US research universities.[8] The overall response rate for the survey was 30%.

1,137 respondents identified themselves as current postdocs in doctorate granting departments at major US research universities in the biological sciences, health sciences, or physical and mathematical sciences. The biological sciences category includes biochemistry, biophysics, and structural biology; cell and developmental biology; ecology and evolutionary biology; genetics and genomics; and neuroscience/neurobiology. Health sciences includes biology/integrated biology/integrated biomedical sciences; immunology and infectious disease; microbiology; and pharmacology, toxicology and environmental health. Physical

[8] Further details of the survey and sample are available in Sauermann, Henry and Roach, Michael, Not All Scientists Pay to Be Scientists: Heterogeneous Preferences for Publishing in Industrial Research (August 15, 2011). Available at SSRN: http://ssrn.com/abstract=1696783. The 20 universities with the most survey responses were Columbia University, Cornell, Duke University, Harvard, Johns Hopkins, Michigan State University, MIT, Ohio State University, UC Berkeley, UC Davis, UC Los Angeles, UC San Diego, UNC Chapel Hill, University of Chicago, University of Florida, University of Michigan, University of Washington, University of Wisconsin, Washington University St. Louis, and Yale.

and mathematical sciences includes astrophysics and astronomy, chemistry, computer science, and physics. This total includes doctoral students identified in the original sampling frame who had become postdocs (either at the same institution or a different one), postdocs identified in the original sampling frame who remained in their appointments, and postdocs who had moved into another postdoc appointment. 281 postdoc respondents indicated they were currently at the university where they earned their doctorates.

The proportions of men and US citizens were comparable to those found in other surveys, such as the 2009 NSF Survey of Graduate Students and Postdoctorates. The current sample had slightly more male (58% vs. 56%) and fewer US citizen (47% vs. 49%) respondents in the biological and health sciences and approximately the same percentage of male (79%) and slightly fewer US citizen (38% vs. 40%) respondents in the physical and mathematical sciences.

The demographic makeup of the sample can also be compared to the population of those earning doctorates in the US, as measured by the 2009 Survey of Earned Doctorates. Overall, 57% of these graduates are male and 70% are US citizens. The current survey sample contains more men and more noncitizens. This difference can be attributed to postdocs coming to the US after earning doctorates abroad.

Analyses are conducted on the 764 complete responses from postdocs at major US research universities in the biological sciences, health sciences, and physical and mathematical sciences. Table 12 presents descriptive statistics for the sample and its three subgroups: biological sciences, health sciences, and physical and mathematical sciences. Table 13 presents a correlation matrix for the full sample.

Dependent variable

Dissatisfaction. Postdocs were asked to respond to the question "Overall, how satisfied are you with your current PostDoc experience?" on a seven-point Likert scale ranging from "Very dissatisfied" to "Very satisfied." The ordinal variable *dissatisfaction* was coded as 1 if the response was very dissatisfied, dissatisfied, or somewhat dissatisfied, 0 if the response was "Neither satisfied nor dissatisfied," and -1 if the response indicated some degree of satisfaction.

Binary variables were created for alternative specifications. The binary variable *dissatisfied* was coded as 1 if the response was very dissatisfied, dissatisfied, or somewhat dissatisfied and zero if the response was neutral or indicated some degree of satisfaction.

Independent variables

Type of research. Three types of variables were used to represent the type of research. The binary variable *research interesting* was coded as 1 if the response to the question "How interesting do you find your current research?" was "Somewhat interesting" or "Extremely interesting" on a five-point Likert scale.

The variable *mismatch average* was created by averaging difference scores based on responses to six questions. First, postdocs responded to the question "To what extent do you agree or disagree with the following phrases regarding the nature of your current research[?]" on five-point Likert scales ranging from "Strongly agree" to "Strongly disagree" with respect to three types of research: basic, applied, and development. Because the use of these terms varies in different contexts (Calvert 2006), the following phrases were used to define the types of research: "My research contributes fundamental insights or theories (basic research)," "My research creates knowledge to solve practical problems (applied research)," and “My research uses knowledge to develop materials, devices, or software (development).” Second, postdocs were asked to respond to the question “When thinking about the future, how interesting would you find the following kinds of work?” on five-point Likert scales ranging from “Uninteresting” to “Interesting.” They were presented with the same three types of research defined previously. Difference scores were calculated as the absolute value of the difference between the current research project rating and the future research interest rating and the difference scores were averaged such that a higher score indicates a greater discrepancy between the postdoc’s current research and future research interests. Responses to each of the six questions about the current research project and future research interests and the relevant interactions were also entered individually into the equation.

Career goals. Three types of variables represented the extent to which the postdoc appointment was consistent with future career goals. The first of these variables recorded whether the respondent took their first postdoc appointment because of difficulty finding another job. Postdocs were asked “Thinking back to when you began your first PostDoc in [year], how important were the following factors in influencing your decision to do a PostDoc?” They were asked to rate four factors on a five-point Likert scale from “Extremely unimportant” to “Extremely important”: “I wanted to deepen my skills in a particular research area,” “I experienced difficulty finding another job,” “A PostDoc increases the chance to get my desired job,” and “I wanted to have more time before deciding on my long-term career.” Noncitizen postdocs were also asked about the influence of coming to or staying in the US. This reason was described as at least moderately important by 17% of noncitizens. A binary variable was coded as 1 if the response was “Extremely important” or “Moderately important” and 0 if the response was neutral or unimportant.

The second career goal measure was *faculty career goal,* whether the postdocs were most likely to pursue a faculty career focused on research compared to other options. Subjects were asked to rank the following careers from most likely to pursue to least likely to pursue: "University faculty with an emphasis on research or development," "University faculty with an emphasis on teaching," "Government job with an emphasis on research or development," "Job in an established firm with an emphasis on research or development," "Job in a startup firm with an emphasis on research or development," and "Other career." To create a set of ordered rankings, the web survey was constructed so that a respondent could not give two careers equal rank. A binary variable was coded 1 if the responded ranked a faculty research career as the most likely future career and coded 0 if any other career was ranked as most likely.

Responses to the questions described previously about interest in types of research were also coded as a binary variables *interest in basic, interest in applied, and interest in development* with 1 corresponding to "Extremely interesting" and "Interesting" and 0 corresponding to neutral responses and lack of interest.

Postdoc-advisor relationship. Five variables were used to measure this relationship. *Advisor ability* was measured as the response to "How would you rate the overall research accomplishments of your advisor relative to his/her peers in their field?" on a continuous scale from 0 to 10 anchored with the following descriptions: "Among Least Accomplished," "Below Average," "Average," "Above Average," and "Among Most Accomplished." Self-rated ability was measured as the response to "How would you rate your research ability relative to other PostDocs in your specific field of study?" on a continuous scale from 0 to 10 anchored with the following descriptions: "Among the least skilled," "Below Average,"

"Average," "Above Average," and "Among the most skilled." 22.27% of the postdoc respondents gave a response of exactly 5. This may indicate an anchoring bias, with mechanical and psychological factors making respondents unlikely to move the web survey's slider bar from the default value.

Advisor often was a binary variable based on the question "On average, how often do you directly interact with your advisor?" It was coded as 1 if the response indicated direct interaction at least once per week and 0 if interaction was less frequent. *Shape current research* was a binary variable based on the question "How much freedom do you have in influencing the direction of your research project(s)?" It was coded 1 if the response indicated complete or great freedom and 0 if the response indicated some, little, or no freedom. *Lab size* represented the response to the question "Including yourself, approximately how many members are in your primary research lab?" Responses ranged from 1 to 25 or more (8%). Only 944 postdocs reported a lab size. Where lab size was included in regressions, records with missing data were not included.

Program quality. Institutional quality was operationalized with a binary variable coded as 1 for approximately 25% of postdocs who were in appointments at top tier of programs based on the NRC assessment. This assessment reported a 90% confidence interval around each doctoral program's ranking based on various criteria (National Research Council 2011). Z-scores were calculated based on each program's 5th percentile score for the regression-based ranking to allow comparison across fields. In some cases, rankings were imputed at the broad field or institution level if the survey response was not complete enough to identify a specific program. Approximately 25% of respondents were in the highest-ranked tier of programs with rankings 1.3 standard deviations better than the mean. Because the sample already focused on leading research universities, defining the top tier as broadly as the top 25% was appropriate to avoid leverage from large individual programs.

Many universities expressed concerns about the NRC assessment and rankings. While these concerns may be very relevant to assessing the quality of individual programs, there is not a particular concern that the subtleties of these rankings would be correlated with the satisfaction of postdocs. A limitation that is perhaps more relevant to the context of this study is that the quality of a postdoc experience may not depend on the same factors as the quality of a research doctorate program. For example, the practice of assigning office space to doctoral students could represent either a resource-rich environment favoring both students and postdocs or competition between students and postdocs for resources.

Demographics. Six demographic variables were used. Binary variables measured *female* gender, whether the postdoc had any *children*, and whether the postdoc was *married*. *Start year* represented the year the respondent started the first postdoc appointment. Responses ranged from 2002 to 2010, the year the study was conducted. Nationality was analyzed by creating two binary variables for non-US citizens. *Non-US high income* was coded 1 for noncitizen postdocs whose nationality was from a country in the World Bank's high income category. Using 2010 definitions, the World Bank classified countries as high income if their gross national income per capita was above $12,276. Further explanation of the definitions can be found on the World Bank website: http://data.worldbank.org/about/country-classifications. The binary variable *Non-US other* was coded as 1 for noncitizen postdocs from countries with lower incomes. US citizens were the reference category for the analysis of nationality.

Equation 5 was estimated using ordered probit regression analysis with postdocs' dissatisfaction as the dependent variable. Alternative specifications treating the dependent variable as multinomial with three unordered categories and as 5-point and 7-point Likert scales are shown in appendix C. These alternative specifications did not appear to fit the data as well as the 3-category ordered probit model.

RESULTS

Table 14 summarizes the results of the ordered probit regression. Results for factors related to research, career goals, postdoc-advisor interaction, program quality, and demographics are presented below.

Research. Engaging in interesting research seemed to be the most influential factor in avoiding postdoc dissatisfaction (b = -1.557, p<0.001). Being involved in interesting research had an average marginal effect of -0.194 on the probability that a postdoc would be dissatisfied. There was a statistically significant effect on dissatisfaction from being involved in basic research for those postdocs with an interest in basic research (b = -0.877, p = 0.040). Satisfaction also did not appear to be related to the extent to which current research did not match future research interests (b= 0.048, p=0.672). The effect of this mismatch may have been captured by the variable measuring interest in the current research project.

Career goals. As expected, those postdocs who took their appointment out of necessity were more likely to be dissatisfied (b = 0.415, p=0.068). There was a statistically significant interaction between the effect of taking a postdoc appointment because there was no other job available and currently being involved in applied research (b = -0.729, p=0.021). Being involved in applied research seemed to offset somewhat the dissatisfaction associated with taking a postdoc out of necessity. Alternatively, this finding could be interpreted as the reduced likelihood of dissatisfaction associated with applied research being stronger for those who took their postdoc out of necessity. Perhaps these postdocs believed that more experience with applied research would improve their future employment prospects.

With respect to career interests, postdocs who intended to pursue faculty careers focused on research were somewhat less likely to be dissatisfied (b = -0.447, p=0.005).

With respect to research interests, an interest in basic research was associated with a higher probability of dissatisfaction (b=-1.042, p=0.015) that, as seen above, was partially offset if the postdoc's current research project involved basic research, which was the case for almost 90% of the postdocs. Interest in basic research was found to reduce the probability of dissatisfaction, but only among female postdocs (b = -1.058, p=0.001). The apparent absence of this relationship for male postdocs is puzzling, but may relate to more male postdocs in the sample doing basic research when basic research did not interest them. 71% of 72 male postdocs who were not interested in basic research reported that their current project involved basic research. This was true for only 61% of 36 similar female postdocs. An interest in applied research or development was not found to be related to dissatisfaction, regardless of the type of research involved in the current project.

Postdoc-advisor relationship. Consistent with the findings of Scaffidi and Berman (2011) and Davis (2009), measures associated with advisors providing effective mentoring and oversight were associated with a lower probability of dissatisfaction. For example, postdocs who interacted with their advisors at least once per week were less likely to be dissatisfied, an effect that was strongest and statistically significant in the biological sciences (b = -0.406, p = 0.045). The association between infrequent postdoc-advisor interaction and dissatisfaction could be interpreted as psychological contract breach if this level of interaction does not match the postdoc's expectation for the advising relationship (Lambert, Edwards, and Cable 2003).

There was a positive correlation between the postdoc's rating of own research ability and advisor research ability ($b = 0.263$, $p<0.001$). The regression coefficients for advisor ability ($b = 0.173$, $p=0.087$), self-perceived ability ($b = 0.333$, $p = 0.008$), and their interaction ($b = -0.041$, $p = 0.004$) were jointly significant. Perceptions of the advisor's and one's own research ability were associated with a higher probability of dissatisfaction. However, this probability of dissatisfaction diminished when the postdoc rated both self and advisor as high ability. Inspection of the marginal effects (see figure 7) indicated that the effects of increases of perceived research ability in either party on dissatisfaction were negative and increasing in magnitude over both types of perceived research ability. That is, the most accomplished advisors were associated with reduced probability of dissatisfaction for the most skilled postdocs. These results were robust to an alternative specification that treated self-ratings of ability equal to 5 as nonresponse.

Program quality. Surprisingly, being appointed in a high quality academic department was associated with a higher probability of dissatisfaction after controlling for the other variables in the model ($b = 0.383$, $p=0.040$).

Program quality was found to be associated with reduced dissatisfaction through its relationship with autonomy ($b = -0.809$, $p = <0.001$). A postdoc appointment in a high-quality academic department only appeared to be associated with reduced dissatisfaction if the postdoc felt free to shape a research project.[9] While being in a high-quality academic department had a positive correlation of 0.063 ($p=0.050$) with having freedom to shape a

[9] In an alternative specification, shape current research was coded as 1 for all respondents who reported at least "Some freedom." In this model, the interaction between the ability to shape current research and high program quality was positive and approached statistical significance ($\beta = 0.872$, $p=0.050$). This suggests that the reduced probability of dissatisfaction depended on a high, not just moderate, level of freedom to shape the project.

project, 30% of 286 postdocs in high-quality departments reported not having the freedom to shape their research project.

Lab size was used as a control variable because the lab often provides the context for the postdoc-advisor relationship, but no significant effect was found for lab size (p=0.422).

While there was no overall relationship between citizenship and satisfaction, postdocs from outside the US who were not from high income countries were less likely to be dissatisfied with their appointments in the biological sciences (b = -0.448, p=0.055). [10]

Postdocs reported greater satisfaction the more recently they had begun their first postdoc appointment (b = -0.058, p=0.075). Estimates of this effect may be conservative due to attrition of the most dissatisfied postdocs.

