Dual Hire Productivity *

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Abstract

We research how the productivity of individuals hired as part of a partner accommodation policy compare to their colleagues within the same institution. We derive conditions for a theory explaining how "dual-hiring" can results in higher quality faculty at lower ranked institutions and test the theory against data for faculty at Ohio State University, Virginia Tech, Washington State University and the University of Wyoming. Using Web of Science records to measure academic productivity, we find evidence that in many cases, these "dual academic hires" differ significantly from their traditionally hired colleagues and that these differences often depend on gender effects. Contrary to previous research, we find evidence that "secondary hires", those being accommodated in the policy, are sometimes less productive than their peers.

Keywords Joint hires, Academic couples, partner accommodation policy, labor
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1 INTRODUCTION

Working couples often face the challenge of finding a job for each partner in the same geographic location. This challenge is especially pronounced academics. Research estimates that seventy-two percent of individuals employed in academia are part of a working couple (Scheibinger et al., 2008). Half of those (or 36 percent of all academics) have a partner who is also in academia. These "dual-career" academic couples face a difficult job search because academic institutions in the U.S. are often geographically isolated.[1]

To remain competitive in an environment in which an increasing share of candidates are part of a couple, many universities have adopted official partner accommodation policies. These policies allow greater flexibility in finding a position for the partner of a desired candidate. A commonly cited concern with "joint hiring" through these policies is the stigma of "less good" that may be attached to the secondary hire because that person was not recruited through the traditional method (Scheibinger et al., 2008). However, little work has been done to rigorously sort out the effects of the presence of, and hiring policies related to, academic couples on the distribution of faculty productivity from either a theoretical or empirical perspective.

Our research question is, "How does the productivity of individuals hired as part of a couple compare to their colleagues within the same institution?" We note two separate phenomena that are likely to influence how academic couples are matched with institutions (and thus affect the distribution of productivity within those institutions). The first of these deals with the *supply* of couples to institutions: it is the willingness of partners in some academic couples to accept an offer from a less prestigious school in order to be near their partner (Helppie and Murray-Close, 2010). In a survey of over 9,000 academics, Scheibinger et al. (2008) found that 20 percent of the couples in the sample reported such behavior. This has the potential to alter the distribution of faculty quality from what would be seen if all candidates behaved as if they were single.

The second phenomena concerns the *demand* for couples in institutions. Institutional partner accommodation policies are designed to provide a position in which timing or mismatch of specialty might otherwise prevent the hire from occurring. However, this does not imply that universities are willing to hire lower-quality candidates so long as they are partnered with a higher-quality partner. For instance, Washington State University's (WSU) official policy states that participation in the accommodation program by individual units (e.g., departments) is voluntary. Since many academic couples are hired into different departments and often different colleges (Ferber and Loeb, 1997), we believe it is likely that couples are often hired only if each candidate is independently deemed worthy of a job offer.

If couples wish to stay together and institutions typically evaluate members of couples independently of one another, lower-tiered institutions should benefit from the presence of couples of heterogenous quality (expected productivity) in the market. We will refer to such couples as mixed-tier couples and their complement as same-tier

[1] Geographic isolation decreases the availability of similar employment opportunities outside the academic institution.

couples. Some individuals who would have received a more prestigious offer as a single candidate are passed over because those institutions did not find that person's partner suitable for an offer, pushing the couple to a less prestigious institution.

Our first contribution is the development of a model in which academic singles and academic couples sort themselves according to their offers into schools of heterogenous rank. The presence of mixed-tier couples along with a preference to remain with their partner allow highly productive individuals to accept employment in lower-ranked institutions. Thus, the average productivity of joint hires should be higher than that of "single" hires in non-elite institutions. Furthermore, secondary hires – those who come to the institution as a result of an accommodation rather than receiving the initial job offer – should be no less productive than their traditionally hired peers, in expectation. These testable implications are the focus of this paper.

We empirically examine whether joint-hire faculty are in fact different in their productivity relative to their non-joint hire colleagues. Previous work by Scheibinger et al. (2008) used faculty survey responses to analyze the productivity of "second hires" (i.e., those whose partners were first recruited by the hiring institution). They find that after accounting for field, gender, and rank, productivity levels (based on self-reports) among the second hires are not significantly different from those of other academics.

Rather than relying on survey data, we use a cross section of administrative data representing the entire population of new tenure-stream faculty hires at Washington State University, Ohio State University, University of Wyoming and Virginia Tech. This data contains information on whether individuals were hired using the university's partner accommodation policy, allows us to compare faculty with other "traditional" hires over the same time frame. To our knowledge, an analysis of joint hires vs. non-joint hires with the universe of faculty at an institution has not previously been performed. Furthermore, in contrast to Scheibinger et al. (2008), we analyze both primary and secondary hires involved with partner accommodation policies in our productivity analysis.

We contribute to the applied literature on joint hires by showing that the findings of (Scheibinger et al., 2008) are not robust to non-survey data across the universe of faculty at a single institution. Using objective measures of productivity on every faculty member at a university (rather than only those who respond) we find that there is evidence in some institutions that secondary hires are of lower-quality on average.

Additionally, we find evidence that the productivity differences between traditional faculty and those participating in partner accommodation polices may differ substantially by sex. While further research is needed, our results may have important implications for the effect of partner accommodation policies on the distribution of female academics and their productivity relative to male faculty.

2 MODEL

In this section we derive a model to explain the effect of academic couple's preferences to stay together on the distribution of faculty quality when institutions use independent hiring policies. The implications of this model will be tested and explored in the following sections.

2.1 Setup

An academic labor market consists of a set of schools S seeking to hire candidates from a set of academics A. Schools in S are partitioned into a finite set of tiers enumerated $1, 2, \ldots, T$ where T represents the highest tier. Each tier seeks to hire a positive number of academics. Academics come in two types, singles and couples partitioned into sets A_s and A_c. Each set has a respective σ-algebra $\mathcal{F}_s$ and $\mathcal{F}_c$. We assume there exist measure spaces $(A_s, \mathcal{F}_s, \mu_s)$ and $(A_c, \mathcal{F}_c, \mu_c)$ where $\mu_s(A_s) = N_s$ and $\mu_c(A_c) = N_c$ are the total measure of single academics and academics in couples respectively. The total measure of academics (the measure of A) is $N_s + N_c$. The proportion of academics in a dual academic couple is defined as the proportion α where

$$\alpha = \frac{N_c}{N_s + N_c}$$

For each measure space above, we define normalized measures, $\mathbb{P}_s$ and $\mathbb{P}_c$

$$\mathbb{P}_s = \frac{\mu_s(B)}{N_s}, \quad B \in \mathcal{F}_s \qquad \mathbb{P}_c = \frac{\mu_c(B)}{N_c}, \quad B \in \mathcal{F}_c$$

creating probability spaces $(A_s, \mathcal{F}_s, \mathbb{P}_s)$ and $(A_c, \mathcal{F}_c, \mathbb{P}_c)$.

Single candidate productivity is a random variable $\theta : A_s \to \mathbb{R}_+$ on probability space $(A_s, \mathcal{F}_s, \mathbb{P}_s)$ with density f and CDF F.

Academic couple productivity is a random variable $c : A_c \to \mathbb{R}^2_+$ on probability space $(A_c, \mathcal{F}_c, \mathbb{P}_c)$ whose values are ordered pairs (θ_1, θ_2). The joint distribution for c is $h(\theta_1, \theta_2) = f(\theta_1)f(\theta_2)$ where f is the density for random variable θ used for single candidates. Intuitively, we are assuming that an individual's productivity has no bearing on the probability that they pair with another academic. This ensures that the productivity of partners are not correlated.

2.2 Single Academic's Problem

The payoff to an academic of being hired at a school in tier t is $u(t) = t$. If $S(\theta)$ is the set of schools making an offer to a person of productivity θ, then each $s \in S(\theta)$ can be enumerated according to its tier, $t(s)$ and individuals will accept an offer from schools in the highest tier represented in $S(\theta)$.

$$\max_s \; u(t(s)) \quad s.t. \quad s \in S(\theta)$$

2.3 Academic Couple's Problem

Each member of an academic couple lexicographically prefers working at the same school as their partner over working in higher tiered schools. Couple i is represented by productivities (θ_1^i, θ_2^i) and for each member of the couple we have a set of offers $S(\theta_1^i)$ and $S(\theta_2^i)$. Couple preferences ensure only offers common to both partners are considered and the couple accepts an offer to maximizes their common utility.

$$\max_s \ u(t(s)) \quad s.t. \quad s \in S(\theta_1^i) \cap S(\theta_2^i)$$

Let $\overline{\theta}^i = \max\{\theta_1^i, \theta_2^i\}$ and $\underline{\theta}^i = \min\{\theta_1^i, \theta_2^i\}$ and note that it is always true that $S(\underline{\theta}^i) \subset S(\overline{\theta}^i)$ implying that $S(\theta_1^i) \cap S(\theta_2^i) = S(\underline{\theta}^i)$. Hence $\underline{\theta}^i$, the least productive member of couple i, will determine the acceptable offer set for the couple. It is this fact that will cause the most productive member's "sacrifice" to work in a less prestigious school to distort the distribution of faculty quality.

