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Human Capital and Productivity in a Team Environment: Evidence from the Healthcare Sector†

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Using panel data from a large hospital system, this paper presents estimates of the productivity effects of human capital in a team production environment. Proxying nurses' general human capital by education and their unit-specific human capital by experience on the nursing unit, we find that greater amounts of both types of human capital significantly improve patient outcomes. Disruptions to team functioning attributable to the departure of experienced nurses, the absorption of new hires, and the inclusion of temporary contract nurses are associated with significant decreases in productivity beyond those attributable to changes in nurses' skill and experience. (*JEL* I11, J22, J24, M12, M54)

We provide new insights into an important, but understudied, factor that shapes the cost and quality of healthcare in the United States—the structure and composition of nursing teams on acute care hospital units. The number of microeconometric studies of the productivity of health care delivery is small relative to the large and expanding role that the health care sector plays in the American economy. Nursing care is a frequently overlooked but critical factor of health care productivity.[1] While doctors make the majority of decisions about when and how to treat patients, nurses fill a pivotal role in implementing treatment plans. Moreover, nurses monitor the progress of their patients, facilitate the frequent adjustments that customize treatments to the evolving needs of individual patients, and coordinate care delivery. These actions, in turn, speed recovery, economize on resources, and

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[1] However, see the study of British hospitals by Propper and Van Reenen (2010) who found that higher outside wages for nurses significantly worsened hospital quality because it was harder to attract and retain skilled nurses.

enhance patient satisfaction. Importantly, nurses work closely with patients and family caregivers to encourage them, and to help patients understand their treatment so they may play an active role in their care.

Using monthly data from the Veterans Administration (VA) hospital system, we study how changes in the human capital attributes of the nursing team impact patient outcomes. We are able to identify when new nurses join the team and when experienced nurses depart, and also observe whether nurses on the unit are regular staff members or agency nurses (who are not part of the regular nursing team) contracted to cover for absences by regular staff nurses. Unlike other contexts in which teams are endogenously formed (for example, Bandiera, Barankay, and Rasul forthcoming), hospital nurses are assigned to existing units as vacancies become available or staff expands. They are compensated based on their seniority and credentials, and do not receive individual or group incentive pay. Month-to-month variations in characteristics of the nursing staff (education, hospital experience, unit experience, contract status) result from absences (vacations, sick days, personal leaves), separations (turnover and retirement) and new hires. We focus on how these changes in the composition of the nursing team impact productivity.

We base our productivity measure on the length of time patients stay in the hospital. Length of stay (LOS) is a relatively inclusive proxy for the cost and quality of a hospital episode of care. To control for variations in patient severity of illness, we compute each patient's residual length of stay as the difference between his actual length of stay and his expected length of stay; the latter measure is based on the patient's admitting diagnoses and other characteristics.

The VA data are unique in that they link each patient to the nursing units in which he was actually treated. [2] This feature of the data enables us to relate changes in the composition of the nursing team within individual hospital units to changes in residual length of stay for patients on those same units. By estimating this relationship in a fixed effects framework (with hospital unit fixed effects), we base our identification on within-hospital unit changes over time. Annual unit fixed effects control for any characteristics of the nursing unit that might influence patient outcomes and that are unlikely to vary within a year.

In this econometric framework, one concern might be that the nurse staffing changes are endogenous (e.g., that nurses change their labor supply in response to the quality of care on the unit). We show that monthly mobility between units, and separations from the VA, are not correlated with patient outcomes on the unit. Another possible concern is that management may adjust nursing staff based on unit performance, reallocating staff from well-performing units to poorly performing units. To address this concern we show that the rate of transfers between like units is less than 1 percent. Furthermore, restricting our analysis to units that are the only one of their type in the hospital (thereby lessening the likelihood of internal transfers), leaves our regression results unchanged. In sum, our unique monthly data

[2] Another advantage of the VA data is that all the hospitals belong to the same umbrella organization with data collection standardized across member hospitals, ensuring that variable definitions and data coding algorithms are identical across the nursing units in our study. The major difference between patients in VA hospitals and patients in non-VA hospitals is that the former do not include children and are less than 10 percent female.

enable us to provide convincing estimates of the impact of various dimensions of nurse human capital on patient outcomes.