The effect of family on women scientists' careers is represented in the model. The interaction between female gender and parenthood reveals that children were associated with an increased probability of dissatisfaction for female postdocs (b = 0.498, p = 0.090).

Dummy variables for life sciences and health sciences were used to control for field fixed effects. The physical and mathematical sciences field was the reference category. Field fixed effects dummies were interacted with all variables to test whether effects were consistent across fields. Two effects specific to the biological sciences have been described previously: postdocs from outside the US but not from high income countries were less likely to be dissatisfied and interacting at least once per week with the advisor was associated with a lower probability of dissatisfaction. In biological sciences, female postdocs were more likely to be dissatisfied (b = 0.672, p = 0.099). On the other hand, in health sciences, female

[10] Using 2010 World Bank definitions. The World Bank defined countries as high income if their gross national income per capita was above $12,276. Further explanation of the definitions can be found on the World Bank website: http://data.worldbank.org/about/country-classifications

postdocs were less likely to be dissatisfied (b = -1.034, p=0.012). For all other variables included in the model, the effects did not differ significantly among fields. In their analysis of job satisfaction in science faculty, Sabharwal and Corley (2009) found that correlates of satisfaction were similar for science and health professions faculty, while correlates were different for engineering and social science faculty.

A surprising aspect of the preceding analysis was the absence of any significant beneficial effect from the quality of the academic department on postdoc satisfaction after controlling for the other variables in the model. In fact, the relationship between quality and satisfaction was in the opposite direction from that expected, with quality increasing the probability of dissatisfaction. The analysis of interaction effects revealed that being in a high-quality program did have a beneficial effect on satisfaction if the postdoc had the freedom to shape a research project.

Frequent advisor interaction was also associated with satisfaction. However, it is possible that faculty in high-quality doctoral research programs have so many competing priorities that they interact less frequently with their postdocs. Seemingly unrelated regression was used to estimate a multiple mediation model (UCLA Academic Technology Services n.d.) that illustrates how freedom to shape a project and less frequent advisor interaction may explain the relationship between quality and satisfaction (see figure 8). High program quality was associated with less frequent advisor interaction (b = -0.128, p<0.001) and greater freedom to shape the current research project (b = 0.061, p=0.064). Further, both frequent advisor interaction (b = -0.200, p<0.001) and freedom to shape the current research project (b = -0.312, p<0.001) were negatively associated with dissatisfaction. The indirect effect of high program quality through advisor interaction was 0.025 (p = 0.002) and the effect through shaping the research project was -0.019 ($p = 0.073$). The total indirect effect was estimated to be 0.007, which was not statistically significant ($p = 0.620$) as expected, because the indirect effects were of opposite sign and similar magnitude. Consistent with the paradox of autonomy (Trevelyan 2001), postdocs in high quality programs appeared to appreciate the increased freedom to shape research projects, but this was offset by less access to advisors, resulting in no net gain from program quality. This finding is also consistent with the dependence of job satisfaction on both autonomy and feedback, especially for workers concerned about career growth, identified in a meta-analytic review of the relationship between job characteristics and job satisfaction (Loher et al. 1985).

While freedom to shape a project could theoretically result from minimal advisor interaction or cause the advisor to allocate less time to supervision, these data do not seem to show a relationship, causal or otherwise, between these variables. The correlation between freedom to shape a project and interacting with the advisor at least once per week was 0.017 ($p = 0.583$).

Chang et al. (2005) identify grantwriting, publishing, teaching, and keeping up with the rapid pace of scientific advancement as demands that compete with postdocs for advisors' time in the interdisciplinary field they study, cancer prevention. Additional responsibilities may mediate the relationship between program quality and less frequent advisor interaction. An index of advisor activity was created based on postdocs' reports of their advisors' involvement in consulting, patenting, advisory board service, and founding or serving as an executive of an entrepreneurial venture. Advisors in high-quality programs participated in a mean of 1.898 activities (CI= 1.516-2.279) and in low quality programs a mean of 0.956 activities (CI= 0.807-1.106).[11]

Modeling this relationship using seemingly unrelated regression (see figure 9), reveals that high program quality is positively associated with the number of advisor activities (b = 0.318, p=0.001). Similar results were obtained by estimating the relationship between program quality and number of activities using zero-inflated Poisson regression, an approach suitable for a dependent variable that is a count measure without overdispersion (StataCorp 2009). There was also a significant negative association between the number of advisor activities and frequent advisor interaction with the postdoc (b = -0.139, p=0.046). While there may be benefits to postdocs from working with advisors with broad experiences and an extensive network of contacts, there did appear to be less frequent interaction. Less frequent interaction was in turn associated with lower levels of satisfaction. Advisor activity measures partially mediated the relationship between program quality and frequency of advisor interaction with the postdoc (c′=0.142, p=002). These findings appear consistent with those of Chang et al. (2005) in that activities such as teaching and grantwriting may also mediate the relationship between quality and advisor interaction.

One limitation of this analysis is the availability of only a binary measure of the advisor's involvement in an activity. It is unknown, for example, how much consulting activity the advisor did or on how many boards the advisor served. There is also no measure available of the advisor's involvement in teaching and mentoring graduate students. It stands to reason that this involvement would be high in high-quality doctoral programs. Further, the

[11] These calculations include only those records where any advisor activities were reported. If records with no advisor activities reported are coded as zero rather than missing data, average number of activities in high quality programs is 0.584 activities (CI= 0.429-0.738) and in low quality programs a mean of 0.360 activities (CI=0.295-0.424).

activities were reported by postdocs, not the advisors themselves. However, it seems likely that postdocs who interacted more frequently with advisors would be more likely to be aware of their advisors' activities, which implies that this estimate of the effect of activities on interaction may be conservative. It is also possible that work-life issues on behalf of either the postdoc or advisor reduce the frequency of interaction. However, postdocs in high quality programs tend to be younger (mean age= 31.876 compared to 32.417, p=0.023), with perhaps fewer work-life conflicts. A final possibility is that reduced interaction with the advisor is a symptom rather than the cause of dissatisfaction. This cannot be dismissed, and the possibility of a negative feedback loop between dissatisfaction and advisor interaction should also be considered.

The postdoc's funding source may also influence the frequency of interaction with the advisor and freedom to shape the research project. There are two potential mechanisms for this influence, which unfortunately cannot be distinguished in these data. First, the postdoc may secure independent funding through a competitive portable fellowship, which would provide the postdoc a great deal of influence over the research project while potentially minimizing the need to interact with an advisor. The advisor may also be less invested in interacting with an independently funded postdoc than with one being paid from grant funding to contribute to the advisor's research. Alternatively, postdocs and advisors could collaborate in securing grant funding. In this case the postdoc and advisor are likely to interact more frequently, particularly during the grantwriting process, and the postdoc may also have more input into the direction of the overall research project or the ability to shape one project within a larger program of research.

DISCUSSION

The probability that the postdoc will be dissatisfied with the appointment is influenced by the type of research being conducted, its relationship to the postdoc's future career goals, postdoc-advisor interaction, and demographic factors. Dissatisfaction is less likely when the postdoc finds the current research project interesting, when the postdoc appointment is consistent with future career interests—especially as a faculty researcher—rather than employment of last resort. Satisfaction is also more likely when the research has an applied element, especially if the postdoc took the appointment for lack of an available job.

Working in a high-quality program does not appear to prevent dissatisfaction and in some cases may even be a contributing factor. If the advisor and postdoc do not interact at least once per week and the postdoc does not have freedom to shape the research projects, the potential benefits of a top program can become liabilities. The postdoc may avoid a potentially unsatisfactory experience by seeking out an appointment that allows greater autonomy and more frequent advisor interaction in a less prestigious department. It also appears that only the most capable, or at least the most confident, are less likely to be dissatisfied when working with advisors they consider among the most accomplished.

These findings should be considered in terms of their implications for national policy, institutions, and individual scientists. One policy approach often advocated to improve the postdoc experience is to fund more postdocs through portable fellowships (Armbruster 2008; COSEPUP 2000). Portable fellowships have the advantage of increasing the postdoc's autonomy. However, they may be associated with less advisor interaction and less integration with labs and university communities. These findings about the influence of program quality on postdoc dissatisfaction suggest that there may be no net benefit if an increase in autonomy is accompanied by a decrease in advisor interaction.

Universities and other research organizations may be able to avoid postdocs' dissatisfaction by providing structure to integrate postdocs into their work environments, even if the postdocs enjoy considerable autonomy in their research direction. Professional development offerings for faculty and postdocs can be designed to facilitate regular interaction as well as promoting the postdocs' empowerment and transition to independent research.

These findings also have implications for new doctorate recipients who are considering taking a postdoc appointment. For those who have the opportunity to take a postdoc appointment that immerses them in interesting research and who plan to pursue faculty research careers, these findings indicate that postdocs are likely to find at least their first appointment satisfactory. However, a faculty research career will be unattainable for many. Actively researching the job market and critically assessing one's own research abilities may bring some scientists to that conclusion sooner rather than later. Those scientists faced with a choice between a postdoc or no job at all may be more satisfied if they secure an appointment involving applied research.

Future research on postdoc satisfaction would be advanced by the use of longitudinal studies that allow for the analysis antecedents and consequences of satisfaction. For example, longitudinal data could be used to investigate the causal relationship between satisfaction and frequency of advisor interaction. It would also be beneficial to incorporate validated global and facet-based measures of satisfaction to facilitate connections to the existing body of satisfaction research in education and employment settings.

Chapter 6

Conclusion

Taken together, the chapters that make up this dissertation advance research on postdocs' motivations, role in research production, and experiences. Much prior research on postdocs has been phenomenological and descriptive in nature. The dissertation approaches the fragmented body of prior research on postdocs with theoretical frameworks that connect the postdoctoral experience with research in psychology, sociology, and economics. The dissertation also takes a multilevel approach to the study of postdoc appointments, considering both individual and organizational factors as well as cross-level relationships. This chapter summarizes findings from the dissertation, describes the current postdoc policy agenda, and suggests directions for further research.

SUMMARY

Chapter 2 reviews the literature on postdocs and suggests potentially testable propositions related to scientists' motivations to pursue postdoc appointments. The annotated bibliography provided in appendix A is comprehensive in its coverage of a wide range of literature discussing postdocs and establishes a valuable starting point for further scholarship on the topic.

The conceptual and empirical chapters of this dissertation suggest a number of implications for policy and directions for further research.

The conceptual model based on the theory of planned behavior, developed in Chapter 3, could potentially suggest several potential policy interventions once it has been empirically validated. First, students in the sciences could be provided with information about academic research careers and other career paths, including government, industry, entrepreneurship, and education. Students should be encouraged to reflect realistically on their own career preferences. Further, it suggests that an understanding of students' beliefs about academic careers and career preferences could be used to develop innovative employment models.

The theory of planned behavior also suggests that lab colleagues, including advisors, can play an important role in socializing doctoral students about the nature and value of various career paths. Increasing the sphere of influential others beyond career academics could help in this regard. Lab relationships that are collegial rather than exploitative are likely to lead students to place more weight on the influence of lab colleagues.

The model suggests that students should also be given opportunities to assess their likely prospects in the scientific labor market. These prospects depend on their level of ability and their success in signaling that ability. Students may also benefit from more information about the level of competition they will face in the labor market, where success depends not just on absolute ability but on relative ability. Their prospects may also be affected by characteristics and choices that constrain their participation in the labor market, such as willingness to relocate or access to capital for entrepreneurial ventures. There may also be opportunities for policy to address these constraints directly through more flexible access to capital and relocation assistance.

Results from Chapter 4 suggest that policies that increase the availability of postdocs, such as relaxed immigration constraints, will support the employment of more faculty since postdocs appear to be complements to faculty. However, such policies may also support the training of more doctoral research assistants, who are likely to also enter the postdoc workforce, perpetuating the cycle.

Chapter 5 implies that advocacy for mentoring is appropriately aligned with the goal of preventing postdoc satisfaction. It also indicates that women scientists may not yet face a level playing field at the postdoctoral stage. These findings also suggest that the autonomy benefits of portable fellowships may be offset if fellowship recipients are not frequently interacting with an advisor.

POSTDOC POLICY AGENDA

The current policy agenda for postdocs in the US is grounded in the 2000 COSEPUP report, *Enhancing the Postdoctoral Experience for Scientists and Engineers: A Guide for Postdoctoral Scholars, Advisers, Institutions, Funding Organizations, and Disciplinary Societies*. This report laid out an agenda of ten action points related to the postdoc experience:

1. Award institutional recognition, status, and compensation commensurate with the contributions of postdocs to the research enterprise.
2. Develop distinct policies and standards for postdocs, modeled on those available for graduate students and faculty.
3. Develop mechanisms for frequent and regular communication between postdocs and their advisers, institutions, funding organizations, and disciplinary societies.
4. Monitor and provide formal evaluations (at least annually) of the performance of postdocs.
5. Ensure that all postdocs have access to health insurance, regardless of funding source, and to institutional services.
6. Set limits for total time of a postdoc appointment (of approximately five years, summing time at all institutions), with clearly described exceptions as appropriate.
7. Invite the participation of postdocs when creating standards, definitions, and conditions for appointments.
8. Provide substantive career guidance to improve postdocs' ability to prepare for regular employment.
9. Improve the quality of data both for postdoctoral working conditions and for the population of postdocs in relation to employment prospects in research.

10. Take steps to improve the transition of postdocs to regular career positions (p. 99).

In the intervening years, institutions have taken steps to address many of these points. Consistent with these recommendations, the NSF added a requirement that postdocs funded out of its grant funds have a mentoring plan included at the proposal stage and documented in annual reports, section 7008 of the 2007 America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science (COMPETES) Act. An evaluation based on data from the Sigma Xi survey documented benefits to postdocs from professional development and structured oversight, but little change in satisfaction associated with improvement to compensation (Davis 2009).

Steps have also been taken to improve data collection about postdocs and establish a new agenda for policy and research. The NPA, the NSF, and the National Academy of Sciences (NAS) COSEPUP are key stakeholder groups in these initiatives.

The NPA, founded in 2002, has hosted annual meetings since 2003. A review of annual meeting agendas from 2003-2012 reveals that policy and collective action have been some of the most consistent priorities at these meetings (National Postdoctoral Association 2012). Other consistent themes at the meetings have been mentoring, diversity, careers, funding, and immigration. Topics that have appeared for the first time on these meeting agendas since 2010, potentially indicating emerging areas of interest, include unionization, industry careers, entrepreneurship, and teaching.

The NSF has initiated a project to improve collection of data on postdocs (Oliver and Rivers 2006; Survey Sciences Group 2008). This project has proceeded through two phases. In the first phase, Survey Sciences Group focused on developing sampling strategies to capture postdocs believed to be missing from current data collection efforts: those on temporary visas who earned their PhD outside the US, those with doctorates other than the PhD, and those outside of academia. In the second phase, Survey Sciences Group tested the feasibility of their proposed sampling strategy, including the use of FastLane data on funding sources for postdocs. While many feasibility challenges were identified, the project has now progressed to development of survey items that can be used in a survey of postdocs and potentially integrated into existing surveys such as the SDR.