2.4 The Hiring Problem

Schools value productive efficiency, θ, according to the nondecreasing function $v(\theta)$. For simplicity, we constrain each tier to hiring exactly their equal share of candidates, $(1/T)(N_s + N_c)$. A representative school in each tier seeks to hire the most productive candidates subject to hiring constraints and the offers of schools in other tiers. The tier t representative school's strategy will be to select a productivity cutoff, x_t such that it will extend employment offers to all candidates of at least that productivity. Selection of x_t must be made with consideration to the hiring constraint and the candidates who will reject the school's employment offers due to better prospects.

Proposition 1. *A Nash equilibrium is a list of lower productivity bounds $\{x_t\}_{t=1}^T$ such that x_t maximizes the productivity of the candidates tier t schools hire subject to its hiring constraint, the choices of x_{-t} by all other schools and such that single candidates maximize utility by accepting the highest tiered offer received and coupled candidates maximize utility by accepting the highest tiered offer received by both members of the couple. Furthermore the value of x_T will satisfy the condition*

$$F(x_T) + \alpha\{F(x_T)[1 - F(x_T)]\} = \frac{T-1}{T} \tag{1}$$

The value of x_t for all $1 < t < T$ will satisfy the condition

$$(1+\alpha)[F(x_{t+1}) - F(x_t)] - \alpha[F(x_{t+1}) - F(x_t)][F(x_{t+1}) + F(x_t)] = \frac{1}{T} \tag{2}$$

and finally the lowest tier select $x_1 = 0$.

The variation in equilibrium minimum productivity requirements between tiers describes the differences in productivity required to receive job offers from different tiered schools. In particular, the gap between the top tiered schools and the lowest tiered schools reflects how exclusive opportunities in the top-tiered schools really are. The inclusion of academic couples with strong preferences for remaining together can affect the ability of the top-tier to hire highly productive individuals who are paired with less productive partners. This leads us to the question as to whether the variation in quality between the highest and lowest tiered schools is affected as the proportion of academic couples in the market increases – in particular is quality compressed, or expanded?

Proposition 2 (Quality Compression)**.** *The difference in the required levels of productivity to receive an offer from the highest and lowest tiered schools decreases as the proportion of academic couples in the market,* α*, increases. In other words,*

$$\frac{d(x_T - x_1)}{d\alpha} < 0$$

The above proposition describes the fact that as more of the academic labor market is composed of dual career couples, the number of *mixed-tier* couples increases. Mixed-tier couples are those in which the most productive member of the couple, $\overline{\theta}$ receives offers from tiers that the least productive member, $\underline{\theta}$ does not. Under these conditions the more productive member rejects their higher tiered offers in order to be with their partner in a lower tiered school. As this happens, there are fewer candidates who will accept offers from the top tiered schools and their hiring constraint forces them to lower their standards in order to find more couples who both quality for an offer.

The primary question of this paper is the relative productivity of academic couples as compared to their single hire cohorts in the same institution. The highest tiered schools will never hire mixed-tier couples, as there is no higher tier and all such couples will accept lower offers in order to remain together. However, for tiers $t < T$ the presence of mixed-tier couples will provide candidates of higher productivity than would be possible in a market without academic couples. The proposition below summarizes these facts.

Proposition 3. *For all tiers* $t < T$ *the average member of a couple hired in tier* t *is strictly more productive than the average single hire in that same tier.*

The above proposition relates the fact that an arbitrary member of a mixed-tier couple has an expected productivity in excess of single hires, while same-tier couples have an expected productivity identical to single hires. As long as the probability of mixed-tier couples is positive, the expectation over the two types of couples results in a strictly greater productivity.

3 THE DATA

Faculty data was obtained from Ohio State University, Virginia Tech University, Washington State University and the University of Wyoming. The administrative data indicates not only which faculty are joint hires, but also an individual's gender, original hire year, separation year (if any), academic rank, and field of work. In addition, many faculty and staff at universities are not directly engaged in the production of academic outputs. We attempt to restrict the data to those faculty most likely to be engaged in productive activities. At each institution, we restrict the sample to faculty whose original hire year occurs during the years included in our sample.[2] Furthermore, to avoid differences in policy at satellite institutions, we remove individuals that are not located at the main campus, when identifiable.

The years covered in our samples differ across institutions. In particular, WSU offered over 15 years of administrative data, while Virginia Tech offered the least, at nine years. Our sample of joint hired faculty is small relative to single hires, indicating the relatively young age of partner accommodation policies. The small number of joint hires in the samples leads to two important implications. First, estimation results are sensitive to the inclusion or exclusion of a small number of individuals from this group. Second, only a small proportion of "dual-academic-career" couples may take advantage of partner accommodation policies. Academic couples in each institution hired as "single hires" likely exist and are not controlled for in our sample. The results of our analysis therefore apply to academic couples that choose to take advantage of explicit policies, and not all academic couples in general.

3.1 Productivity Data

The Web of Science (WOS) contains many records on various types of academic output. While not all fields of academic efforts are well represented in the database, a substantial quantity is and it may be the best current source of external productivity data. For each university in our study except Virginia Tech, we obtained every record in the WOS database associated with that institution over several decades. Virginia Tech administration matched their faculty to Web of Science publications and then provided us with the data.

A primary difficulty in measuring non-self-reported academic productivity is matching academic output, such as journal articles, to faculty members at a university. The difficulty stems from a number of sources. First, large numbers of both publications and faculty require a programmatic matching approach.[3] Unfortunately, for most authors, there does not exist a unique identifier linking them unambiguously to a unique publication identifier.[4] We match authors to their publications on the basis

[2] This restriction does remove some joint hires from the overall sample. However, since partner accommodation policies are relatively new, most of the joint hires in the original sample are preserved.

[3] Trying to match publications on the basis of their CV may or may not be more accurate, but is certainly too labor intensive to facilitate large scale studies.

[4] Web of Science offers a *ResearcherID* and there also exists an *ORCID*, both of which were created to solve the problem of author-publication identification. Unfortunately, these unique identifiers are not

of their name. In particular, the WOS database uses a default naming convention involving the author's last name followed by the first initials of the author's first and middle name. For example, an author named John Doe Smith would be represented as `Smith,JD` or perhaps `Smith,J` (depending on the publication). We used the provided faculty names in the administrative data and matched them against the authors listed on publications associated with each institution.

Matching faculty to publications on the basis of text string representations of their names is subject to error. For robustness in the matching process, we consider six different, but related, methods to capture several permutations in the form of an author's name. We then use the maximum measurement to both ameliorate some of the measurement error and reduce the chance of incorrectly assigning an author zero publications.

From the above matching we are able to create three key productivity metrics. First, we count the number of WOS publications matched to each individual. Second, using within-WOS citation counts, we measure the quantity of citations an individual's work generates as of 2014. Finally, using the matched publications and the citation count for each of those publications we derive a quasi-H-index for the work generated by an individual during the years represented in the sample. We discuss the creation of specific productivity measures in the next section.

Measuring productivity using WOS matching poses additional problems in constructing the most appropriate sample for testing our theory. First, we cannot definitively observe whether a given individual is engaged in the production of academic output. Faculty members who are not actively trying to publish will not have their productivity accurately measured and will confound our results. Because WOS matching is imperfect, when we fail to match any publications to a given individual, we do not know if that is because they truly have zero publications and were trying to publish, or whether they have zero publications because they are not trying to publish, or finally whether they have positive publication counts but we have failed to match them. This difficulty results in an excessive number of zero counts for productivity measures across faculty.

Inclusion of faculty with zero publication counts introduces measurement error and misspecification in the sense that we are comparing individuals who may not be engaged in research to those who are. Combined with small samples of joint hired faculty, it may distort the picture of relative productivity. Exclusion of faculty with zero publication counts may result in a sample bias. However, it is unclear whether the bias from exclusion is worse than the bias from inclusion. To reduce the excessive number of zeros and with the assumption that the individuals we are most interested in comparing are those most seriously engaged in publication generating research activities, we restrict our estimation samples from OSU, WSU and UoW to those individuals for whom we match to at least one publication. We do include zeros from Virginia Tech, as in this case zeros are less likely to represent measurement error as these faculty had their publications counted by university administration.

used widely enough for our purposes.