We find that higher levels of general human capital and specific human capital among nurses on the unit are associated with shorter patient stays in the hospital. The degree of specificity of the registered nursing staff's human capital is shown to be an important determinant of patient outcomes; while unit-level tenure is significant, the effect of a nurse's hospital tenure outside of the unit is insignificant. Further evidence of the importance of specific human capital is that staffing by contract nurses does not improve patient outcomes; while the presence of a contract nurse increases staffing intensity, these additional resources are not productive in improving patient outcomes.

A unique feature of our study is that we are able to model human capital in ways that are different from previous studies.[3] The essence of team production is that it involves interaction among team members, typically of the sort involving communication, knowledge sharing, and coordination. When experienced teams are disrupted by the absence of a key member, the presence of an outsider, or the addition of a new member, these activities that manage interdependencies are likely to be impaired. We find evidence of negative productivity effects when nursing teams are disrupted by the departure of experienced nurses or the absorption of new hires.

The paper is organized as follows. Section I describes the hospital setting, the relevance of various dimensions of nurse human capital, and the VA dataset. Section II describes our empirical strategy and addresses potential challenges to the exogeneity of our measures of monthly changes in nurse staffing. Regression results, including a number of robustness checks, are presented in Section III. Section IV concludes.

I. The Context and Data

A. *Nurse Staffing in Hospital Units*

Hospital patients are assigned to nursing units based on the type of care they require (e.g., acute care units such as medical, surgical, neurology, oncology, cardiac care, and intensive care units). In our sample of acute care units, there is an average of sixteen patients who are cared for by a team of three registered nurses (RNs) on a given shift (or eight to nine RNs on a given day). Registered nurses are assisted by licensed practical nurses (LPNs) and unlicensed assistive personnel (UAPs) (commonly referred to as nursing aides), who have less extensive educational requirements and clinical training. LPNs are not allowed to conduct patient assessments or care planning or administer intravenous medications. UAPs are restricted to very basic patient tasks. Units are managed by nurse managers.

While specific RNs are assigned primary responsibility for a patient, some tasks, such as checking certain medications, wound care, or administering blood, require

[3] Unlike organizational level studies that relate aggregate human capital measures of the workforce to firm-level outcomes (Fox and Smeets 2011; Black and Lynch 2001), our study is more closely related to studies of peer effects. See Mas and Moretti (2009) on the impact of monitoring by more productive peers and Chan, Li, and Pierce (2011) on the role of informal teaching done by an experienced salesperson who is colocated with an inexperienced salesperson.

two RNs, and, if a patient's primary nurse is busy with another patient or off the unit, other RNs provide help. In addition, nursing care is provided by multiple shifts per day requiring nurses on one shift to share information regarding a patient's condition and treatment with nurses on other shifts. Hence, the work on a nursing unit is best described as a group production process that utilizes knowledge workers, i.e., individuals who apply their knowledge to solving specific problems and communicating solutions to coworkers (Garicano and Hubbard 2007).

B. *Human Capital*

General human capital is higher in units that have a greater proportion of RNs compared to LPNs and UAPs, or a greater proportion of RNs with more prior nursing experience. Since hospitals often use their own systems, policies, procedures and protocols, RNs acquire knowledge and skills that may be specific to the hospital in which they work.[4] Within a hospital, human capital can be specific to the unit in which the RN works, because the nature of care that patients require differs across units and because unit managers are free to establish their own norms and work processes. Survey data on RNs changing jobs (Blythe, Baumann, and Giovannetti 2001) suggests that they do indeed acquire significant amounts of hospital-specific and unit-specific human capital.

Although the licensing requirements are the same for VA and non-VA RNs, the VA RN workforce is older, slightly more educated, more ethnically diverse and has a larger proportion of males than the non-VA RN workforce (National Commission on VA Nursing 2004). The VA pegs the wages of its RNs to the wages of RNs in non-VA facilities in the local labor market (Staiger, Spetz, and Phibbs 2010).