The NAS COSEPUP has established a committee to undertake a project on "The State of the Postdoctoral Experience for Scientists and Engineers Revisited." As described on the NAS Current Projects System website (accessed April 3, 2012) the committee has been charged with addressing the following questions:

> 1) General characteristics of postdoctoral fellows and positions in the U.S.
> How many postdoctoral fellows are there in the U.S.? Where are they working, in what fields, and for how many years?
> 2) Current conditions for postdocs
> Are expectations of principal investigators made clear? Do postdocs receive adequate professional status and privileges as well as salary and benefits? Are the rules clear about credit they receive for their discoveries in the lab, and are they receiving adequate career guidance and development?
> 3) Institutional provisions.
> Do postdocs serve as investigators on grants? Are questions of intellectual property identified and provided for? At universities, is teaching required; if not, is it encouraged or discouraged?
> 4) Career paths
> Where do postdocs come from? What do we know and what can we learn about what postdocs do after they complete their programs. How well are the postdoc programs matched with the career opportunities that are open to them?
> 5) Recent trends and changes
> Have previous recommendations been implemented and to what effect? Are there other developments in the research enterprise that have had a significant effect on postdocs?
> 6) Participation in the research enterprise
> Are postdocs being invited to review journal articles and to write grant proposals, either formally by journals and agencies or informally by PIs, and is this experience useful? What are the impressions of postdocs about peer review today? Are postdocs being used effectively in research? Are postdocs acquiring the skills they need to become productive independent researchers in the future?

This dissertation provides information that could potentially inform points 2, 4, and 6 of the committee's charge. With respect to point 2, current conditions for postdocs, Chapter 5 on postdoc dissatisfaction sheds light on the nature of the postdoc experience. With respect to point 4, career paths, Chapter 3 provides a conceptual framework for understanding the relationship of postdoc appointments to career plans. With respect to point 6, participation in the research enterprise, Chapter 4 provides an economic perspective on the effective use of postdocs in research.

DIRECTIONS FOR FURTHER RESEARCH

There are three potential extensions of this dissertation research. First, the theory of planned behavior offers a framework for the empirical study of decision making in scientific careers more broadly, encompassing the choice between industry and academia and, within industry careers, the choice between startups and established firms. By integrating findings from behavioral economics, it may be possible to create a more thorough understanding of seemingly irrational decisions to pursue graduate study in the face of highly uncertain career opportunities.

Second, it would be useful to examine the role of postdocs as a labor input in the production of university research over time. Just as technology can be a substitute for labor in some contexts and a complement in others, postdocs' role in the production of research may be different under different circumstances.

Third, research on satisfaction and dissatisfaction can make use of existing validated facet-based measures of satisfaction to connect this research with the extensive literature on satisfaction in work and educational settings. Longitudinal research on satisfaction will make it possible to study causal effects and potentially evaluate the results of policy interventions.

Table 1

Postdoctoral Scholars in the US: Large-scale Surveys

Survey name	Description
Postdoctoral Work in American Universities	16 campus visits conducted in 1960 by Bernard Berelson and David Sills for the Association of American Universities. Surveys were also mailed to presidents of AAU member schools and the researchers met with representatives of major funders of postdoctoral research.
The Invisible University: Postdoctoral Education in the US	Conducted by Richard Curtis for the National Research Council. A census of postdocs was taken in spring 1967 and qualitative data were gathered from interviews in agencies, non-profits, and industry and 20 campus visits.
Postdoctoral Appointments and Disappointments	A two stage study directed by Porter Coggeshall for the National Research Council. In the first stage, survey responses from 150 university administrators and 40 R&D managers in government and industry as well as information from site visits to 50 departments at 15 universities were used to craft a proposal for the study's second stage, which included surveys of chairmen of science and engineering departments, US citizens with science and engineering doctorates, and foreign citizens holding postdoctoral appointments.
Extending the Educational Ladder: The Changing Quality and Value of Postdoctoral Study	Compiled by William Zumeta for the National Science Foundation, Spencer Foundation, Lilly Endowment, Mellon Foundation, and Higher Education Research Institute. Data are from a variety of sources including the Survey of Earned Doctorates, Survey of Doctorate Recipients, other National Research Council Surveys, and the Higher Education Research Institute Survey of Mobility and Nontraditional Careers in Science and Engineering.
PhDs 10 Years Later	Conducted by Maresi Nerad and Joseph Cerny in approximately 1996 and funded by the Mellon Foundation and National Science Foundation. The survey involved almost 6000 PhDs from biochemistry, computer science, electrical ,engineering, English, mathematics, and political science from 61 institutions.

Table 1 (*continued*)

Survey name	Description
Enhancing the postdoctoral experience for scientists and engineers	Directed by Deborah Stine for the Committee on Science, Engineering, and Public Policy from 1999-2000. Includes analysis of secondary data as well as survey responses from 40 organizations with postdoctoral appointees, 39 focus groups, and a day-long workshop with over 100 participants.
Sigma Xi	Led by Geoff Davis for Sigma Xi in partnership with the National Postdoctoral Association, Science NextWave Postdoc Network between December 2003 and April 2005. Includes 22,400 postdocs at 47 institutions.
American Association of Universities	Conducted by the Graduate and Postdoctoral Education Committee of the AAU in March 2005. Included responses from 25 public and 14 private AAU universities.

Table 2

National Science Foundation Surveys with Data about Postdoctoral Scholars

Survey Name	Description
Survey of Earned Doctorates (annual)	Provides information about new doctorate recipients with post-graduation commitments for employment or study. Postdoctoral appointments are counted as "study" for this purpose. Summary data tables are publicly available.
Survey of Doctorate Recipients (biennial)	1993 and 1997 surveys asked if current job is a postdoctoral appointment. 1999, 2001, 2003, and 2008 ask if job was a postdoc and reasons for taking the postdoc. 1995 and 2006 asked respondents if current job is a postdoctoral appointment, number of postdocs held, and details about up to 3 postdocs. In 1993 an indicator of whether the position is a postdoc is available for public use. Other data about postdocs available only in restricted use dataset.
Survey of Graduate Students and Postdoctorates in Science and Engineering (annual)	This survey of US academic institutions provides aggregate data on the number and characteristics of postdoctoral scholars.

Table 3

Substitution and Complementarity: Selected Studies of Research Production

Study	Factors	Key findings	Methods	Data
David et al. 1999	Public R&D (grants and contracts) and private R&D	Ambiguous	Review	30 studies conducted over 35 years at the line of business/ lab, firm, industry, and aggregate levels.
Caloghirou et al. 2004	Internal knowledge creation and external knowledge seeking	Both contribute to innovation in a potentially complementary way.	OLS	558 firms from Greece, Italy, Denmark, UK, France, Germany and the Netherlands surveyed in 2000.
Mowery and Ziedonis 2007	Invention disclosures, licenses, patents and materials transfer agreements (MTAs)	MTAs do not reduce commercialization	Comparison of means.	83 invention disclosures linked to MTAs at U. of MI
Blume-Kouhout et al. 2009	Federal funding and non-federal funding for life sciences university R&D	Complementarity	Multivariate linear regression, fixed effects, and instrumental variables	NSF Survey of Research and Development Expenditures at Universities and Colleges and NIH administrative records.

Table 4

Substitution and Complementarity: Selected Studies of Contingent Employment

Study	Factors	Key findings	Methods	Data
Houseman et al. 2003	Agency temporary workers and regular employees in tight labor market	Substitutes	Case studies, interviews	Interview data from 6 hospitals and 5 auto parts manufacturing firms, 1999 and 2000
Ko 2003	Contingent and internal employment.	Complements	Tobit regression	727 employers from the National Organizations Study, 1991
Harrison 2007	US multinationals' employees in US and in other countries (offshoring)	Complements in high-income countries, substitution in low-income countries.	Regression plots	1,746 parent firms and their foreign affiliates from Bureau of Economic Analysis, 1977 to 1999.
Crino 2009	Developed country and offshore workers	Weak substitutability	Review	42 empirical studies of offshoring

Table 5

Substitution and Complementarity: Selected Studies of Immigration

Study	Factors	Key findings	Methods	Data
Grossman 1982	Immigrants, 1st generation, natives	All labor groups are substitutes, small wage effects on native workers	Cross-sectional factor share calculations, seemingly unrelated regression	19 Standard Metropolitan Statistical Areas. National Origin and Language Subject Report, County and City Data Book, Census of Manufacturing, and Annual Survey of Manufacturing, 1969-1970.
Borjas 2003	Immigrants and native workers across range of education and experience	College graduates and high school dropouts experience largest wage decrease from immigration	Regression	1960, 1970, 1980, 1990 Decennial Census Public Use Microdata Samples and 1999, 2000, 2001 Annual Demographic Supplement of the Current Population Surveys
Mendola 2008	Migration and adoption of technology	Complementary	IV, simultaneous equations.	3,404 households Bangladesh.
Okkerse 2008	Immigrants and native workers	Mixed results, effects on native workers generally small if any	Review	Simulation and econometric analyses immigration labor market effects.

Table 6

Data Sources Used in Production Equation for University Research

Data element	Variable	Source	Unit
Life sciences articles published	Q	Web of Science	Program
Life sciences citations	Q	Web of Science, National Research Council (NRC) Assessment	Program
NIH Stipend	$w_{POSTDOC}$	Ruth L. Kirschstein National Research Service Award (NRSA)	Nation
Faculty salaries	$w_{FACULTY}$	National Education Association faculty salary report, Almanac of Higher Education	University
Construction cost of lab space	$w_{CAPITAL}$	RSMeans Construction Cost Data	City
Rental rate of lab space	$w_{CAPITAL}$	Published accounts	City
WebCaspar interface			
Graduate tuition and fees, out-of-state	$w_{DOCTORAL}$	Integrated Postsecondary Educational Data System (IPEDS) Institutional Characteristics Survey Tuition Data	University
Graduate tuition and fees, in-state	$w_{DOCTORAL}$	IPEDS Institutional Characteristics Survey Tuition Data	University
Number of postdocs	$X_{POSTDOC}$	National Science Foundation (NSF) Graduates and Postdoctorates	Program

Table 6 (*continued*)

Data element	Variable	Source	Unit
Net assignable square footage	$X_{CAPITAL}$	NSF Survey of Science and Engineering Research Facilities	Program
NRC Assessment of Research Doctoral Programs			
Number of PhD students	$X_{DOCTORAL}$	NRC Assessment	Program
Research assistantships	$X_{DOCTORAL}$	NRC Assessment	Program
International	w_{PHD}	NRC Assessment	Program
Total faculty	$X_{FACULTY}$	NRC Assessment	Program

Table 7

Descriptive Statistics for Research Production Function

Variable	Mean	s.d.
Doctoral	259.235	22.658
Percent international	0.314	0.011
Graduate tuition, in-state	12,518.740	931.631
Graduate tuition, out-of-state	19,043.530	652.055
Postdocs	185.455	31.774
Total doctoral faculty	358.862	30.992
Average salary	79.467	1.320
Average benefits	20.807	0.423
Lab space (sq. ft.)	535,262.700	46,075.590
Lab rent	50.457	0.585
Publications	1,064.690	98.351
Citations	4,037.335	539.323
Doctoral students	327.476	27.241
Public	0.690	0.039
Share doctoral	0.102	0.005
Share postdocs	0.064	0.004
Share faculty	0.376	0.017
Share capital	0.304	0.023

Table 8

Correlations Between Variables in Seemingly Unrelated Regression Equations

		1	2	3	4	5	6	7
1	Share doctoral	1.000						
2	Share postdoc	0.199 *	1.000					
3	Share faculty	-0.078	-0.381 ***	1.000				
4	Share capital	-0.523 ***	-0.266 **	-0.671 ***	1.000			
5	lndoctoral	0.259 **	0.293 ***	-0.051	-0.231 *	1.000		
6	lnpostdocs	0.102	0.644 ***	-0.213 **	-0.187 *	0.835 ***	1.000	
7	lnfaculty	-0.100	0.119	0.168 *	-0.164 *	0.893 ***	0.764 ***	1.000
8	lncapital	-0.226 *	0.180 *	-0.272 **	0.264 **	0.814 ***	0.767 ***	0.877 ***

+ p<0.10, * p<0.05, ** p<0.01, *** p<0.001

Table 9

Seemingly Unrelated Regression Results for Research Production Factor Share Equations

	Factor share											
Factor	Doctoral b/se			Postdocs b/se			Faculty b/se			Capital b/se		
Model 1. Full sample												
lnDoctoral	0.096	(0.005)	***	-0.006	(0.003)	*	-0.052	(0.005)	***	-0.038	(0.004)	***
lnPostdocs	-0.006	(0.003)	*	0.054	(0.003)	***	-0.018	(0.003)	***	-0.029	(0.003)	***
lnFaculty	-0.052	(0.005)	***	-0.018	(0.003)	***	0.218	(0.007)	***	-0.147	(0.005)	***
lnCapital	-0.038	(0.004)	***	-0.029	(0.003)	***	-0.147	(0.005)	***	0.215	(0.006)	***
Constant	0.505	(0.030)	***	0.361	(0.023)	***	1.434	(0.037)	***	-1.300	(0.044)	***
n=145												
r2	0.748			0.728			0.886			0.892		
chi2	449.700			395.600			1199.700			1460.100		
p	< 0.001			<0.001			<0.001			<0.001		
Model 2. Public												
lnDoctoral	0.072	(0.003)	***	-0.006	(0.002)	***	-0.038	(0.003)	***	-0.031	(0.003)	***
lnPostdocs	-0.006	(0.002)	***	0.049	(0.003)	***	-0.019	(0.003)	***	-0.024	(0.003)	***
lnFaculty	-0.038	(0.003)	***	-0.019	(0.003)	***	0.227	(0.006)	***	-0.167	(0.004)	***
lnCapital	-0.031	(0.003)	***	-0.024	(0.003)	***	-0.167	(0.004)	***	0.222	(0.005)	***
Constant	0.418	(0.021)	***	0.318	(0.024)	***	1.585	(0.035)	***	-1.321	(0.041)	***
n=100												
r2	0.867			0.732			0.929			0.943		
chi2	693.500			291.900			1735.900			1895.900		
p	<0.001			<0.001			<0.001			<0.001		

Table 9 *(continued)*

	Factor share											
	Doctoral b/se			Postdocs b/se			Faculty b/se			Capital b/se		
Model 3. Private												
lnDoctoral	0.136	(0.012)	***	-0.017	(0.005)	**	-0.076	(0.011)	***	-0.039	(0.007)	***
lnPostdocs	-0.017	(0.005)	***	0.064	(0.006)	***	-0.014	(0.006)	*	-0.034	(0.005)	***
lnFaculty	-0.076	(0.011)	***	-0.014	(0.006)	*	0.199	(0.015)	***	-0.110	(0.010)	***
lnCapital	-0.039	(0.007)	***	-0.034	(0.005)	***	-0.110	(0.010)	***	0.183	(0.010)	***
Constant	0.541	(0.059)	***	0.403	(0.041)	***	1.156	(0.076)	***	-1.099	(0.073)	***
n=45												
r2		0.791			0.705			0.811			0.888	
chi2		168.300			135.100			200.000			390.000	
p		<0.001			<0.001			<0.001			<0.001	

†p<0.10, * p<0.05, ** p<0.01, *** p<0.001

Table 10

Elasticities of Factor Complementarities at the Mean of the Factor Shares.