4 ESTIMATION AND RESULTS

We model individual i's research productivity, Y_i, as a function of joint-hire status as a dummy variable, $J_i \in \{0, 1\}$ as well as the number of years an individual has to generate research, sex, rank indicator variables, field indicator variables, and an individual's original hire year:

$$Y_i = f(J_i, \mathbf{X}_i, \varepsilon_i) \tag{3}$$

where $\mathbf{X}_i$ is the vector of covariates mentioned above and ε is the regression error. A list and description of all dependent and explanatory variables can be found in Table 2.

When primary and secondary hires are modeled separately, the single indicator variable J_i is replaced with indicators P_i (S_i) equal to 1 when the person is a primary (secondary) hire and zero otherwise. The model is now specified as,

$$Y_i = g(P_i, S_i, \mathbf{X}_i, \eta_i) \tag{4}$$

where $\mathbf{X}_i$ is as before and η_i is the regression error for this second specification.

We examine three distinct measures of research productivity, encompassing dimensions of research quantity and research quality. A count of the number of publications recorded in the WOS database is used as a measure of the *quantity* of research only, as it disregards the "impact" that research has. A count of the total citations for a person's publications measures the quality of that research portfolio by its impact, without reference to the quantity. Finally, we use an improvised H-index for an individual for publications produced throughout the years in the sample and with citations as of 2014 in the WOS database. The H-index is a measure of research productivity designed to balance the quantity and quality factors into a single measure of productivity.[5]

Academic productivity is a broad term encompassing a large spectrum of activities. Which activities and outcomes are valued most highly by institutions can differ substantially by institution and its departments. For most fields, publications, such as books, journal articles, stories, magazine articles, etc., are key measures of academic impact. More particularly for science-based fields, publications in journals are the most critical measure of productivity relevant for obtaining tenure, promotion and grants.

Across fields, the majority of academics produce only a few publications while an exceptional minority produce them in great quantities. The resulting distribution is highly skewed with a predominant mode near zero. Every school in our sample demonstrates the same pattern. Figure 1 shows frequency histograms of publication counts for each university in or sample for those below the 99th percentile.

Although the highly skewed right tail pulls the mean upward, the large mass of publications at small numbers results in a fairly small median. The positive count

[5] To calculate an H-index, enumerate an individual's n publications in descending order of citations. Descending from the most cited publication, we "count" publication i if its citation count, c_i, satisfied $c_i \geq i$. In words, the H-index is the number of publications that has at least that same number of citations.

nature of the data is often represented by a Poisson process. However, the large right tail causes the variance to be significantly greater than the mean, resulting in overdispersion. To account for this, the negative binomial distribution is a good substitute for the Poisson process. Thus, we estimate the regression models (3) and (4) via maximum likelihood using the Negative Binomial distribution as the likelihood and robust standard error calculations.

To account for additional differences across faculty, we control for the field which the data suggests an individual belongs to and also the rank and original hire year. Due to the small numbers of joint hires in the sample, sampling error can cause some combinations of original hire years, rank at hire and field to not contain any joint hires. This causes two potential problems. First, it reduces the comparability of joint hires to single hires. Second, it can reduce the stability of the estimation procedures by leading to near collinearities of variables and non-concavities in the likelihood function. We therefore identify variable groupings which do not contain both joint hires and single hires and drop the incomparable observations.

4.1 Pooled Sample Estimates

We first estimate the negative binomial regression for a sample pooling all schools into a single sample and including fixed effects for different schools. The results are presented in Table 3.

When both sexes are included, a randomly selected member of a joint hire couple is estimated to be quite similar to a single hire. The coefficient, -0.393, while not zero, is not economically significant and is furthermore statistically insignificant. This pattern appears consistent across samples for each gender as well.

In fact, all measures of productivity fail to be statistically significant enough to reject the hypothesis that joint hires differ in their productivity. Most estimates are also economically insignificant, except for an unusually large estimate of 35.91 for females when we measure productivity by citations.

Although arbitrary members of a joint hire couple may not significantly differ from single hires in their productivity, when separating those whom we expect were "recruited" from those that were "accommodated", significant differences may emerge.

For the all gender specification, the pooled estimates for primary hires are all larger than those for all joint hires, as would be expected if the most productive member of the couple was drawn from a higher quality distribution. Unfortunately, the signal is not entirely clear as not all estimates are statistically significant, but those that are provide interesting insight.

When all genders are included, the sample provides significant evidence that primary hires have a 0.643 higher H-index then single hires, suggesting higher quality faculty when publication impact is balanced with publication quantity. The effect is not robust to gender, however, as males have significantly higher H-index, but female primary hires do not. Interestingly, female primary hires do have significantly higher citation counts.

If partner accommodation policies are truly doing independent hiring, then all secondary hires must meet the same department standards for employment as any other single hire. If, instead, institutions either explicitly or implicitly implement an average hiring policy, then secondary hires are likely less productive on average than single hire cohorts. Pooled sample estimates appear most consistent with the average hiring policies, rather than independent hiring policies.

Across all genders, secondary hires have significantly lower quantities of publications and citations. Strangely, their H-index, while estimated to be lower than single hires, is not significantly so. These effects increase in economic significance when we look at only male faculty and weakened when considering only female faculty. These results begin to suggest a possible difference in male and female joint hires. The negative effect associated with being a secondary hire appears to be primarily driven by male, rather than female, secondary hires.[6]

4.2 Separate Sample Estimates

Estimates of the marginal effect of the joint hire indicator in the pooled sample assume all coefficients (except school effects) are identical across universities. Given that each institution may use partner accommodation policies differently and may attract different types of faculty, the assumption may be strong. If so, then the pooled sample may "under-fit" the model relative to the between school heterogeneity.

Table 4 presents estimated marginal effects for each of our four universities for samples including all genders. Tables 5 and 6 are the estimated average marginal effects for samples containing only males and females respectively.

4.2.1 Joint Hires

The effects for joint hires vary by institution and in general we lack statistical significance in many cases.

At OSU, all joint hires, both male and female, are less productive than single hires. The marginal effects for publication count are −2.085, and even lower for males (−4.112). Even though we have a negative estimate of −0.0182 for females, the estimate is close to zero and statistically insignificant. A similar pattern holds for the other measures of productivity.

At Virginia Tech, the comparative productivity of joint hires differs by whether we prioritize quantity or quality. In general, joint hires are estimated to have −0.422 fewer publications while males may be even less productive at −1.866. Interestingly, female joint hires are predicted to have 2.947 additional publications. Unfortunately, all estimated effects for publication counts have standard errors so large we cannot be sure that these joint hires are truly different from single hire cohorts.

[6] This pattern is most pronounced at Ohio State University. The OSU sample is many times larger than the samples of other institutions and may have an outsized effect on the pooled sample results.

Joint hires at Virginia Tech may be more likely to produce impactful research, especially female joint hires, though evidence is weak. Citation count and H-index adjust a faculty's research publications for the impact that they have as measured by citations. Female joint hires have a large and statistically significant difference of 0.792 in their H-index measure of productivity.

In general, WSU joint hires cannot be conclusively differentiated from single hires as all marginal effects are insignificant and inconsistent in their sign. However, when breaking the marginal effects out by gender, the marginal effects for males are positive and significant at 2.813 additional publications and an H-index that is predicted to be 1.05 units higher. By contrast, female joint hires have negative estimated effects for all three measures of productivity, though all estimates are statistically insignificant.

Estimates for joint hire effects at the University of Wyoming are sufficiently noisy, relative to the small number of joint hires, that all estimates fail to be statistically significant. However, we may still learn some things from the signs of the coefficients. First, both male and female joint hires are predicted to have more citations and a higher H-index, despite estimates of a lower overall publication count. While far from anything conclusive, this is a developing pattern we will discuss more later in the paper. The different effects may be noise, but also may be evidence of the need to carefully consider how we measure productivity and what forms of productivity universities are considering when they evaluate candidates for employment.

4.2.2 Primary Hires vs Secondary Hires

Given any dual career academic couple, we suppose that one member of the couple may be considered the most productive of the pair. If this assumption is true, then according to the model of section 2, the member of the couple most strongly recruited is likely to be this most productive member. While our data does not permit us to identify the most productive member of a couple (or identify actual couples for that matter) it may be reasonable to assume that in the majority of cases, the person designated as the "primary hire" may be the most productive member while the "secondary hire" is the less productive member. Although the secondary hire may, in many cases, be less productive than their primary hire partner, this does not imply, a priori, that they are less productive than others at the institution. Under an independent hiring policy, secondary hires must meet the same quality standard as any single hire. For average hiring policies, it is possible that given a highly productive primary hire partner, a secondary hire could be less productive than the average single hire.