	Elasticities of factor complementarities with respect to the quantity of							
	Doctoral		Postdocs		Faculty		Capital	
Doctoral	-0.122	***	0.422	*	0.097	***	0.107	***
Postdocs			-0.288	***	0.534	***	-0.015	**
Faculty					-0.066	***	0.029	***
Public								
Doctoral	-0.245	***	0.213	***	0.209	***	0.163	***
Postdocs			-0.293	***	0.457	***	0.086	**
Faculty					-0.227	***	-0.004	***
Private								
Doctoral	-0.074	***	0.178	***	-0.002	**	0.254	***
Postdocs			-0.311	***	0.698	*	-0.065	***
Faculty					-0.105	***	0.087	***

Elasticities of factor complementarity are defined as d $\ln(p_i/p_j)$/d $\ln(q_i/q_j)$, or $C_{ij}=(\gamma_{ij}+S_iS_j)$ and $C_{ii}=(\gamma_{ii} + S_i^2 - S_i)/S_i$, where γ_{ij} is the translog production function coefficient and S_i is the share of factor *i* in output. The estimates above are evaluated at the means of the S_i's. Factors are substitutes if $C_{ij} < 0$) and complements if $C_{ij}>0$.

†p<0.10, * p<0.05, ** p<0.01, *** p<0.001

Table 11

Selected Published Surveys Measuring Postdoc Satisfaction in the US

Survey	Data year	Sample	Measure	Findings
Sigma Xi Postdoc Survey (Davis 2005)	2003	Postdocs in academic and non-academic organizations in science, engineering, social science, and humanities fields.	5-point Likert scale	22% of postdocs expressed dissatisfaction.
Survey of Doctorate Recipients (Corley and Sabharwal 2007)	2001	Postdocs who earned PhDs in the US	Rated 9 aspects of postdoc experience on 5-point Likert scale, very dissatisfied to very satisfied.	Foreign-born scientists less satisfied on 5 criteria. Postdocs satisfied with intrinsic motivation, somewhat dissatisfied with extrinsic motivation.
Survey of Scientists and Engineers (National Research Council 1981)	1979	Postdocs in the biosciences who had received their PhDs in 1972 and 1978.	Qualitative comments	75% of 1972 graduates described postdoc appointments as highly rewarding. Approximately 75% of 1978 graduates were dissatisfied.
Postdoctoral Experience Questionnaire (Curtis and National Research Council 1969)	1967	Academic scientists	Rated 8 aspects of postdoc experience on 3-point scale unsatisfac-tory to highly satisfactory.	Only opportunity to teach was rated less than satisfactory.

Table 12

Descriptive Statistics for Total Sample and Three Fields: Biological Sciences, Health Sciences, and Physical and Mathematical Sciences

	Sample							
Variable	Total		Biological sciences		Health sciences		Physical and mathematical sciences	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Satisfaction	5.464	0.047	5.422	0.061	5.506	0.067	5.535	0.074
Research interesting	0.945	0.008	0.954	0.009	0.966	0.009	0.930	0.014
Mismatch average	0.873	0.018	0.937	0.024	0.937	0.027	0.784	0.026
Current basic	0.899	0.010	0.947	0.010	0.945	0.011	0.821	0.021
Current applied	0.591	0.017	0.527	0.021	0.529	0.024	0.696	0.025
Current development	0.339	0.016	0.201	0.017	0.216	0.020	0.568	0.027
Reason - No job	0.199	0.014	0.192	0.017	0.193	0.019	0.210	0.022
Reason - Desired job	0.862	0.012	0.874	0.014	0.878	0.016	0.842	0.020
Reason - Skills	0.865	0.012	0.863	0.015	0.855	0.017	0.869	0.019
Reason - More time	0.387	0.016	0.388	0.021	0.386	0.023	0.386	0.027
Faculty career plans	0.523	0.017	0.548	0.021	0.533	0.024	0.483	0.028
Interest in basic	0.901	0.010	0.916	0.012	0.922	0.013	0.875	0.018
Interest in applied	0.943	0.008	0.941	0.010	0.943	0.011	0.945	0.013
Interest in development	0.597	0.017	0.532	0.021	0.545	0.024	0.705	0.025
Advisor ability	8.229	0.054	8.225	0.067	8.251	0.075	8.235	0.090
Advisor 1+ per week	0.789	0.014	0.797	0.017	0.809	0.019	0.775	0.023
Self-rated ability	6.975	0.056	7.017	0.070	7.066	0.078	6.905	0.093
Shape current research	0.666	0.016	0.686	0.020	0.683	0.022	0.635	0.027
Lab size	11.107	0.214	10.408	0.246	10.297	0.277	12.252	0.387
High quality program	0.267	0.015	0.229	0.018	0.205	0.019	0.331	0.026

Table 12 (*continued*)

Variable	Sample							
	Total		Biological sciences		Health sciences		Physical and mathematical sciences	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Female	0.346	0.016	0.420	0.021	0.409	0.024	0.222	0.023
Children	0.299	0.015	0.347	0.020	0.347	0.023	0.222	0.023
Married	0.698	0.016	0.729	0.019	0.733	0.021	0.647	0.026
Start year	2007.283	0.065	2007.106	0.087	2007.172	0.099	2007.562	0.095
Non-US high income	0.201	0.014	0.183	0.017	0.184	0.019	0.231	0.023
Non-US other	0.297	0.015	0.256	0.019	0.257	0.021	0.368	0.027

Table 13

Correlation Table for Analysis of Postdocs' Dissatisfaction

		1		2		3		4		5		6	
1	Satisfaction	1											
2	Research interesting	0.386	***	1									
3	Mismatch average	-0.244	***	-0.184	***	1							
4	Current basic	0.113	***	0.109	***	-0.042							
5	Current applied	0.182	***	0.118	***	-0.476	***	-0.142	***	1			
6	Current development	0.083	**	0.036		-0.358	***	-0.140	***	0.379	***	1	
7	Reason - No job	-0.124	***	-0.052	†	0.053	†	-0.089	**	0.059	†	0.010	
8	Reason - Desired job	0.082	**	0.080	**	0.001		0.088	**	0.033		-0.076	*
9	Reason - Skills	0.158	***	0.073	*	-0.119	***	0.068	*	0.142	***	0.041	
10	Reason - More time	-0.057	†	-0.021		0.049		-0.018		-0.007		-0.027	
11	Faculty career plans	0.177	***	0.141	***	-0.118	***	0.094	**	0.034		-0.015	
12	Interest in basic	0.150	***	0.183	***	-0.065	*	0.233	***	-0.080	**	-0.074	*
13	Interest in applied	0.046		0.039	*	0.065	*	0.015		0.188	***	0.065	*
14	Interest in develop	-0.035		0.001		0.100	**	-0.021		0.175	***	0.414	***
15	Advisor ability	0.254	***	0.095	**	-0.039		0.071	*	0.030		0.048	
16	Advisor 1+ per week	0.161	***	0.045		-0.016		0.017		0.059	†	0.009	
17	Self-rated ability	0.125	***	0.049		-0.078	*	0.124	***	0.082	**	0.064	*
18	Shape current research	0.289	***	0.175	***	-0.089	**	0.138	***	-0.001		-0.055	†
19	Lab size	0.097	**	0.027		-0.040		-0.071	*	0.066	*	0.088	**
20	High quality program	0.012		-0.007		0.018		-0.020		0.018		0.019	
21	Female	-0.009		0.003		0.047		-0.004		-0.053	†	-0.138	***
22	Children	0.025		0.010		0.030		-0.003		0.000		0.004	
23	Married	0.064	*	0.028		0.067	*	-0.010		0.005		-0.044	
24	Start year	0.057	†	-0.017		-0.031		-0.093	**	0.066	*	0.072	*
25	Non-US high income	0.013		-0.005		0.003		-0.015		-0.079	**	-0.021	
26	Non-US other	-0.015		-0.038		-0.088	**	-0.057	†	0.150	***	0.119	***

Table 13 (*continued*)

		7		8		9		10		11		12	
7	Reason - No job	1											
8	Reason - Desired job	-0.110	***	1									
9	Reason - Skills	-0.213	***	0.354	***	1							
10	Reason - More time	0.049		-0.022		0.014		1					
11	Faculty career plans	-0.190	***	0.126	***	0.145	***	-0.120	***	1			
12	Interest in basic	-0.086	**	0.116	***	0.069	*	-0.069	*	0.213	***	1	
13	Interest in applied	0.027		0.036		0.043		-0.012		0.045		0.180	***
14	Interest in develop	0.000		-0.072	*	0.019		0.038		0.013		0.004	
15	Advisor ability	-0.098	**	0.029		0.062	*	-0.026		0.079	**	0.035	
16	Advisor 1+ per week	0.010		0.022		0.010		-0.016		-0.014		0.078	*
17	Self-rated ability	-0.054	†	0.062	*	0.067	*	-0.065	*	0.188	***	0.057	†
18	Shape current research	-0.131	***	0.086	**	0.017		-0.027		0.154	***	0.137	***
19	Lab size	-0.053		0.039		0.024		-0.070	*	0.023		-0.032	
20	High quality program	-0.035		0.012		0.005		-0.017		0.133	***	0.051	†
21	Female	0.016		0.019		-0.013		0.066	*	-0.110	***	0.000	
22	Children	-0.024		-0.017		-0.026		-0.057	†	-0.004		-0.089	**
23	Married	-0.015		-0.002		-0.030		-0.041		0.025		-0.047	
24	Start year	0.138	***	-0.021		-0.068	*	0.036		-0.147	***	-0.061	*
25	Non-US high income	-0.111	***	0.042		0.037		-0.052	†	0.086	**	0.028	
26	Non-US other	0.084	**	-0.072	*	0.005		0.043		-0.005		-0.153	***

Table 13 (*continued*)

		13		14		15		16		17		18	
13	Interest in applied	1											
14	Interest in develop	0.256	***	1									
15	Advisor ability	0.037		0.035		1							
16	Advisor 1+ per week	0.070	*	0.020		-0.024		1					
17	Self-rated ability	0.054	†	0.125	***	0.263	***	0.012		1			
18	Shape current research	0.018		-0.035		0.196	***	0.017		0.196	***	1	
19	Lab size	0.025		0.066	*	0.302	***	-0.277	***	0.098	**	0.103	**
20	High quality program	0.021		0.024		0.097	**	-0.133	***	0.006		0.058	†
21	Female	0.003		-0.124	***	-0.037		-0.032		-0.142	***	0.006	
22	Children	0.007		0.054	†	0.023		-0.008		0.104	***	-0.089	**
23	Married	0.040		0.011		0.018		0.000		0.047		-0.019	
24	Start year	-0.040		-0.055	†	-0.019		0.004		-0.226	***	-0.043	
25	Non-US high income	0.043		0.004		0.015		-0.075	*	0.008		0.025	
26	Non-US other	-0.048		0.100	***	-0.016		-0.010		0.131	***	-0.176	***

Table 13 (*continued*)

		19		20		21		22		23		24		25	
19	Lab size	1													
20	High quality	0.236	***	1											
21	Female	-0.042		-0.047		1									
22	Children	-0.013		-0.067	*	-0.061	*	1							
23	Married	-0.005		0.028		0.004		0.407	***	1					
24	Start year	-0.047		-0.019		0.095	**	-0.153	***	-0.058	†	1			
25	Non-US high income	0.074	*	0.090	**	0.005		-0.039		-0.060	*	-0.108	***	1	
26	Non-US other	-0.054	†	-0.069	*	-0.100	***	0.144	***	0.010		-0.127	***	-0.354	***

†p<0.10, * p<0.05, ** p<0.01, *** p<0.001

Table 14

Probit Models of Dissatisfaction with Current Postdoc Experience

Category	Variable	Ordered probit			Binary probit		
Research	Research interesting	-1.557	(0.300)	***	-1.917	0.337	***
	Mismatch average	0.048	(0.125)		-0.023	0.162	
	Current basic	0.431	(0.430)		0.778	0.579	
	Current applied	0.114	(0.527)		-0.308	0.195	
	Current development	-0.476	(0.407)		-0.203	0.216	
Career plans	Reason - No job	0.415	(0.228)	†	0.632	0.255	*
	Reason - Desired job	0.105	(0.172)		0.300	0.177	†
	Reason - Skills	-0.288	(0.176)		0.003	0.222	
	Reason - More time	0.098	(0.096)		-0.005	0.131	
	Faculty career plans	-0.447	(0.159)	**	-0.539	0.205	**
	Interest in basic	1.042	(0.429)	*	1.358	0.568	*
	Interest in applied	-0.079	(0.270)		0.680	0.468	
	Interest in development	0.253	(0.158)		0.343	0.162	*
Postdoc-advisor relationship	Advisor ability	0.173	(0.101)	†	0.406	0.114	***
	Advisor 1+ per week	-0.217	(0.224)		-0.187	0.366	
	Ability (self-rated)	0.333	(0.126)	**	0.678	0.125	***
	Shape current research	-0.237	(0.185)		-0.196	0.249	
	Lab size	-0.009	(0.011)		-0.010	0.014	
Program quality	High quality program	0.383	(0.187)	*	0.506	(0.220)	*
Demographics	Female	0.552	(0.356)		0.465	0.555	
	Children	-0.366	(0.192)	†	-0.372	0.175	*

Table 14 (*continued*)

Category	Variable	Ordered probit			Binary probit		
	Married	-0.221	(0.123)		-0.200	0.166	
	Start year	-0.058	(0.032)	†	-0.127	0.036	***
	Non-US high income	-0.041	(0.161)		-0.239	0.180	
	Non-US other	0.128	(0.224)		-0.354	0.349	
Interactions	Basic current x interest	-0.877	(0.427)	*	-1.009	0.669	
	Applied current x interest	-0.458	(0.558)		—[a]	—[a]	
	Develop current x interest	0.540	(0.471)		—[a]	—[a]	
	No job x applied	-0.729	(0.316)	*	-1.284	(0.444)	**
	Ability x advisor ability	-0.041	(0.014)	**	-0.082	(0.015)	**
	High quality x shape	-0.809	(0.241)	**	-1.073	(0.355)	**
	Female x interest in basic	-1.058	(0.322)	**	-1.570	(0.518)	**
	Female x children	0.498	(0.294)	†	0.641	(0.356)	†
	Female x biological sciences	0.672	(0.407)	†	1.522	(0.553)	**
	Female x health sciences	-1.034	(0.411)	*	-1.264	(0.561)	*
	Non-US other x bio science	0.448	(0.233)	†	-0.492	(0.351)	
	Advisor 1+ per week x bio science	-0.406	(0.202)	*	-0.568	(0.318)	†
	Biological sciences	0.547	(0.276)	*	-0.079	(0.430)	
	Health sciences	0.139	(0.246)		0.677	(0.404)	†