OSU Primary and Secondary Hires In general, primary hires at Ohio State University are predicted to be less productive than single hires, an unexpected result. Though results are, in general insignificant, estimates are both economically and statistically significant for male primary hires. Specifically, male primary hires on average have 4.26 fewer publications, 64 fewer citations and an H-index that is approximately 1.412 units lower. Interestingly, female primary hires have estimated coefficients substantially closer to zero (though still negative) and are not statistically negative. This suggests there is a larger difference between a primary hire and single hire for males than for females.

Table 4 also shows that secondary hires are significantly less productive than single hires at Ohio State. For all measures of productivity, marginal effects are negative and statistically significant, unlike the general effects for primary hires. When looking only at a single sex, results become more bizarre. Male secondary hires, like primary hires, are significantly less productive. However, they may be more productive than primary hires. Male primary hires had a marginal effect of −4.26 for publications, where male secondary hires have an effect of only −3.715. The key reason why secondary hires of both genders are significantly less productive than single hires, when primary hires are not, is because female secondary hires appear much less productive than female primary hires. This is particularly true for quality-based productivity measures such as citations and H-index. Female secondary hires have 3.014 fewer publications on average than female single hires (bigger than −4.26 for males) but have 64.34 fewer citations and a substantial drop in H-index of −2.049.

Virginia Tech Primary and Secondary Hires Primary hires at Virginia Tech vary a great deal with gender. In general, estimates of the marginal effects are positive across productivity measures, but fail to be statistically significant, a result of poorly performing male primary hires. Female primary hires are unambiguously more productive than their single hire cohorts at VT, having on average an additional 6.3 publications, 42 more citations and an additional 1.434 H-index points. Male primary hires, like those of OSU, have negative effects across all productivity measures, but unlike OSU, estimates are not statistically significant. It is quite possible that VT male primary hires are no less productive than single hire males. Again, as with OSU, we see marked differences in outcomes between males and females participating in partner accommodation policies.

Washington State Univ Primary and Secondary Hires With genders combined, no significant signal emerges as to the relative productivity of primary and secondary hires to single hires. Both positive and negative estimates occur for different measures of productivity and none of the estimates are statistically significant. However, it is the case that the estimates for primary hires are larger than single hires. The marginal effect (which may be zero) is estimated in the sample as 1.14 publications for primary hires, but only 0.188 for secondary hires. A similar story holds for citations and H-index.

Estimates by gender reveal a little more information as male primary hires have significantly more (3.704) publications than male single hires and a higher H-index (+1.238). Female primary hires on the other hand, have consistently negative estimates, but nothing is statistically significant.

Male secondary hires appear largely similar to male single hires when taking the size of standard errors into account, with only publications being marginally significant (10% level) and negative. Curiously, female secondary hires, while not significant, are estimated to have greater publications than female single hires.

Univ of Wyoming Primary and Partner Hires Most estimates for faculty at the University of Wyoming are not statistically significant. Likely, a large variance in productivity combined with relatively small samples of joint hires have resulted in rather imprecise estimates. However, we do see some evidence that male primary hires have significantly more publications (+11.09) than male single hires and may also have a higher H-index at weaker confidence levels. Secondary hires appear to be significantly less productive having 14.96 fewer publications. Additionally, though lacking statistical significance, primary hires in general have higher point estimates of marginal effects than secondary hires, suggesting that its possible that primary hires are more productive than secondary hires at UoW.

4.2.3 Males vs. Females

Comparing the estimated differences in productivity for joint hires as well as primary and secondary hires, we see interesting differences in the productivity of male and female participants of partner accommodation policies. We now make some explicit comparisons among policy participants of the productivity differences relative to each sex's cohorts.

Ohio State male joint hires are consistently and significantly less productive than male single hires, however, joint hire females at OSU are not less productive than female single hires. This pattern persists for primary hires and only begins to deteriorate when we look at secondary hires. A similar pattern appears at Virginia Tech as well.

At Virginia Tech, male joint hires, primary hires and secondary hires are generally predicted to be less productive than male single hires (negative coefficients), though estimates are not statistically significant. However, when we look at females, most coefficients are positive and in the case of citation count and H-index are statistically significant.

Washington State is the first school to buck this trend and have significant evidence that male joint hires and primary hires are more productive than the average male single hire at the university. Although insignificant, estimates for females are mostly negative suggesting at least that female joint and primary hires are no less productive than female single hires. Unfortunately, the sample from the University of Wyoming does not appear to demonstrate any kind of consistent pattern worth discussing in this regard.

5 DISCUSSION AND CONCLUSIONS

As Tables 4, 5, and 6 make clear, the estimated relative productivity of joint hires across the different institutions in our samples vary in sign, magnitude and statistical significance. While strong consistent patterns are difficult to detect, it seems clear that the findings in (Scheibinger et al., 2008) are not robust when extended beyond survey data to the universe of faculty at an institution with objective productivity measures. Our estimates suggest that indeed some joint hires (whether primary or secondary) are significantly less productive than their single hire peers. Whether this evidence is sufficient to justify any "less good" stigmas is not yet clear, but cannot be easily rejected.

Our estimates are, in many cases, inconsistent with our theory which we developed in section 2. A number of possibilities exist as to why our results, though not consistent, do not necessarily falsify the developed theory.

First, our theory suggests that the average productivity of joint hires would exceed that of single hires and that this strict excess is derived from the presence of mixed-tier couples. Let $M = 1$ if a couple is of mixed-tier and $M = 0$ if the couple is same tier and let p be the probability that $M = 1$. Using the law of iterated expectations we have,

$$E[Y_i|J = 1] = E[Y_i|J = 1, M = 1]p + E[Y_i|J = 1, M = 0](1 - p)$$

Note that if $p = 0$ then joint hires are not expected to be any different than single hires. However, even if $p > 0$, but is small, the productivity effect can be quite small. If this small effect is then compounded with small samples, our theory becomes a theory of outliers. Essentially, the greater productivity of joint hires is entirely predicated on a school attracting a notable mixed-tier couple. If p is small, then samples of joint hires at universities where there are few joint hires will have a high likelihood of not including a mixed-tier couple. If so, then the effect predicted by our theory would not appear. Even if a sample does contain a mixed-tier couple, or two, they would be outliers in the sample. Our samples seem to display such a property. Robust results have been difficult to find, as small adjustments to the sample can easily include or exclude these influential joint hires as well as influential single hires, leading to significant changes in results.

Our model assumes that universities are using independent hiring policies. That is, all members of a couple must meet or exceed the institution's minimum quality cut-off to receive employment under the policy. While we have information that this ideal is likely followed at WSU, we do not know the degree to which such methods are used at the other schools in our sample.

An alternative hiring strategy could be an average hire policy. Under such a policy the university evaluates the couple's entire contribution to the stock of faculty quality, rather than evaluate them separately. If the combined or average productivity of the couple improves the stock of quality, then the couple is hired. Under this strategy, the least productive member of a couple could be at, or well below, the quality cut-off for single hires. The university may be willing to hire the couple, if the most productive member is sufficiently more productive than single hires so as to offset their partner's low quality. If universities followed such a strategy and if primary and secondary hires corresponded to the most and least productive members, then we would expect primary hires to be significantly more productive than single hires on average and secondary hires to be as or less productive than single hires.[7] This pattern does appear in our sample, but often lacks enough statistical significance and robustness to allow any strong conclusions.

[7] Again this assumes that the probability of mixed-tier couples appearing to take advantage of the policy to be sufficiently high.

For Ohio State, whether considering all genders together or separately, the results are inconsistent with an independent hiring hypothesis. The average hire hypothesis also seems inconsistent with the results, except when focusing only on female joint hires. In the case of OSU female joint hires, the marginal effect signs are correct, but the significance prevents any serious conclusion.

The results from Virginia Tech are also inconsistent with independent hiring except for female joint hires, for whom it may hold. Similarly, it appears that the average hire policy may also hold with females, but resists clarity in determining consistency with the other groups.

Washington State University is somewhat different from OSU and VT. In particular, we know that the official policy is that of independent hiring. However, only male joint hires appear to have results consistent with this type of hiring. Unfortunately, it is also possible that male hires are consistent with average hiring as results are not mutually exclusive.

No group at the University of Wyoming appears consistent with independent hiring. Instead, they are all more consistent with an average hiring policy, if we are willing to ignore the lack of statistical significance.

Another assumption in our theory is that of complete information about both productivity and the offerings and openings at schools. In reality, a person's academic productivity, especially early in their career, is difficult to ascertain and is not directly observable by institutions. Furthermore, candidates seeking employment are not aware of all opportunities and instead follow a search process with its own costs and frictions. Our model does not make any predictions about how these factors affect the sorting of mixed-tier (and even same-tier) couples into different ranked schools and its impact on the overall mean productivity of joint hires there.

Incomplete information may have a serious impact on the application of partner accommodation policies. Whether a university uses an independent hiring or average hiring policy, each requires an estimation of a person's unobservable productivity. Estimation is subject to error and the nature of partner accommodation policies may reduce opportunities to correct this error relative to the "traditional" hiring practices.

Another contribution of this paper is the comparison of joint hire productivities with respect to both publication quantity and publication quality. While the large battery of estimates previously discussed begins to shed some light on the potential for joint hires to differ on one measure, but not others, we may be mis-measuring productivity and that could partially explain the data's lack of support for our theory. In particular, we look at the relationship between publications and the quantity of citations. In essence, we might be interested in the citations per publication generated by different types of faculty. Figure 2 shows scatter plots of citations against publications, colored by joint hire status and with quadratic curves fit to the data. The data used for these graphs are pooled across all universities to try and look at the most general relationships for joint hire faculty. Additionally, data are restricted to the 99th percentile of productivity outcomes.

Figure 2a shows that there may be a tendency for joint hires to have more citations for a given number of publications than single hires. This potential demonstrates the importance of understanding how schools are evaluating and measuring productivity when making their joint hire decisions. It is possible that we have misspecified the true measurement of faculty quality and that is the reason we failed to support our theory. The phenomena is most potent for males, and appears to be non-existent for female faculty. These relationships, which appear across the pooled data, may provide guidance for future research into joint hire faculty productivity.

6 APPENDIX: FIGURES

Figure 1: Distribution of Publication Counts by University

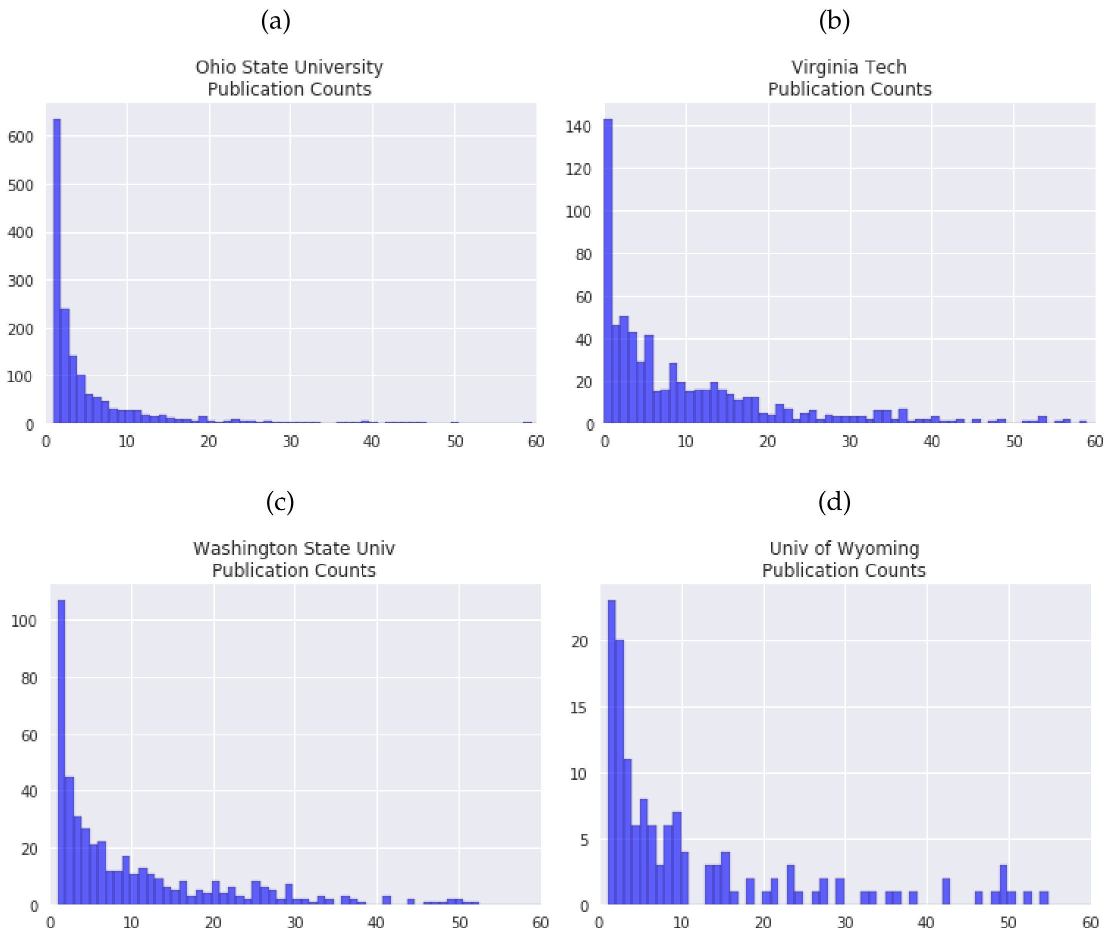
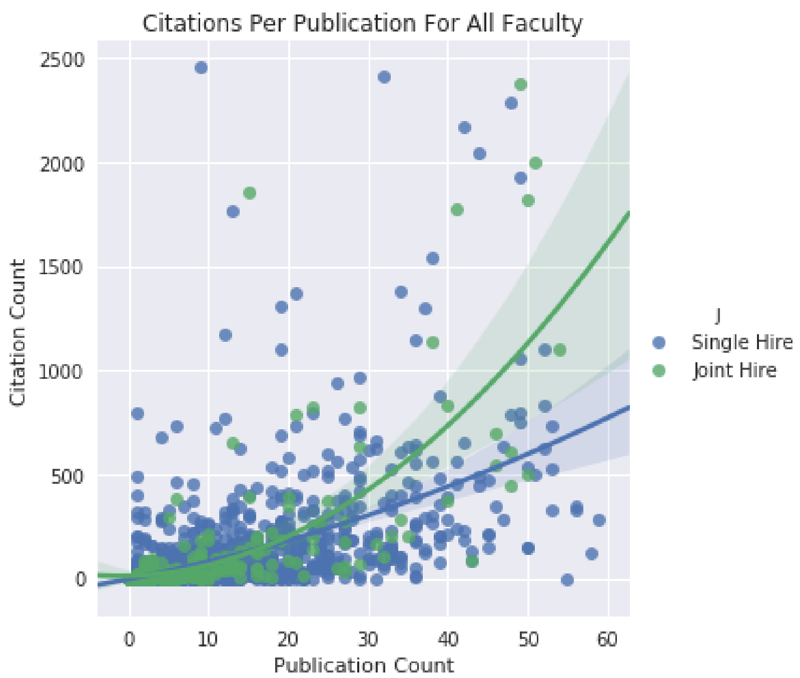
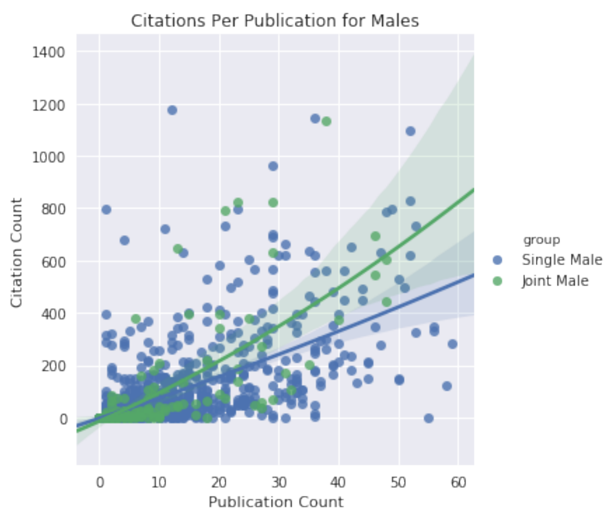


Figure 2: Citations Per Publication

(a)



(b)



(c)

7 APPENDIX: TABLES

Table 1: Sample years, faculty and joint hires by institution.

Institution	Years of Admin Data	Number of Faculty	Number of Joint Hires	Percent
Ohio State Univ	2004 – 2014	1,730	90	5%
Virginia Tech Univ	2006 – 2014	723	63	9%
Washington State Univ	1999 – 2014	741	135	18%
Univ of Wyoming	2000 – 2014	543	39	7%

Table 2: Common set of variables used for regression analysis across universities.