Table 14 (*continued)*

Category	Variable	Ordered probit			Binary probit		
	Constant				250.708	(73.042)	***
	Cut 1 constant	-115.531	(65.428)	†			
	Cut 2 constant	-115.092	(65.435)	†			
	pseudo r-squared		0.254			0.395	
	N		764			764	
	p		<0.001			<0.001	
	ll		-332.480			-161.247	

[a] Omitted due to fully determined observations

† p<0.10, * p<0.05, ** p<0.01, *** p<0.001

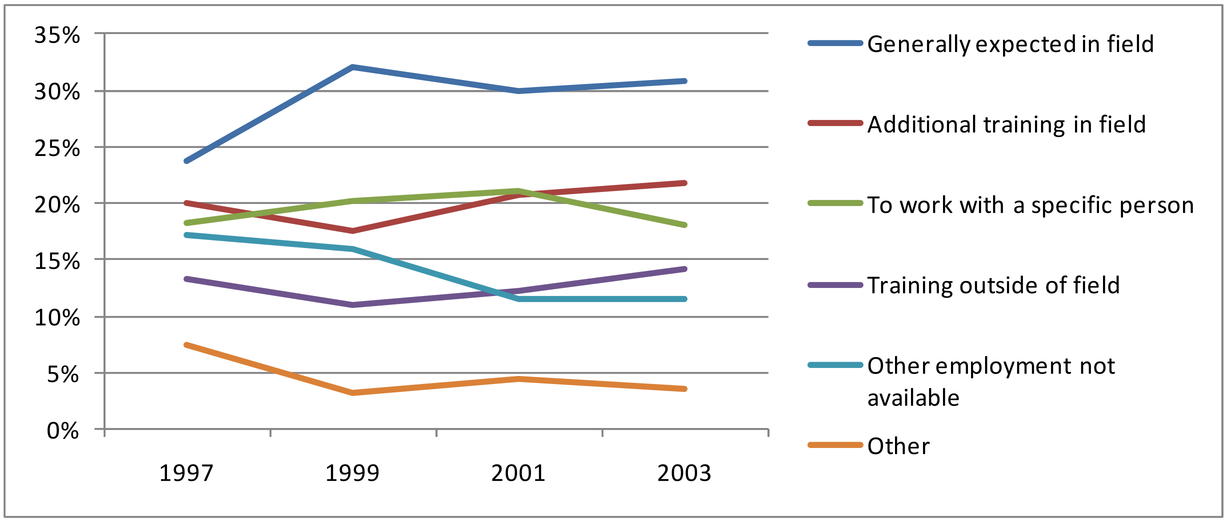

Figure 1. Primary reasons for becoming a postdoc.

Source: Survey of Doctorate Recipients data from SESTAT Metadata Explorer.

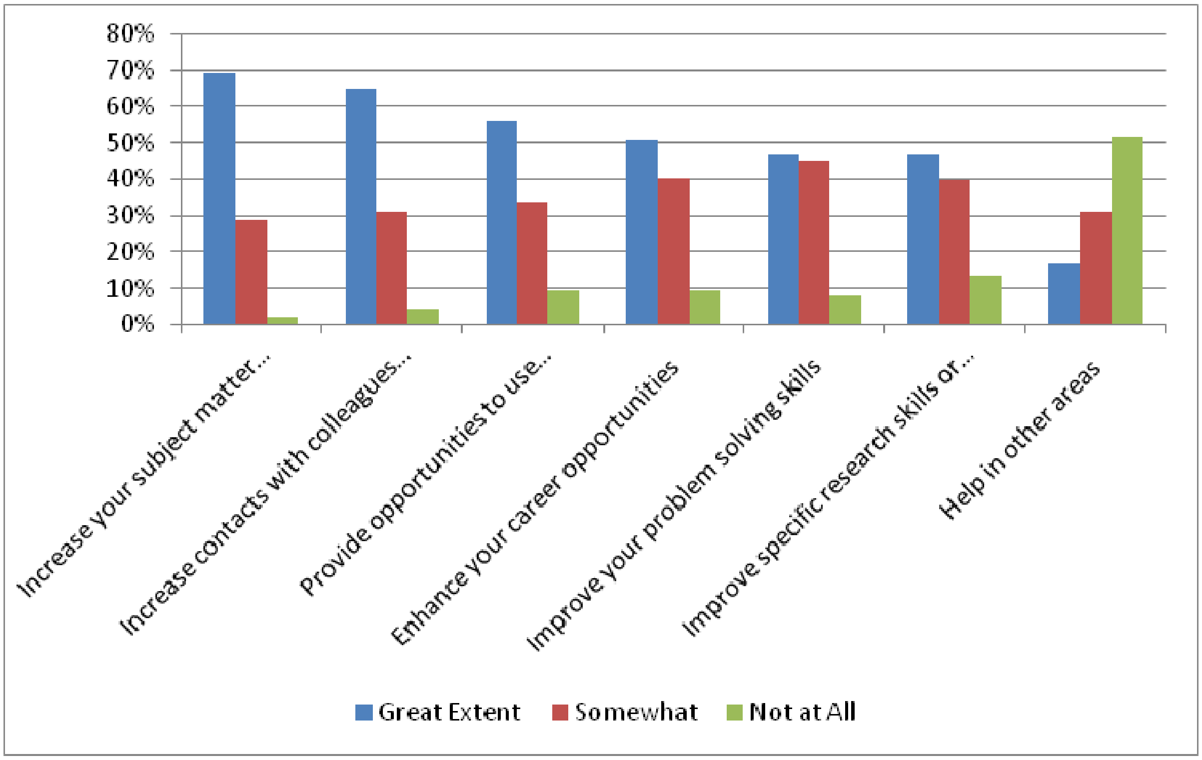

Figure 2. Benefits of postdoc appointments.

Source: Survey of Doctorate Recipients data from SESTAT Metadata Explorer.

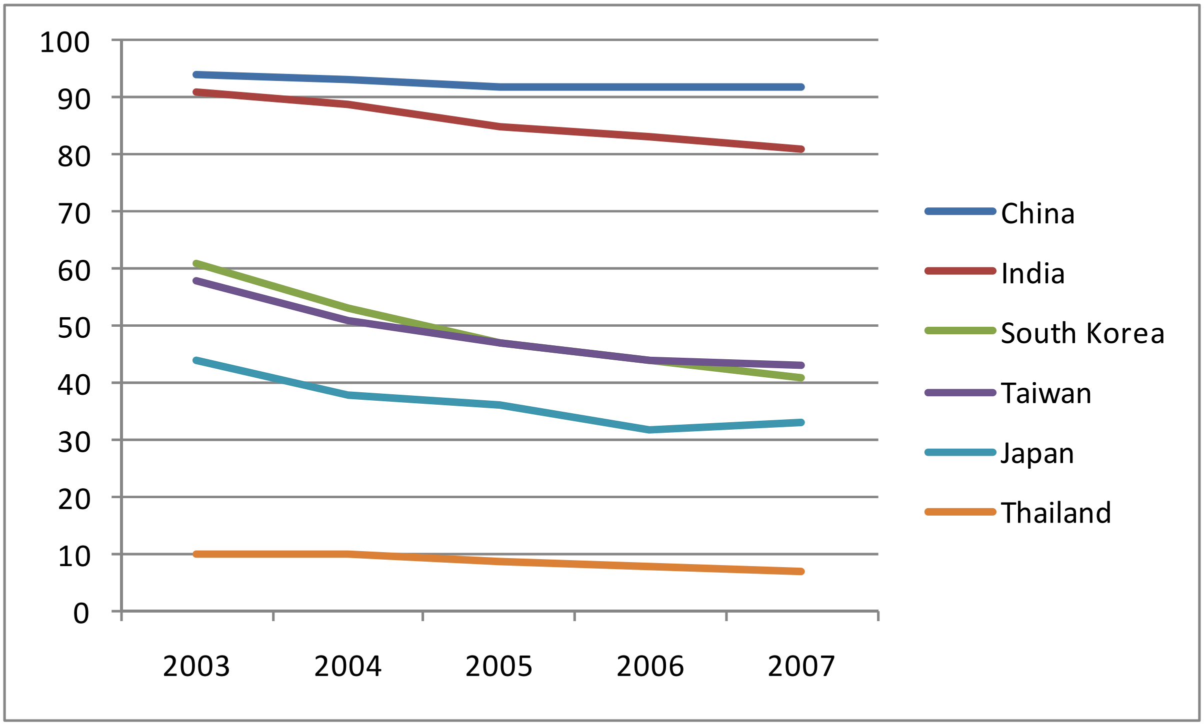

Figure 3. Stay rates for 2002 temporary resident science and engineering doctorate recipients from Asian nations.

Source: Adapted from Finn, M. G. (2010). Stay rates of foreign doctorate recipients from US universities, 2007 (pp. 33). Oak Ridge, Tennessee: Oak Ridge Institute for Science and Education.

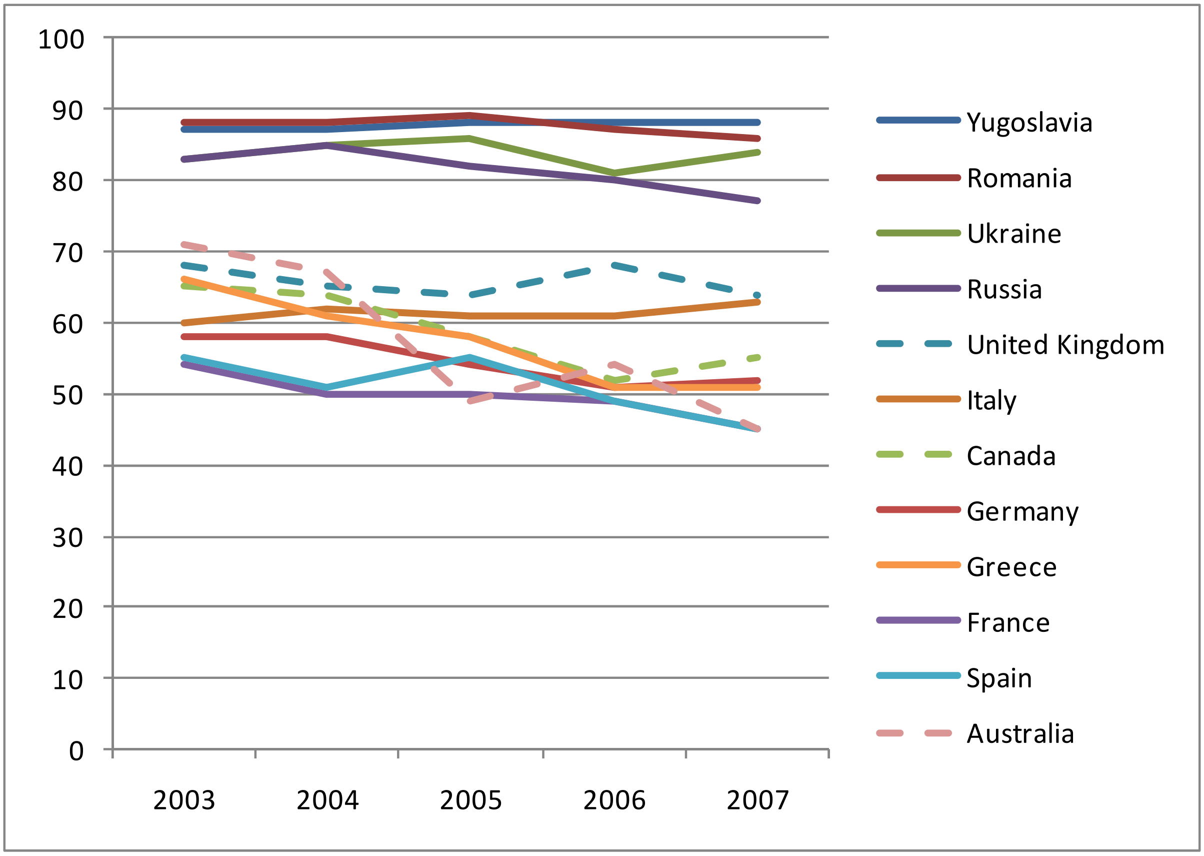

Figure 4. Stay rates for 2002 temporary resident science and engineering doctorate recipients from Anglo-Saxon and European nations.

Source: Adapted from Finn, M. G. (2010). Stay rates of foreign doctorate recipients from US universities, 2007 (pp. 33). Oak Ridge, Tennessee: Oak Ridge Institute for Science and Education.

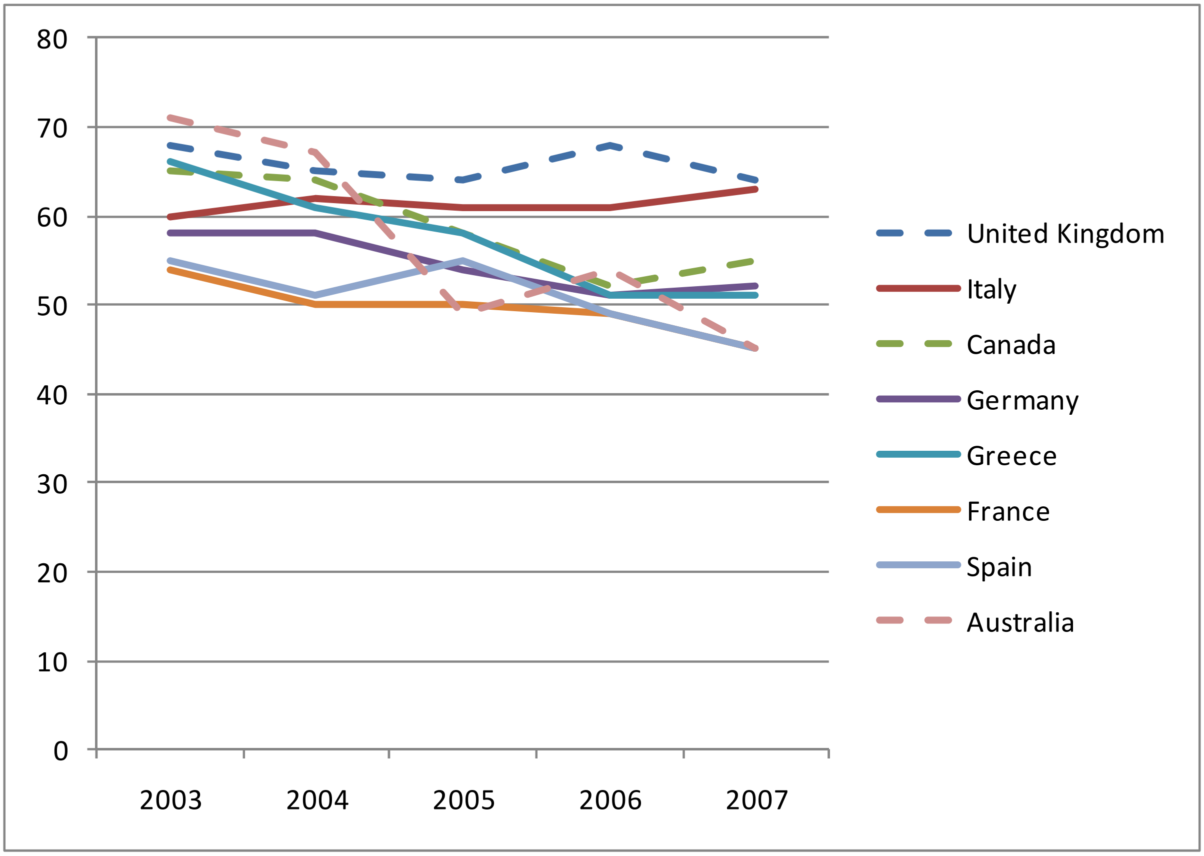

Figure 5. Stay rates for 2002 temporary resident science and engineering doctorate recipients from Anglo-Saxon and continental European nations.