Variable	Description	Data Type
Productivity		
Publications	Count of WOS publication during years of the data.	Real
Citations	Count of the within WOS citations during years of the data.	Real
H-index	H-index created from WOS publications and associated citation count as of 2014.	Real
Type of Hire		
Joint Hire	Indicator for individual being part of an accommodated couple.	Binary
Primary	Indictor for individual being primary hire of the couple.	Binary
Partner	Indicator for individual being the partner hire of the couple.	Binary
Controls		
Female	Indicator for individual being female.	Binary
School Years	Number of years individual had to produce output (endyear original hire year).	Count
Rank	Academic rank in the first year person appears in administrative data.	Categorical
Original Hire Year	Original year an individual was hired at the university.	Categorical
Field	General field of work in which an individual produces academic output.	Categorical

Table 3: Marginal effects of Joint-hiring on productivity with all schools together

		(1) Publications	(2) Citations	(3) H-index
ALL	Joint Hire	-0.393	5.089	0.246
		(0.962)	(26.88)	(0.287)
	Primary Hire	1.225	41.09	0.643*
		(1.049)	(32.51)	(0.314)
	Secondary Hire	-4.180***	-79.58*	-0.679
		(1.534)	(37.00)	(0.465)
	N	2839	2839	2839
MALE	Joint Hire	0.365	-0.647	0.405
		(1.340)	(32.63)	(0.401)
	Primary Hire	2.190	32.81	0.885*
		(1.492)	(35.60)	(0.426)
	Secondary Hire	-5.332***	-104.4+	-1.123
		(2.051)	(62.66)	(0.725)
	N	1784	1784	1784
FEMALE	Joint Hire	-0.123	35.91	0.385
		(0.959)	(26.96)	(0.323)
	Primary Hire	0.777	67.46+	0.614
		(1.120)	(40.66)	(0.392)
	Secondary Hire	-1.396	-7.751	0.0727
		(1.375)	(26.83)	(0.456)
	N	1055	1055	1055

Standard errors in parentheses

$^{+}$ $p < .10$, * $p < .05$, ** $p < .025$, *** $p < .01$

Table 4: Marginal effects of Joint Hire on productivity by school.

		(1) Publications	(2) Citations	(3) H-index
OSU	Joint Hire	-2.085*	-30.25*	-0.759*
		(0.876)	(14.41)	(0.327)
	Primary Hire	-1.411	-18.47	-0.467
		(1.081)	(16.54)	(0.372)
	Secondary Hire	-3.726***	-64.34**	-1.603**
		(0.956)	(20.72)	(0.508)
	N	1567	1567	1567
VT	Joint Hire	-0.422	9.342	0.291
		(1.366)	(16.36)	(0.303)
	Primary Hire	0.858	21.26	0.457
		(2.121)	(23.98)	(0.464)
	Secondary Hire	-1.593	-2.342	0.140
		(1.519)	(18.92)	(0.359)
	N	676	676	676
WSU	Joint Hire	0.991	-29.37	0.354
		(1.160)	(29.21)	(0.391)
	Primary Hire	1.144	-28.26	0.417
		(1.202)	(29.89)	(0.404)
	Secondary Hire	0.188	-34.75	0.0276
		(2.772)	(67.82)	(0.903)
	N	460	460	460
UOW	Joint Hire	-2.813	171.5	0.476
		(3.446)	(242.9)	(1.111)
	Primary Hire	2.336	342.6	1.467
		(3.308)	(273.4)	(1.187)
	Secondary Hire	-14.96**	-391.5	-1.695
		(5.653)	(284.3)	(1.584)
	N	136	136	136

Standard errors in parentheses

$^{+}$ $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$

Table 5: Marginal effects on productivity for male faculty.

		(1) Publications	(2) Citations	(3) H-index
OSU	Joint Hire	-4.112***	-56.80***	-1.331***
		(1.248)	(16.80)	(0.359)
	Primary Hire	-4.260**	-64.10**	-1.412***
		(1.469)	(19.91)	(0.403)
	Secondary Hire	-3.715*	-43.62+	-1.129
		(1.798)	(26.38)	(0.693)
	N	932	932	932
VT	Joint Hire	-1.866	-25.08	-0.194
		(1.823)	(23.62)	(0.392)
	Primary Hire	-3.043	-46.54	-0.542
		(2.894)	(33.00)	(0.539)
	Secondary Hire	-0.832	-8.718	0.135
		(2.109)	(32.47)	(0.535)
	N	452	452	452
WSU	Joint Hire	2.813*	25.33	1.050*
		(1.406)	(29.29)	(0.444)
	Primary Hire	3.704**	27.09	1.238**
		(1.413)	(29.94)	(0.451)
	Secondary Hire	-6.610+	10.79	-0.666
		(3.821)	(87.44)	(1.094)
	N	313	313	313
UOW	Joint Hire	3.818	89.52	0.936
		(5.244)	(210.9)	(1.744)
	Primary Hire	11.09*	289.6	3.142+
		(5.561)	(252.0)	(1.732)
	Secondary Hire	-14.92	-377.2	-4.206
		(9.426)	(419.8)	(2.906)
	N	87	87	87

Standard errors in parentheses

+ $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$

Table 6: Marginal effects of Joint Hire on productivity, female faculty only.

		(1) Publications	(2) Citations	(3) H-index
OSU	Joint Hire	-0.0182	-18.64	-0.156
		(0.962)	(21.13)	(0.441)
	Primary Hire	1.548	6.043	0.445
		(1.156)	(21.48)	(0.443)
	Secondary Hire	-3.014**	-115.0***	-2.049**
		(0.921)	(34.50)	(0.736)
	N	635	635	635
VT	Joint Hire	2.947	29.74+	0.792*
		(2.013)	(17.80)	(0.392)
	Primary Hire	6.275*	41.97*	1.434**
		(3.119)	(19.69)	(0.510)
	Secondary Hire	-0.0858	9.625	0.242
		(2.157)	(18.38)	(0.438)
	N	224	224	224
WSU	Joint Hire	-0.621	-60.64	-0.742
		(2.090)	(74.21)	(0.853)
	Primary Hire	-3.570	-100.9	-1.308
		(2.208)	(85.46)	(0.912)
	Secondary Hire	5.600	35.77	0.492
		(3.993)	(156.8)	(1.386)
	N	147	147	147
UOW	Joint Hire	-2.899	167.6	0.656
		(2.139)	(140.9)	(0.919)
	Primary Hire	-2.741	259.6	0.476
		(2.574)	(214.4)	(1.199)
	Secondary Hire	-3.215+	-8.930	0.917
		(1.935)	(140.1)	(0.757)
	N	49	49	49

Standard errors in parentheses

$^{+}$ $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$

8 APPENDIX: PROOFS

8.1 Proposition 1

A Nash equilibrium is a list of lower productivity bounds $\{x_t\}_{t=1}^{T}$ *such that* x_t *maximizes the productivity of the candidates that tier t schools hire, subject to their hiring constraint, the choices of* x_{-t} *by all other schools, and such that single candidates maximize utility by accepting the highest tiered offer received and coupled candidates maximize utility by accepting the highest tiered offer received by both members of the couple. Furthermore, the value of* x_T *will satisfy the condition*

$$F(x_T) + \alpha\{F(x_T)[1 - F(x_T)]\} = \frac{T-1}{T}$$

The value of x_t *for all* $1 < t < T$ *will satisfy the condition*

$$(1+\alpha)[F(x_{t+1}) - F(x_t)] - \alpha[F(x_{t+1}) - F(x_t)][F(x_{t+1}) + F(x_t)] = \frac{1}{T}$$

and finally the lowest tier select $x_1 = 0$.

Proof.
Each tier seeks to maximize its payoff $\int v(\theta)\,\mathrm{d}\theta$ subject to its contraint that it must hire $(N_s + N_c)/T$ of the academics on the market. We let $v(\theta)$ be an increasing function of θ so that each tier seeks to acquire the highest quality candidates it can. Academics seeking employment are either single or in a couple and derive utility from the "prestige" of the tier hired into such that $u(t) = t$ for $t = 1, 2, \ldots, T$. Each single candidate maximizes utility through accepting the offer of the highest tiered school in their offer set. Let $S(\theta)$ represent the offer set of an individual with productivity θ and let (θ_1, θ_2) represent a couple. It is common knowledge that candidates will solve their utility maximization problems:

$$\text{Singles: } \max_t \; S(\theta) \qquad \text{Couples: } \max_t \; S(\theta_1) \cap S(\theta_2)$$

The strategy available to each tier is to choose a cut-off x such that for all $\theta > x$ the tier extends on offer and for all $\theta \leq x$ the tier does not extend on offer. By set compliment, whether we view the tiers as selecting the set of academics to extend offers to or those to whom no offer will be extended, it is the same. Hence, without loss of generality we will view each tier's choice as one of selecting the set of individuals who will not be extended offers. Each tier must take into account the cut-offs selected by other tiers to infer which candidates might accept employment in their tier if extended an offer.

The tier T school knows that every candidate maximizes utility by accepting offers from it if extended. Hence, tier T can choose its cut-off, x_T without thought to the strategies of the other players. Tier T will maximize its value function by taking the top measure $(N_s + N_c)/T$ of candidates leaving $(T-1)(N_s + N_c)/T$ of the candidates without an offer. Furthermore, because there are no higher tiers, tier T knows that any couple in which both members receive an offer will accept. If x_T is chosen then the proportion of single candidates accepting offers to tier T will be $\int_{x_T}^{\infty} f(\theta)\,\mathrm{d}\theta$ while the proportion of couples accepting job offers is $\int_{x_T}^{\infty}\int_{x_T}^{\infty} f(\theta_1)f(\theta_2)\,\mathrm{d}\theta_1\,\mathrm{d}\theta_2$. Therefore the proportion of singles and couples not being hired into tier T are represented by 1 minus these quantities. Tier T will choose x_T to satisfy the following condition representing the total measure of candidates not hired into tier T.

$$N_s\left(1 - \int_{x_T}^{\infty} f(\theta)\,\mathrm{d}\theta\right) + N_c\left(1 - \int_{x_T}^{\infty}\int_{x_T}^{\infty} f(\theta_1)f(\theta_2)\,\mathrm{d}\theta_1\,\mathrm{d}\theta_2\right) = \frac{(T-1)(N_s + N_c)}{T}$$

Describing the above condition in terms of the CDF and using the independence of (θ_1, θ_2) we have

$$\begin{aligned}
N_s - N_s[1 - F(x_T)] + N_c - N_c[1 - F(x_T)]^2 &= \frac{(T-1)(N_s + N_c)}{T} \\
N_s F(x_T) + N_c\left\{1 - [1 - F(x_T)]^2\right\} &= \frac{(T-1)(N_s + N_c)}{T} \\
N_s F(x_T) + N_c\left\{2F(x_T) - F(x_T)^2\right\} &= \frac{(T-1)(N_s + N_c)}{T} \\
(1-\alpha)F(x_T) + \alpha\left\{2F(x_T) - F(x_T)^2\right\} &= \frac{T-1}{T} \\
(1-\alpha)F(x_T) + 2\alpha F(x_T) - \alpha F(x_T)^2 &= \frac{T-1}{T} \\
(1+\alpha)F(x_T) - \alpha F(x_T)^2 &= \frac{T-1}{T} \\
F(x_T) + \alpha\{F(x_T)[1 - F(x_T)]\} &= \frac{T-1}{T}
\end{aligned}$$

The value x_T that satisfies the above condition is a dominant strategy for tier T since it is optimal regardless of the offer strategies adopted by other tiers. Tier $T-1$ takes tier T's behavior into account knowing that if it chooses some x_{T-1} and makes offers to all candidates exceeding those cut-offs that only singles with $\theta < x_T$ and couples where $\theta_1, \theta_2 \geq x_{T-1}$ but at least one member has $\theta_i < x_{T-1}$ will accept. This implies that tier

$T-1$ will choose x_{T-1} to satisfy the condition below.

$$
\begin{aligned}
N_s \int_{x_{T-1}}^{x_T} f(\theta)\,\mathrm{d}\theta + N_c \left(\int_{x_{T-1}}^{\infty} \int_{x_{T-1}}^{\infty} f(\theta_1) f(\theta_2)\,\mathrm{d}\theta_1\,\mathrm{d}\theta_2 - \int_{x_T}^{\infty} \int_{x_T}^{\infty} f(\theta_1) f(\theta_2)\,\mathrm{d}\theta_1\,\mathrm{d}\theta_2 \right) &= \frac{N_s + N_c}{T} \\
N_s[F(x_T) - F(x_{T-1})] + N_c \left[(1 - F(x_{T-1}))^2 - (1 - F(x_T))^2 \right] &= \frac{N_s + N_c}{T} \\
(1-\alpha)[F(x_T) - F(x_{T-1})] + \alpha \left[(1 - F(x_{T-1}))^2 - (1 - F(x_T))^2 \right] &= \frac{1}{T} \\
(1-\alpha)[F(x_T) - F(x_{T-1})] + \alpha \left[(1 - 2F(x_{T-1}) + F(x_{T-1})^2) - (1 - 2F(x_T) + F(x_T)^2) \right] &= \frac{1}{T} \\
(1-\alpha)[F(x_T) - F(x_{T-1})] + \alpha \left[2[F(x_T) - F(x_{T-1})] + F(x_{T-1})^2 - F(x_T)^2 \right] &= \frac{1}{T} \\
(1+\alpha)[F(x_T) - F(x_{T-1})] - \alpha \left[F(x_T)^2 - F(x_{T-1})^2 \right] &= \frac{1}{T} \\
(1+\alpha)[F(x_T) - F(x_{T-1})] - \alpha[F(x_T) - F(x_{T-1})][F(x_T) + F(x_{T-1})] &= \frac{1}{T} \\
(1+\alpha)[F(x_T) - F(x_{T-1})] - \alpha[F(x_T) - F(x_{T-1})][F(x_T) + F(x_{T-1})] &= \frac{1}{T}
\end{aligned}
$$

It is therefore also true for all tiers $1 < t < T$ that

$$
(1+\alpha)[F(x_{t+1}) - F(x_t)] - \alpha[F(x_{t+1}) - F(x_t)][F(x_{t+1}) + F(x_t)] = \frac{1}{T}
$$

Finally, for $t = 1$ the choice will be $x_1 = 0$ so that the lowest tier makes offers to all candidates and the choice of $x_1 = 0$ will satisfy

$$
(1+\alpha)F(x_2) - \alpha F(x_2)^2 = \frac{1}{T} \tag{5}
$$

$$
[(1+\alpha) - \alpha F(x_2)]F(x_2) = \frac{1}{T} \tag{6}
$$

8.2 Lemma 2

For the random variables $\overline{\theta} = \max\{\theta_1, \theta_2\}$ *and* $\underline{\theta} = \min\{\theta_1, \theta_2\}$ *the joint distribution of* ($\overline{\theta}$, *partner*) *is*

$$
\begin{aligned}
f(\overline{\theta}, \underline{\theta}) &= 2(2-1) f(\overline{\theta}) f(\underline{\theta}) [F(\overline{\theta}) - F(\underline{\theta})]^{2-2};\ \overline{\theta} > \underline{\theta} \\
&= 2 f(\overline{\theta}) f(\underline{\theta}) \chi[\overline{\theta} > \underline{\theta}]
\end{aligned}
$$

Proof This is a textbook result for order statistics and is relevant because even though (θ_1, θ_2) may be independent random variables $(\overline{\theta}, \underline{\theta})$ are not independent. ■

8.3 Lemma 3

The average member of a mixed-tier couple hired in tier t is strictly more productive than the average single hire in tier t.

Proof Let M be the event that an individual is in a mixed tier couple hired in tier t. Let $\overline{\theta}$ be the most productive member of the couple and $\underline{\theta}$ be the least productive member. Then the random variables $(\overline{\theta}, \underline{\theta})$ have

$$h(\overline{\theta}, \underline{\theta}) = 2f(\overline{\theta})f(\underline{\theta})\chi[\overline{\theta} \geq \underline{\theta}]$$

The event M can be described as $\{(\overline{\theta}, \underline{\theta}) \in \mathbb{R}^2_+ : \overline{\theta} \geq x_{t+1} \text{ and } x_t \leq \underline{\theta} \leq x_{t+1}\}$. The probability of the event M for tier t is

$$\begin{aligned} Pr(M) &= \int_{x_t}^{x_{t+1}} \int_{x_{t+1}}^{\infty} 2f(\overline{\theta})\,\mathrm{d}\overline{\theta} f(\underline{\theta})\,\mathrm{d}\underline{\theta}\chi[\overline{\theta} \geq \underline{\theta}] \\ &= 2\int_{x_t}^{x_{t+1}} f(\underline{\theta})\,\mathrm{d}\underline{\theta}\left(\int_{x_{t+1}}^{\infty} f(\overline{\theta})\,\mathrm{d}\overline{\theta}\right) \\ &= 2\int_{x_t}^{x_{t+1}} f(\underline{\theta})\,\mathrm{d}\underline{\theta}\,(1 - F(x_{t+1})) \\ &= 2\,(F(x_{t+1}) - F(x_t))\,(1 - F(x_{t+1})) \end{aligned}$$

Conditioning the joint density on M yields conditional joint density

$$h(\overline{\theta}, \underline{\theta} \mid M) = \frac{f(\overline{\theta})f(\underline{\theta})}{[F(x_{t+1}) - F(x_t)][1 - F(x_{t+1})]} \cdot \chi[\overline{\theta} \geq x_{t+1}] \cdot \chi[x_t \leq \underline{\theta} \leq x_{t+1}]$$