Source: Adapted from Finn, M. G. (2010). Stay rates of foreign doctorate recipients from US universities, 2007 (pp. 33). Oak Ridge, Tennessee: Oak Ridge Institute for Science and Education.

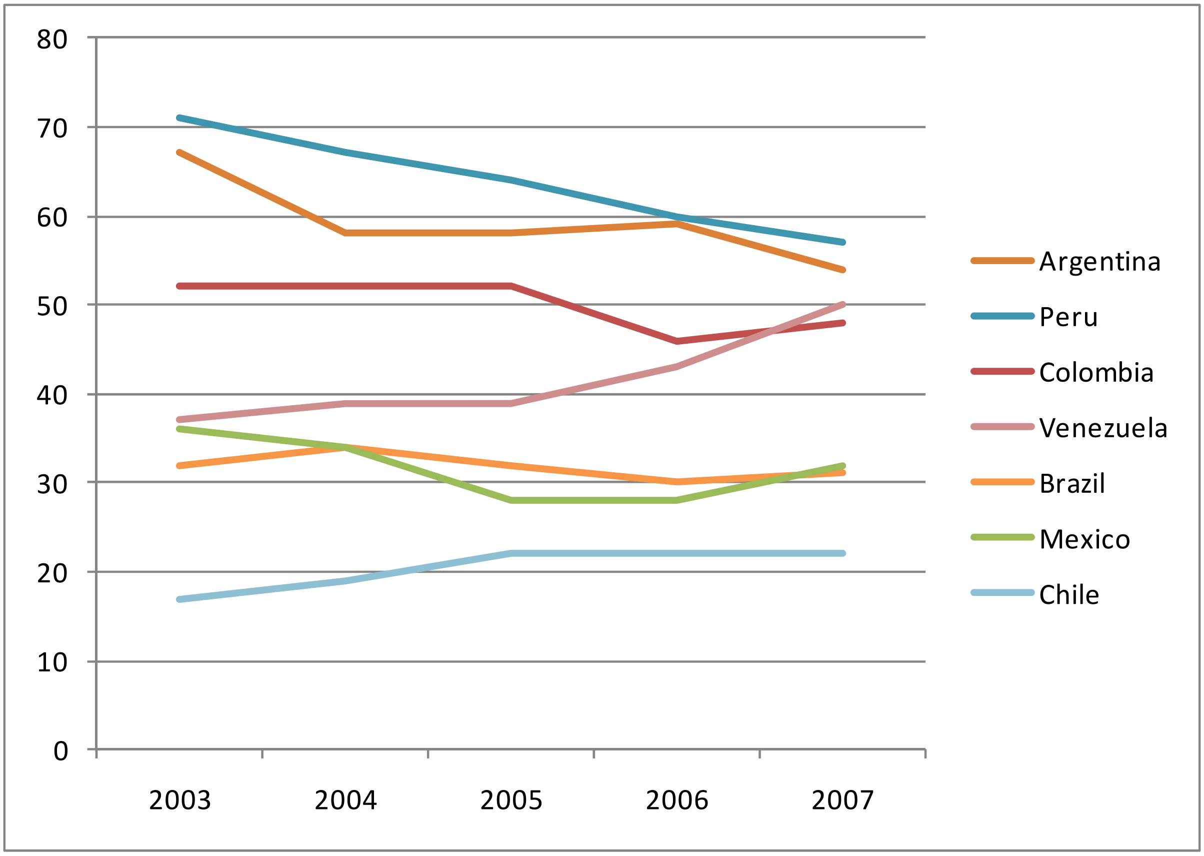

Figure 6. Stay rates for 2002 temporary resident science and engineering doctorate recipients from Latin American nations

Source: Adapted from Finn, M. G. (2010). Stay rates of foreign doctorate recipients from US universities, 2007 (pp. 33). Oak Ridge, Tennessee: Oak Ridge Institute for Science and Education.

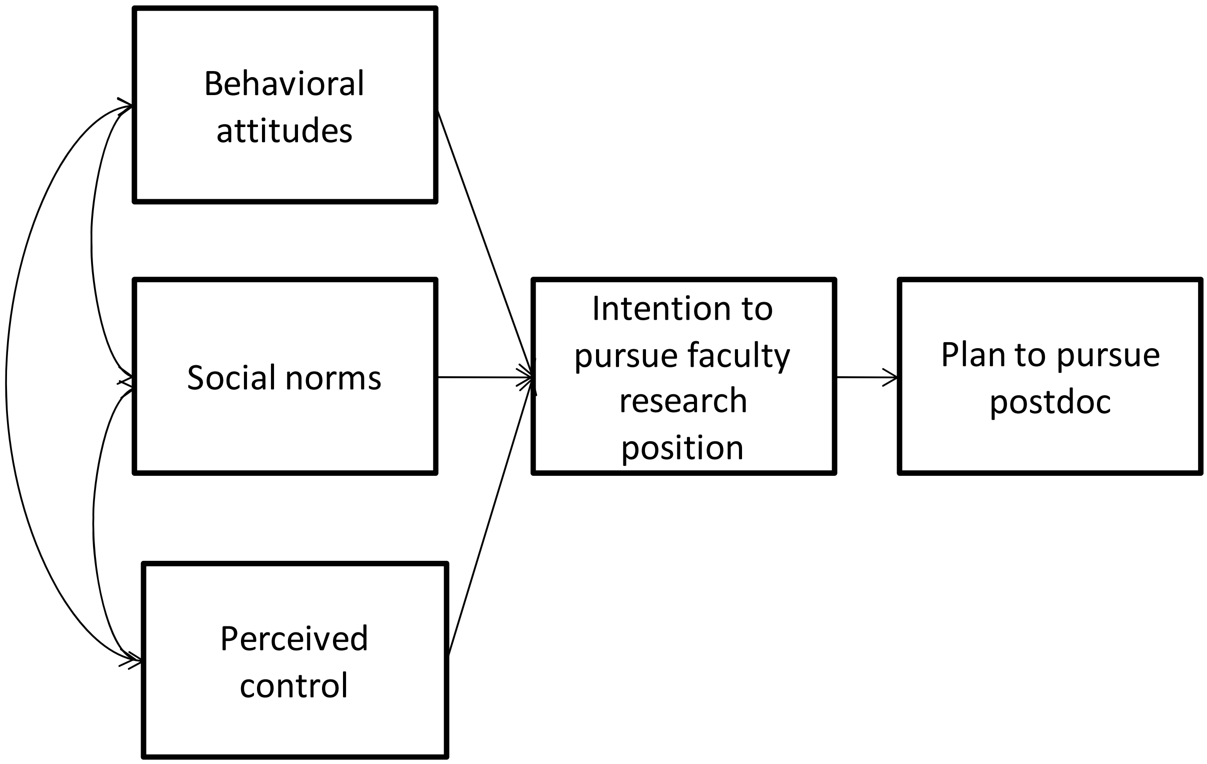

Figure 7. Theory of planned behavior model of doctoral students' plans to pursue a postdoctoral appointment

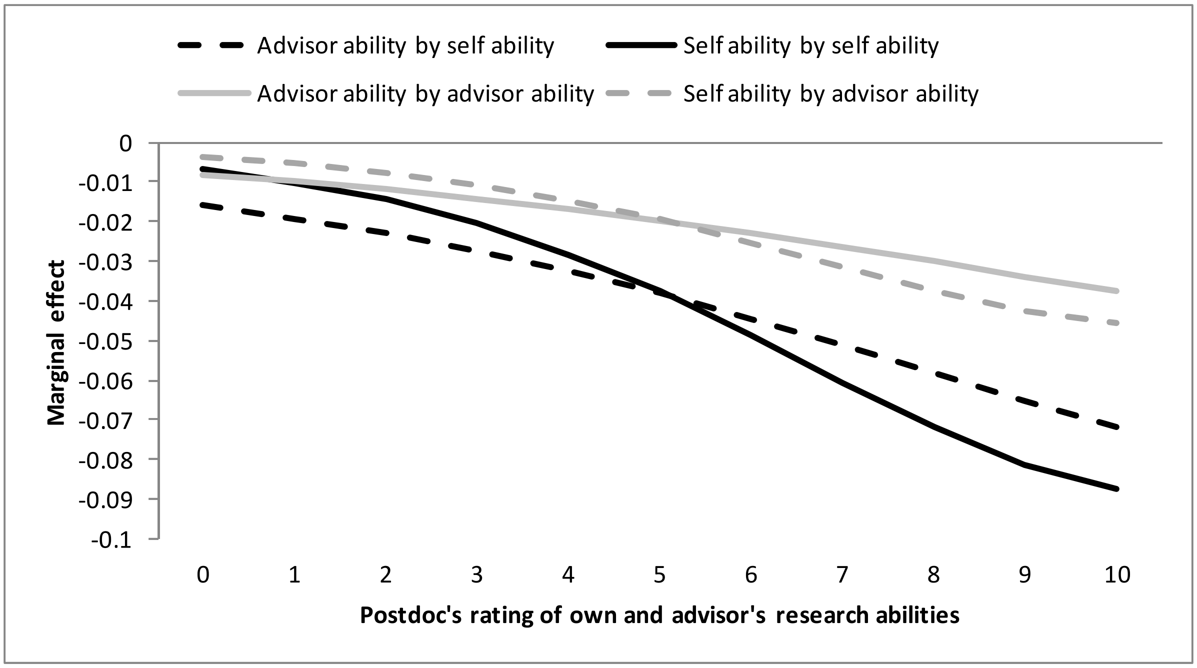

Figure 8. Marginal effects of postdoc's own and advisor's perceived research ability on probability of dissatisfaction.

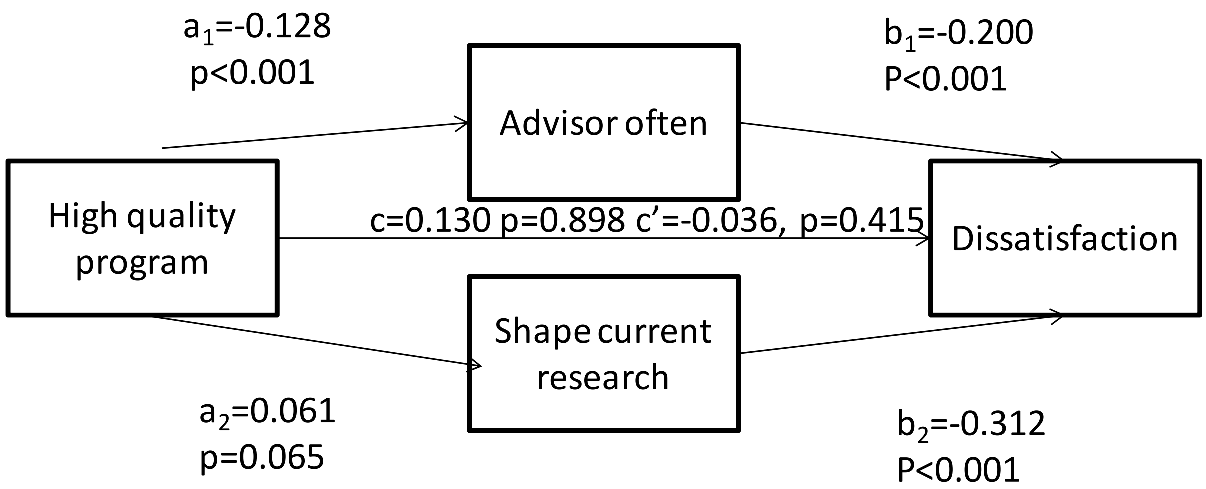

Figure 9. Frequency of advisor interaction and freedom to shape current research mediate relationship between program quality and postdoc dissatisfaction

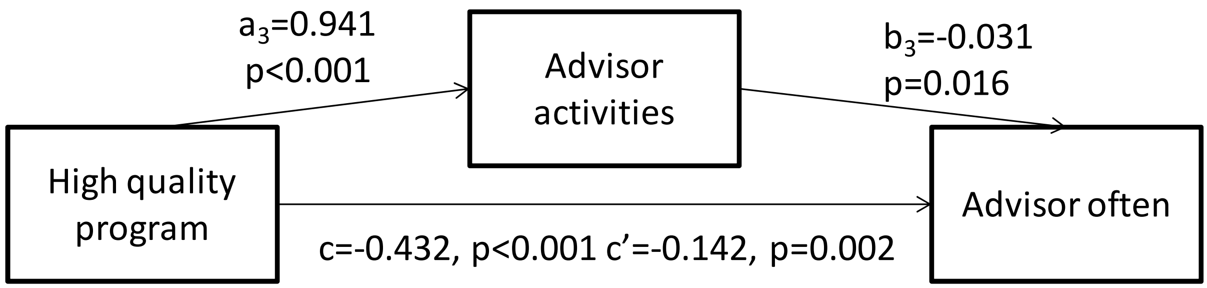

Figure 10. Advisor activities mediate relationship between program quality and frequency of advisor interaction.