In event M, the range of values for the least productive member are always less than the possible values for the most productive member. Therefore the dependence inherent in the joint density h, $h(\cdot; \mid M)$ meaning we can integrate out $\overline{\theta}$ over its values x_{t+1} to ∞

leaving us with the marginal conditional density $h_{\underline{\theta}}(\theta|M)$.

$$\begin{aligned}
h_{\underline{\theta}}(\theta \mid M) &= \frac{2f(\underline{\theta})\int_{x_{t+1}}^{\infty} f(\overline{\theta})\,\mathrm{d}\overline{\theta}}{2\,(F(x_{t+1})-F(x_t))\,(1-F(x_{t+1}))} \\
&= \frac{2f(\underline{\theta})[1-F(x_{t+1})]}{2\,(F(x_{t+1})-F(x_t))\,(1-F(x_{t+1}))} \\
&= \frac{f(\theta)}{F(x_{t+1})-F(x_t)}\cdot\chi[x_t \le \theta \le x_{t+1}]
\end{aligned}$$

Similarly, we can obtain the marginal conditional density of $\overline{\theta}$, $h_{\overline{\theta}}(\theta \mid M)$ as

$$\begin{aligned}
h_{\overline{\theta}}(\theta \mid M) &= \frac{2f(\overline{\theta})\int_{x_t}^{x_{t+1}} f(\underline{\theta})\,\mathrm{d}\underline{\theta}}{2\,(F(x_{t+1})-F(x_t))\,(1-F(x_{t+1}))} \\
&= \frac{2f(\overline{\theta})[F(x_t)-F(x_{t+1})]}{2\,(F(x_{t+1})-F(x_t))\,(1-F(x_{t+1}))} \\
&= \frac{f(\theta)}{(1-F(x_{t+1}))}\cdot\chi[\theta \ge x_{t+1}]
\end{aligned}$$

The last density we need is that of single hires in tier t. The probability of a single hire in tier t is given as $F(x_{t+1}) - F(x_t)$. Hence the conditional density is

$$f(\theta|x_t \le \theta \le x_{t+1}) = \frac{f(\theta)}{F(x_{t+1})-F(x_t)}\cdot\chi[x_t \le \theta \le x_{t+1}]$$

Letting θ_s represent the productivity of single hires we now find the expected values for the random variables $\theta_s, \underline{\theta}$ and $\overline{\theta}$.

$$\begin{aligned}
E[\theta_s|t] &= \frac{\int_{x_t}^{x_{t+1}} \theta_s f(\theta_s)\,\mathrm{d}\theta_s}{F(x_{t+1})-F(x_t)} \\
E[\underline{\theta}|t] &= \frac{\int_{x_t}^{x_{t+1}} \underline{\theta} f(\underline{\theta})\,\mathrm{d}\underline{\theta}}{F(x_{t+1})-F(x_t)} \\
E[\overline{\theta}|t] &= \frac{\int_{x_{t+1}}^{\infty} \overline{\theta} f(\overline{\theta})\,\mathrm{d}\overline{\theta}}{1-F(x_{t+1})}
\end{aligned}$$

From the above expressions for the expected productivities we see that for mixed couples, $E[\underline{\theta}] = E[\theta_s]$, telling us that the least productive member of a mixed-tier couple in some tier t has the same productivity as the single hires. However, the values for the expectation of $\overline{\theta}$ are taken from a strictly greater set and so we can conclude that $E[\overline{\theta}|t] > E[\theta_s|t]$. The value of $\underline{\theta}$, represents the productivity of a member of a couple conditional on them being the least productive member. By the law of iterated expectations we know that the expected value of an arbitrary member of a mixed-tier couple in tier t is $E[\theta_c|t] = E[\theta|t, \min\{\theta_1, \theta_2\}](1/2) + E[\theta|t, \max\{\theta_1, \theta_2\}](1/2)$. Therefore we see that $E[\theta_c|t] > E[\theta_s|t]$; which completes the proof.

■

8.4 Lemma 4

Same-tier couples are at least as productive as single hires in the same tier.

Proof The event associated with same-tier couples is

$$B = \{(\overline{\theta}, \underline{\theta}) \in \mathbb{R}^2_+ : x_t \leq \overline{\theta} \leq x_{t+1} \text{ and } x_t \leq \underline{\theta} \leq x_{t+1}\}$$

if we consider the dependent random variables $(\overline{\theta}, \underline{\theta})$. However, in this case it is not useful to specify who is the most productive and least productive member of the couple since both will be contained in the same interval $[x_t, x_{t+1}]$. Hence we have the event $\{(\theta_1, \theta_2) \in \mathbb{R}^2_+ : x_t \leq \theta_1 \leq x_{t+1} \text{ and } x_t \leq \theta_2 \leq x_{t+1}\}$ and the probability of this event $Pr(B)$ is

$$\begin{aligned} Pr(B) &= \int_{x_t}^{x_{t+1}} \int_{x_t}^{x_{t+1}} f(\theta_1) f(\theta_2) \, \mathrm{d}\theta_1 \, \mathrm{d}\theta_2 \\ &= [F(x_{t+1}) - F(x_t)]^2 \end{aligned}$$

This yields the conditional joint distribution $\frac{f(\theta_1)f(\theta_2)}{[F(x_{t+1})-F(x_t)]^2}$. Without loss of generality we can integrate out either θ_1 or θ_2 to get the same conditional marginal distribution

$$\frac{f(\theta)}{F(x_{t+1}) - F(x_t)}$$

Therefore we have

$$\begin{aligned} E[\theta_c|B] &= \frac{\int_{x_t}^{x_{t+1}} \theta f(\theta) \, \mathrm{d}\theta}{F(x_{t+1}) - F(x_t)} \\ &= E[\theta_s|t] \end{aligned}$$

■

8.5 Proposition 2

The difference in quality cutoffs between the highest and lowest tiers, x_T and x_1 decreases as the proportion of couples in the academic labor market increases.

Proof The difference in quality between the highest and lowest tiers is $x_T - x_1$ and in equilibrium we know that $x_1 = 0$ so the level of x_T represents the quality range. Consider tier T's equilibrium hiring condition

$$G(x_T, \alpha, T) = F(x_T) + \alpha F(x_T)[1 - F(x_T)] - \frac{T-1}{T} = 0$$

We will use implicit differentiation on tier T's equilibrium hiring condition to ascertain the sign of $dx_T/d\alpha$.

$$\begin{aligned}
\frac{dx_T}{d\alpha} &= -\frac{G_\alpha}{G_{x_T}} \\
&= -\frac{F(x_T)[1 - F(x_T)]}{F'(x_T) + \alpha[F'(x_T)[1 - F(x_T)] - F(x_T)F'(x_T)]} \\
&= -\frac{F(x_T)[1 - F(x_T)]}{f(x_T)\,(1 + \alpha[1 - 2F(x_T)])}
\end{aligned}$$

The numerator in the ratio above is strictly positive. The sign of the denominator will depend upon the magnitude of $\alpha[1 - 2F(x_T)]$. Whenever this term is greater than or equal to -1, the denominator will be positive.

$$\begin{aligned}
\alpha[1 - 2F(x_T)] &\geq -1 \\
1 - 2F(x_T) &\geq -\frac{1}{\alpha} \\
1 + \frac{1}{\alpha} &\geq 2F(x_T) \\
\frac{1}{2} + \frac{1}{2\alpha} &\geq F(x_T) \\
\frac{1+\alpha}{2\alpha} &\geq F(x_T)
\end{aligned}$$

Since $1 + \alpha \geq 2\alpha$ for all $\alpha \in [0, 1]$, we know $(1 + \alpha)/2\alpha \geq 1$. Hence the denominator is positive whenever $F(x_T) \leq 1$ is true and this condition always holds. The ratio is positive and therefore the entire derivative is negative - implying that x_T decreases with increases in the proportion of couples α. ∎

8.6 Proposition 3

For all tiers, $t < T$, the average member of a couple hired in tier t is strictly more productive than the average single hire in tier t.

Proof Let M be the event that a candidate is part of a mixed-tier couple and let B be the event that a person is part of a same-tier couple. If θ_c is the productivity of an arbitrary member of a couple hired in tier t, then

$$\begin{aligned} E[\theta_c|t] &= E[\theta_c|M]Pr(M) + E[\theta_c|B]Pr(B) \\ &= E[\theta_c|M]Pr(M) + E[\theta_s|t]Pr(B) \quad \text{by Lemma 2.4} \\ &> E[\theta_s|t]Pr(M) + E[\theta_s|t]Pr(B) \quad \text{by Lemma 2.3} \\ &= E[\theta_s|t] \end{aligned}$$

■

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