Appendix A

Empirical Studies of Postdoctoral Scholars

Table A1

Empirical Studies of Postdoctoral Scholars

Author and date	Subjects	Data	Methods	Key findings	Limitations
Akerlind, 2005	22 postdoctoral researchers and 10 supervisors at 5 top-8 Australian universities.	Semi-structured interviews	Content analysis	Career development support is focused on academic and pure research careers and is not systematic and institutionalized. Other career paths are seen as failures. After 5-6 years as a postdoc there is a sharp drop in employability	Exploratory. Set in Australia. Supervisors available for interview may represent biased sample.
Akerlind, 2009	1,011 PDRs from 38 Australian universities, 22 PDRs and 10 supervisors from Australian top-8 universities,	Online survey results and interview transcripts	Online survey and in-depth interviews	Many PDRs define their career goal as a research career rather than an academic career, do not see the PDR as an interim step, already feel they are doing independent research, and engage in significant non-research activities, especially supervision.	Exploratory. Set in Australia. Does not consider gender or national origin.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Black and Stephan, 2008	Authors of 267 Science Research Articles and Reports published 11/2/2007-5/2/2008.	Broad field of research, # of authors, name of each author, institution, location, academic position, affiliation, usually from web page of last author's lab. Melissa data on ethnicity of names.	Crosstabulations and descriptive statistics.	Establishes the strong roles played by non-US postdocs and grad students in US research based on publication records. 86.5% of *Science* articles have at least one postdoc or student as an author. 74.6% of the first authors located in the US are postdocs or students. 59% of postdoc authors have non -English/European names.	Descriptive. Assumptions about authorship order and name-based classification of researchers by ethnicity.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Bohmer and Von Ins, 2009	Applicants for Emmy Noether fellowships 1999-2006	Peer review documents for 48 applications, bibliometric analysis, 462 online survey responses, 21 interviews	Triangulation, bibliometric, online survey, interviews, document review	Evaluation of the Emmy Noether fellowship program.	Findings relate to a specific, highly prestigious German fellowship program. Successful and rejected applicants were uniformly highly qualified.
Bornmann and Daniel, 2006	30% of 1,954 doctoral and 743 postdoctoral fellowship applicants, 1985-2000. Prestige data analyzed only for those moving within Germany, and for shorter time span.	Archival data from fellowship applications. German research foundation data on universities. Rankings.	Chi-square tests, Cramer's V, Monte Carlo	BIF more likely to award doctoral and postdoctoral fellowships in basic biological research rather than clinical medicine, consistent with its mission. The use of categorical variables and German subsample may have compromised power and biased the study.	Only analyzed the 30% of doctoral applications both coming from and going to a German university. Only analyzed postdoc data through 1995. Use of categorical measures for continuous variables. Field-based selection interpreted as bias more than mission.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Bryson, 1998	Over 400 contract research staff at 10 UK universities. CRS at one UK university. Directors of Personnel in all UK HEIs.	Survey data of CRS at 10 universities. Administrative data from 1 university. National statistics, job ads for CRS in 1996, preliminary results from survey of Directors of Personnel.	Qualitative summary of survey results.	Describes features of CRS system in the UK. The author believes the main root causes of problem are weak academic union involvement and institutional inertia.	Data collected in the UK 1994-1998. Article has a strong advocacy tone.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Burris, 2004	Full-time faculty members listed in American Sociological Association's *Guide to Graduate Departments of Sociology* (1995)	For each faculty member, school where PhD was received.	Crosstabulations and expected frequencies in matrix.	Prestige is very stable due to the self-replicating nature of social capital. The self-replicating behavior usually happens under the guise of universalism and meritocracy. "The more common pattern among the lucky few who have been able to parlay a PhD from a non-top 20 department into a job at a top 20 department is that they achieved this at the time of their first job—often with the aid of a postdoctoral fellowship from a prestigious department or an accompanying bachelor's or master's degree from an elite university" (p. 251). [This seems to be the only direct relevance to postdocs.]	Sample consists of sociologists. Postdocs are not the focus of the study. Data gathered from faculty in 1995, so they reflect earlier labor market conditions.
Chang et al., 2005	Cancer Prevention Fellowship Program at the National Cancer Institute	Archival information, alumni placement records, administrative records	Case study. Competing demands on mentors, working conditions, training for interdisciplinarity, and career development support.	The program could be used as a model for other interdisciplinary fields, since university disciplinary departments don't provide this type of postdoc opportunity. Slightly over half of participants (55%) go on to take positions in government.	Single case study. May not generalize to university postdocs. Authors affiliated with the National Cancer Institute may not provide unbiased evaluation.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Corley and Sabharwal, 2007	7980 science and engineering academics who worked full-time at four year colleges or universities, medical schools or university research institutes.	2001 SDR	Chi square, t-tests, OLS	Foreign born more likely to be in postdoc positions, and to have taken that position due to lack of other opportunities. Foreign born postdocs much less likely to have taken a postdoc to work with a specific person. Foreign-born postdocs less satisfied and more productive, except for patents.	Cross-sectional. Did not disaggregate foreign-born by country of origin. SDR data only include those with PhDs earned in US
Curtis, 1969	10,740 postdocs. 4,040 departments at 357 schools. 2,195 faculty who mentor postdocs and 564 who don't. 125 universities. 20 campuses. Fellowship sponsors.	Surveys, interviews, campus visits.	Primarily descriptive	Census and description of US postdocs.	Older data of primarily historical interest.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Davis, 2009	Includes 22,400 postdocs at 47 institutions	Survey	Correlations, robust regression with an M-estimator, logistic regression, Poisson regression.	Postdocs benefited from structured oversight and professional development. Few benefits tied to compensation. Writing research/ career plans at beginning of appointments associated with 25% productivity increase. Other beneficial activities: teaching, learning about non-academic careers, and training in proposal writing and project management.	Cross-sectional. Limited causal inference. Underrepresentation of African-Americans and noncitizens among respondents.
Fox and Stephan, 2001	2348 doctoral students in 80 departments of chemistry, computer science, electrical engineering, microbiology, and physics, 1993-1994.	Mail survey by Fox, SDR.	Chi-square tests, crosstabulations	The wide availability of postdoctoral positions in microbiology may lead new PhDs in that discipline to view their career prospects more favorably than fields without those options, regardless of availability of tenure-track positions.	Data collected from doctoral students in 1993-1994 and 1993 SDR data from PhDs completed in 1987-1992. Lack of data on number of job candidates and openings.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Gaughan and Robin, 2004	400 French life science PhDs and 407 US life and physical scientists at URCs. French rec'd PhD 1984-1994 and US 1984-1997.	French data were from a survey and US data were coded from CVs (per Dietz et al. 2000).	Discrete time proportional hazards model.	Postdocs delayed entry into long-term academic employment in France, but not in the US, probably due to emphasis on early career mobility in the US. About 1/3 of each group took a postdoc. Note: French postdocs are almost by definition outside of France.	CVs do not provide data on non-academic career paths. Selection on dependent variable. Data reflect doctorates earned 1984-1997.
Helbing et al., 1998a	1,322 Postdoctoral fellows in life, physical, and social sciences.	43 Likert-type items from a mail survey.	Factor analysis and one-way ANOVA.	Satisfaction decreased and stress increased the longer someone was a postdoc. 60-70% reported being actively engaged in the search for a new job. Postdocs in Canada are typically not treated as employees.	Canadians, mostly in Canada and some in the US Cross-sectional. Data collected in 1996.
Helbing et al., 1998b	Same as Helbing et al. 1998a.	Same as Helbing et al. 1998a.	Factor analysis and one-way ANOVA.	Women and men were similar in many ways. Women were more likely to be found in lecturer/ research associate roles or to name those as career goals.Women with children expressed stress primarily related to isolation and workload. Men with children expressed stress primarily in relation to finances.	Canadians, mostly in Canada and some in the US Cross-sectional. Data collected in 1996. Emphasis on advocacy may compromise neutrality.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Hornbostel et al., 2009	695 applicants for Emmy Noether fellowships. Particular focus on 294 applicants in physics and medicine, of whom 50 were selected for review.	Publications from Web of Science database and internet search via Google and MSN. Online survey. Interviews. Applicant files.	Content analysis, bibliometrics, descriptive statistics.	Reviewers were successful in selecting productive researchers. In medicine, there was little difference in outcomes between the selected and rejected applicants. In physics, the selected applicants had better placement and productivity outcomes.	Applies to a single prestigious fellowship in Germany. Focus on disciplines of physics and medicine. Prestige of coauthors may bias measures of publication productivity.
Horta, 2009	492 doctorate-holding faculty members at higher education institutions in Mexico	Data from 1999-2002 gathered in the survey by CONACYT and UNAM.	Written survey. Ordered probit negative binomial regression.	Postdoc was significantly associated with increased levels of all types of international information exchange.	Study focused on those who were faculty members in Mexico 1999-2002. Differences between younger and older faculty indicate that effects of postdoc appointments have changed over time and may not generalize to the present.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Lan, 2009	Chinese and Indian students earning S&E PhDs 1994-2000, ages 27-36, with 4-7 years doctoral study.	SED data.	Uses eligibility for the 1990 Chinese Student Protection Act (EO12711) as an instrument for permanent visa. Linear probability model, OLS and 2SLS. Probit model to estimate marginal effects. Local Average Treatment Effects (LATE).	New PhDs from developing countries are more likely to take postdocs if they have temporary visas than if they have permanent ones. This effect is not found for PhDs from developed countries. The role of visa status is isolated through the use of CSPA as an instrument. This effect is most significant in fields where postdocs are not expected of most PhDs, such as chemistry and physics.	Lan notes that it was not possible to differentiate between different types of permanent visas, which may bias estimates.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Laudel and Glaser, 2008	16 Australian researchers, 9 of whom are in the sciences	Interview transcripts, bibliographic records, ISI, SCI	Secondary analysis. Creation of chronological career profile including publications, citations, research topics, job positions and their characteristics in terms of resources and autonomy.	Apprentices fade from community career by abandoning research or taking a role where they support research by others. All ECRs became independent researchers had built on the PhD topic.	In Australia. Universities were hiring those without research experience for faculty positions, unlikely in the US. Career profiles were a methodological innovation. Some desirable information not available in secondary data.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Libarkin and Finkelstein, 2001	28 Fellows (PhD scientists) and 11 mentors in the 3 cohorts of Postdoctoral Fellowships in Science, Mathematics, Engineering and Technology Education (PFSMETE), 1997-1999.	Open-ended survey questions from NSF (fellows only), Likert-scale program evaluation questions (Fellows and mentors), and open-ended topical questions (Fellows and mentors).	Thematic and quantitative descriptive content analyses	Most respondents were highly satisfied with the program. Consider implications of providing funding that is not through host institution (benefits, status, isolation) and challenges of participating in multiple disciplines.	Evaluates a specific NSF-funded fellowship program for scientists interested in science education research. Evaluators had also been program participants. Not enough time had passed to measure long-term outcomes.
Martinez et al., 2007	1,322 postdoctoral fellows at NIH. 42.6% women.	A 48-question web survey that collected demographics, info on quality of postdoc experience (not presented) and on career transition decisions.	Chi-square tests	Women are less likely to seek a PI position and less likely to persist in seeking a PI position if they don't find one right away. Therefore, PIs are selected from a pool with fewer women. Women express a lot more concern about children and family relative to career planning. They also express less confidence in abilities and have few female role models.	Cross sectional. Respondents were intramural postdocs at NIH and may differ from academic postdocs.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
McGinnis et al. 1981	557 biochemists who earned PhDs in late 50s early 60s	Archival, bibliometric	OLS, logit, multinomial logit	Predoctoral research productivity does not influence who does a postdoc or the postdoc's prestige. A postdoc does not seem to affect one's chances of getting a prestigious job, but the prestige of the postdoc has a major impact on the prestige of subsequent jobs. Postdoctoral training seems to result in substantial increases in later citation rates, but where the training occurred makes little difference in citation rates. The modest effect of postdoctoral training on publication rates disappears when employment sector is held constant.	Sample restricted to biochemists who earned doctorates in 1957, 58, 62, and 63. This study examined a period of plentiful academic jobs.
Melin 2004	284 Swedish PhDs who had a stay abroad as a junior guest researcher	Mail survey	Quantitative descriptive, Gini-coefficients	Swedes tended to do postdocs in countries that have been historically dominant in science rather than emerging. About half did postdocs in US. Networks played a role in finding postdoc, but supervisor was usually not directly involved. Collaborations often continued after the postdoc.	Swedish respondents had received grants 1984-1999. That is, all had Swedish government funding. Those who had left Sweden were not in the sample. Retrospective self-report data.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Melin, 2005	Same data as Melin (2004) plus 15 telephone interviews.	Same data as Melin (2004) plus 15 telephone interviews.	Quantitative and qualitative description.	Negative consequences of postdocs were mainly related to reintegration back at the home institution and were somewhat greater for women than for men. This has negative institutional as well as personal effects.	Similar to Melin 2004. The fact that Swedish postdocs typically had a home institution to return to is very different from the US model.
Meng and Su, 2009	388 scientists at R1 universities	CVs and survey responses from Research value mapping project. Prestige rankings.	Negative bionomial regression	Postdocs increase research productivity over first 3 years in PhD. This effect does not vary by gender. Women's production remains lower whether or not there is a postdocs.	Respondents were faculty members at R1 universities, so they were selected on a dependent variable. Significant truncation of information on CVs may bias sample.
Mishagina, 2009a	15,000 white men with PhDs in natural sciences and engineering	SDR 1973-2001	Transition model with independent competing risks.	Those who did many postdocs were more likely to leave S&E for good, but were no more likely to switch between R&D and applied work. The more time passes without getting an R&D position, the more likely the person is to leave science.	While this is one of the methodologically stronger studies, the data generally reflect a much earlier time period. In some analyses, only male scientists are included.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Mishagina, 2009b	Men and women in the life sciences. Comparison of trends in exit rates across disciplines.	SDR 1973-2001	Dynamic occupational choice model. Method of simulated moments.	Data seem most consistent with scientists seeking information about their level of research ability. Results are consistent with sorting based on comparative, not absolute, advantage. Not specifically about postdocs.	While this is one of the methodologically stronger studies, the data generally reflect a much earlier time period.
Mishagina, 2009c	Doctorate recipients 1957-2005, not just scientists.	SED	Nested logit model, probit model for EU-15.	US doctorates became more likely to take a first position in Canada over time. US citizens were more likely to move to Canada during the Vietnam war and Middle Eastern graduates were more likely to move to Canada after 9/11. High US unemployment made US and 3CNs more likely to go to Canada, but did not affect Canadians. (This essay was not really about postdocs, but was about first position after the doctorate).	While this is one of the methodologically stronger studies, the data generally reflect a much earlier time period.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Musselin, 2004	18 departments of history and mathematics in France and Germany	Observations	Field research	A European academic labor market is impeded by differences among national labor markets. Individual actors also make use of academic mobility in a way that does not lead to careers outside of the home country.	Focus is on France and Germany and disciplines of math and history. France and Germany may be somewhat unique in expecting instruction to take place in the local language. This paper summarizes findings from reports of research for the French government and does not describe methodology. The reports were completed in 1997 and 2002.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Nerad and Cerny, 1999	5,854 PhD graduates from 61 univesities in biochemistry, computer science, electrical engineering, English, mathematics, political science, 1982-85.	Ph.D.s--Ten Years Later Survey	Crosstabulations and descriptive statistics.	Biochem stayed longer in postdocs and had lowest % tenured faculty. Women were much more likely to take a postdoc because it worked for them and their spouse. Postdocs had a strong effect at moving male PhDs into tenure track and tenured positions.	Subjects obtained PhDs in 1982-85. This is a summary of a larger study and provides little methodological detail.
Nolan et al., 2004	1,595 tenure track faculty at NRC top-50 chemistry departments	2001 ACS Directory of Graduate Research, WebCaspar	Description and crosstabulation, Gottselig and Oeltjen "impact factor" for success of graduate placement.	Over 90% of new faculty had held a postdoc. Fellowships at top 5 supplier schools had strong beneficial effects on placement in top 50 programs. Women continued to face barriers to hiring in chemistry.	Subjects were chemistry faculty in top departments, half of whom had received doctorates before 1979.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Nolan et al., 2008	455 graduates (135 women) from 11 top chemistry departments, 1988-1992	Survey data	MANOVA	Women's responses indicated a lower perceived level of interest by their postdoc advisor in their research findings, research ideas, and publication opportunities. No difference was found in how men and women rated their post doc advising relative to others in their program or how they found their first career position.	Relied on retrospective self-reports of mentoring experiences. Subjects received PhDs in chemistry from top-10 departments in 1988–1992.
Puljak and Sharif, 2009	301 postdocs at the UT Southwestern Medical Center in 2005	Survey results	Harcopy survey, 37 questions	This is a heavily immigrant postdoc population. People stay in postdocs for a long time because faculty positions scarce. Most postdocs would like to stay in science. Priorities are job placement, salary, and training, which should lead institutions to focus on job and training opportunities.	Single site. Those with strong opinions or interest in joining an association may have been more likely to respond. Postdocs on long assignments may have been oversampled.
Recotillet, 2007	1,744 French PhDs from 1996 in science, engineering and humanities.	Survey in 1999.	Treatment effect model, bivariate selection rule.	Postdocs function as a signal because the wage premium associated with them disappears when selection bias is controlled.	Subjects received doctorates in France in 1996. Does not distinguish among types of postdoctoral appointments.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Reskin, 1976	450 doctoral chemists who earned degrees in US 1955-1961. 221 were female, 223 were a systematic random sample of males.	Directory of Graduate Research, American Men and Women in Science, other biographical sketches, and mailed questionnaires. Chemical Abstracts, Science Citation Index.	Analysis of covariance	For men, postdocs reflected predoctoral achievement and predicted future career advancement. These relationships did not hold for women, a finding most consistent with a sex discrimination explanation.	Subjects earned PhDs in chemistry 1955-1961. Postdocs were defined so as to only include prestigious fellowships.
Stephan & Ma, 2005	US PhD recipients in 10 broad fields of science & engineering who indicated they planned to stay in the US.	SED data, 1981-2000, SDR data for 1995, which contains additional career history questions, including up to 3 postdocs.	Logit analysis and duration model of log length of postdoc experience.	Graduates have become more likely to take postdocs and remain in postdocs for longer periods of time because a higher proportion of them are on temporary visas, a higher proportion of them are in the life sciences, and they have faced a more difficult job market. Human capital may be wasted because of age and tenure effects.	SED data span from 1981-2000. Labor market conditions measured subjectively.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Su, 2009a	Subsample of 514 scientists with adequate career data from 1647 responses and 1106 CVs from tenured or tenure track faculty in 13 S&E disciplines at 150 research universities.	From Research Value Mapping project at GA Tech.	Questionnaire responses and coded CVs. Multinomial logit regression.	Did not support the idea that postdocs were less qualified than non postdocs. Postdocs in prestigious departments were associated with appointments in prestigious departments. Prestige of PhD department also had an effect. No evidence that pre-doctoral productivity mattered. At about 3 years, a postdoc shows its placement benefit Foreign postdocs are more likely to be placed in prestigious departments, except for Asians. No gender differences.	Subjects were faculty at R1 universities. Difficulty in determining which positions were postdocs from CV data. Absence of gender effect may be due to not including other demographics like marriage and children.
Su, 2009b	Subsample of 860 scientists. 388 w/in 3 years of degree, 245 w/in 9 years of degree, and 227 w/in 13 years of degree	From Research Value Mapping project at GA Tech.	Questionnaire responses and coded CVs. Negative binomial regression.	Postdocs increase research productivity but only during first 3 years. Departmental prestige increases productivity but only in highly prestigious departments. In an example of cumulative advantage, postdocs increase future productivity by increasing the chances of being hired in a highly prestigious department.	Average year of PhD receipt was 1986. Subjects were faculty at R1 universities.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Subotnik and Arnold, 1995	11 women doctoral scientists identified as high potential in H.S. 4 were currently postdocs.	1-2 hour taped phone interviews	Grounded theory	Taxonomy of factors that influenced women's careers: professional advancement structures in science, the funding climate for scientific research, dual career constraints, commitment to social change, and maintenance of friendship and family ties. Career categories: facing in, peering out, open to opportunity, and focusing on balance. Of the 4 postdocs, 3 were classified as peering out.	Exploratory study included only 4 current postdocs.
Wei, Levin, and Sabik, 2009	3,255 postdocs in the US	Sigma Xi survey conducted 2003-2005	Simple comparisons, OLS, Poisson, and probit regression, fixed effects	Foreign postdocs use more impersonal search methods, although they begin to use more personal methods over time. People who use personal search methods are more likely to be in their degree field. Those who stay in the same fields are more satisfied, implying that field switching is probably involuntary. Foreign postdocs have higher turnover. Personal search methods are also associated with increased productivity.	Subjects at top 20 universities and NIH. Difficulty categorizing subjects by personal or impersonal search method.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Zubieta, 2009	100 UK university researchers, recipients of Engineering and Physical Sciences Research Council project grant. From 38 academic institutions in four scientific fields:	CVs coded to identify career transitions, ISI Web of Knowledge, patent data from the European Patent Office	Exploratory and descriptive.	There seem to be two common patterns of careers -- going straight to a job or going on a postdoc at another institution (often int'l) and returning to the doctoral institution. Using postdocs for mobility was more common in the pure sciences than in transfer sciences. Findings about the mechanism by which postdocs provide an advantage was ambiguous. Unlikely to generalize to the US	Exploratory descriptive study. Sample were UK researchers with an average of 18.5 years of experience. Low response rate (15%). Unable to distinguish causal role of international postdoc appointment on productivity and career.
Zumeta, 1984	Varied	SED, SDR, HERI Surveys of 3 groups.	Stepwise discriminant analysis, MANOVA	Growing share of postdocs was in distinguished departments. A lower proportion of postdocs received fellowships. Many more scientists are now using postdoc appointments to train in a field other than the PhD. Postdocs may now be spending slightly more time on paperwork than on research.	Describes postdoc experiences in '60s and '70s.

Table A1 (*continued*)

Author and date	Subjects	Data	Methods	Key findings	Limitations
Zumeta, 1985	Varied	SED, SDR, 1976 Survey of Biomedical and Behavioral Scentists, HERI Surveys (1977)	Stepwise discriminant analysis, MANOVA	Quality of postdocs has declined in some key fields and this needs to be considered in evaluating outcomes. The lack of job opportunities for new PhDs has led to the increase in postdocs. Postdocs are becoming more common in the humanities/ social sciences, and there is little rationale or evidence for their effectiveness in that context. A postdoc does not appear to improve future earnings. Total career research productivity may increase as a result of a postdoc, but this may not be justified by value to the individual or society, especially in behavioral and social sciences. In natural sciences, society may benefit, but the individual may not.	Describes postdoc experiences in '60s and '70s.

Appendix B

Alternative Specifications of Postdoc Dissatisfaction Model

Table B1

Dissatisfaction Measured on 5 Point and 7 Point Likert Scales

Category	Independent variable	Dissatisfaction (5-point scale)			Dissatisfaction (7-point scale)		
		b/se			b/se		
Research	Research interesting	-1.352	(0.238)	***	-1.226	(0.214)	***
	Mismatch average	0.116	(0.085)		0.118	(0.078)	
	Current basic	0.218	(0.315)		0.088	(0.253)	
	Current applied	-0.288	(0.525)		-0.386	(0.409)	
	Current development	-0.577	(0.320)	†	-0.213	(0.202)	
Career plans	Reason - No job	0.264	(0.149)	†	0.184	(0.151)	
	Reason - Desired job	0.233	(0.147)		0.296	(0.116)	*
	Reason - Skills	-0.299	(0.144)	*	-0.384	(0.118)	**
	Reason - More time	-0.014	(0.081)		0.064	(0.069)	
	Faculty career plans	-0.356	(0.124)	**	-0.279	(0.109)	*
	Interest in basic	0.831	(0.337)	*	0.397	(0.252)	
	Interest in applied	-0.192	(0.183)		-0.104	(0.151)	
	Interest in development	0.205	(0.104)	†	0.173	(0.101)	†
Postdoc-advisor relationship	Advisor ability	0.081	(0.096)		-0.031	(0.099)	
	Advisor 1+ per week	-0.507	(0.202)	*	-0.479	(0.142)	***
	Self-rated ability	0.223	(0.124)	†	0.112	(0.127)	

Table B1 (*continued*)

Category	Independent variable	Dissatisfaction (5-point scale)			Dissatisfaction (7-point scale)		
	Shape current research	-0.402	(0.108)	***	-0.383	(0.101)	***
	Lab size	-0.025	(0.008)	**	-0.015	(0.006)	*
Program quality	High quality program	0.212	(0.148)		0.208	(0.137)	
Demographics	Female	0.527	(0.261)	*	0.046	(0.286)	
	Children	-0.299	(0.148)	*	-0.235	(0.122)	†
	Married	-0.228	(0.100)	*	-0.182	(0.083)	*
	Start year	-0.078	(0.026)	**	-0.063	(0.022)	**
	Non-US high income	-0.185	(0.140)		-0.140	(0.109)	
	Non-US other	0.135	(0.196)		0.141	(0.150)	
Interactions	Basic current x interest	-0.733	(0.368)	*	-0.571	(0.309)	†
	Applied current x interest	-0.136	(0.540)		0.031	(0.420)	
	Develop current x interest	0.794	(0.378)		0.283	(0.279)	
	No job x applied	-0.350	(0.214)		-0.104	(0.192)	
	Self-rated ability x advisor ability	-0.026	(0.014)	†	-0.014	(0.015)	
	High quality x shape	-0.382	(0.155)	*	-0.244	(0.150)	
	Female x interest in basic	-0.776	(0.247)	**	-0.274	(0.274)	
	Female x children	0.235	(0.210)		0.260	(0.141)	†
	Female x biological sciences	0.341	(0.253)		0.228	(0.214)	
	Female x health sciences	-0.454	(0.267)	†	-0.279	(0.228)	

Table B1 (*continued*)

Category	Independent variable	Dissatisfaction (5-point scale)			Dissatisfaction (7-point scale)		
	Non-US other x bio science	-0.472	(0.232)	*	-0.300	(0.190)	
	Advisor 1+/wk x bio sci	-0.011	(0.220)		-0.117	(0.166)	
	Biological sciences	0.493	(0.261)		0.494	(0.208)	*
	Health sciences	-0.182	(0.226)		-0.130	(0.190)	
	Cut 1 constant	156.815	51.751	**	-129.624	43.308	**
	Cut 2 constant	157.363	51.781	**	-128.227	43.308	**
	Cut 3 constant	157.786	51.767	**	-128.227	43.292	**
	Cut 4 constant	158.558	51.768	**	-127.472	43.293	**
	Cut 5 constant				-127.060	43.317	**
	Cut 6 constant				-125.785	43.308	**
	N		764			764	
	p		<0.001			<0.001	
	ll		-702.019			-1024.699	

† p<0.10, * p<0.05, ** p<0.01, *** p<0.001

Table B2

Multinomial Probit Model of Postdoc Satisfaction

	Satisfied b/se			Dissatisfied b/se		
Research interesting	0.417	(0.507)		-2.366	(0.536)	***
Mismatch average	-0.165	(0.186)		-0.169	(0.290)	
Current basic	0.389	(0.608)		1.345	(0.758)	†
Current applied	0.551	(0.275)	*	0.077	(0.319)	
Current development	-0.296	(0.257)		-0.521	(0.397)	
Reason - No job	0.050	(0.412)		0.977	(0.424)	*
Reason - Desired job	0.111	(0.335)		0.471	(0.310)	
Reason - Skills	1.008	(0.368)	**	0.779	(0.391)	*
Reason - More time	-0.386	(0.195)	*	-0.345	(0.239)	
Faculty career plans	0.275	(0.248)		-0.49	(0.317)	
Interest in basic	-0.436	(0.630)		1.409	(0.587)	*
Interest in applied	1.199	(0.532)	*	1.613	(0.724)	*
Interest in development	-0.462	(0.313)		0.083	(0.325)	
Advisor ability	0.308	(0.248)	**	0.797	0.272	
Advisor 1+ per week	0.258	(0.395)		0.797	(0.272)	**
Self-rated ability	0.397	(0.330)		-0.018	(0.644)	
Shape current research	0.578	(0.219)	**	1.228	(0.307)	***
Lab size	0.011	(0.019)		0.213	(0.316)	
High quality program	0.029	(0.433)		0.653	(0.433)	
Female	-0.241	(0.705)		0.462	(0.908)	
Children	0.453	(0.400)		-0.156	(0.309)	
Married	0.255	(0.229)		-0.037	(0.294)	
Start year	-0.139	(0.072)	†	-0.299	(0.074)	***
Non-US high income	-0.490	(0.298)	†	-0.759	(0.349)	*
Non-US other	-1.025	(0.422)	*	-1.379	(0.638)	*
Basic current x interest	0.588	(0.600)		-0.781	(0.910)	
No job x applied	0.098	(0.527)		-1.743	(0.707)	*
Self-rated ability x advisor ability	-0.042	(0.039)		-0.145	(0.041)	***
High quality x shape	0.306	(0.371)		-1.173	(0.616)	†
Female x interest in basic	0.296	(0.584)		-1.921	(0.820)	*

Table B2 (*continued*)

	Satisfied b/se			Dissatisfied b/se		
Female x children	0.058	(0.584)		0.934	(0.650)	
Female x bio sciences	-0.184	(0.638)		1.969	(0.982)	*
Female x health sciences	1.007	(0.642)		-0.904	(1.041)	
Non-US other x bio sciences	0.346	(0.415)		-0.373	(0.610)	
Advisor 1+/wk. x bio sciences	0.225	(0.390)		-0.598	(0.613)	
Biological sciences	-1.660	(0.525)	**	-1.532	(0.821)	†
Health sciences	0.748	(0.386)	†	1.59	(0.701)	*
Constant	274.511	145.254	†	592.169	149.856	***
N		764				
ll		-289.845				
bic		991.281				

† p<0.10, * p<0.05, ** p<0.01, *** p<0.001

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