In order to provide adequate nurse staffing at all times, hospitals use overtime as well as temporary agency contracts (50 percent of the units in our sample employ contract nurses at some point during the study period). Under an agency contract, the RN is employed by another firm (an agency) but provides nursing services on site at the contracting hospital for a fixed period of time, ranging from one day to 13 weeks. Contract nurses receive little or no orientation training and are typically brought into the unit on very short notice; they are likely to be unfamiliar with the procedures, practices and equipment in the unit as well as with their nursing colleagues, and are therefore expected to have less specific human capital than regular staff RNs.[5]

Individual knowledge and skills specific to a production process in a particular location is one commonly studied dimension of specific human capital. Another dimension of specific human capital, particularly important in team settings, relates to relationships among coworkers. First, relationships with coworkers that facilitate communication and coordination are likely to generate positive externalities when

[4] For evidence of hospital-specific human capital for cardiac surgeons, see Huckman and Pisano (2006).

[5] Gruber and Kleiner (2012) found that in-hospital mortality was higher for patients admitted during nurse strikes when hospitals often use contract nurses to replace staff nurses. For evidence from other sectors of the economy, see Rebitzer (1995) and Guadalupe (2003) who find that the use of contract workers is associated with an increased incidence of work accidents and Herrmann and Rockoff (2012) who find that replacing absent teachers with temporary substitutes negatively impacts students' test scores.

work is interdependent (Gittell, Seidner, and Wimbush 2010). In our context, this would occur when the productivity of one nurse spills over to positively impact the productivity of a team member. Second, mentoring of less experienced nurses by more experienced nurses has the potential for improving performance of the team while also building human capital to improve future performance. When the absence of an experienced regular staff nurse is covered by either an inexperienced nurse or a contract nurse, these mentoring activities are less likely to occur: inexperienced nurses lack the knowledge and skills to draw on in mentoring, and contract nurses lack the incentives to mentor and the relationships with regular staff nurses that would facilitate mentoring.

C. *Data*

We use data from the Veterans Administration Healthcare System, which is one of the largest healthcare systems in the United States with over 7.2 million veterans enrolled for health services (National Commission of VA Nursing, 2004). Measuring the impact of human capital on productivity in hospitals requires a dataset that links patients to the actual nursing teams that provided their care. The VA hospital data systems are uniquely qualified for this task. Unlike the system used by most hospitals, the VA's integrated accounting system (DSS) creates a separate record for each nursing unit stay for each patient so that it is possible to identify the nursing units in which the patient was treated during his hospital stay.[6] This dataset provides monthly data on the number of nursing hours actually worked on each unit for each type of nursing labor tracked by the VA (RN, LPN, UAP), the number of overtime hours by staff RNs as well as the number of contract nursing hours charged to each unit.

The VA's Personnel and Accounting Integrated Data (PAID) includes employee qualifications and employment history data for all nursing staff. It is an individual-level dataset with information on each nurse's age, education, prior experience, VA hire date, start date at the VA hospital where he/she is currently working, and when the employee started at his/her current nursing unit. This dataset enables us to link each nurse to the unit in which he/she worked during each two week pay period and provides information on the actual number of hours worked on the unit for each nurse in each pay period. We are also able to identify if a nurse transfers to a different unit from one pay period to the next (i.e., an internal transfer) or if a nurse who is new to the hospital joined the unit at the start of a pay period (external hire).

The Patient Treatment File (PTF) is a patient-level dataset that includes the dates of admission and discharge for each bed section as well as the admission and discharge dates for the overall hospitalization. It also includes International Classification of Diseases, 9th version Clinically Modified (ICD) diagnoses, the Medicare Diagnosis Related Group (DRG), the Elixhauser index which measures comorbidities (Elixhauser et al. 1998), and the patient's age.

[6] Each bed-section in the hospital corresponds to a type of care, not a specific unit. There is a 1-to-1 correspondence between unit and bed-section for 89 percent of the acute-care bed-section stays. An additional 6 percent of the patients were assigned to a specific unit based on the fact that the patient spent less than one day on the second unit; the remaining 5 percent of the patients were dropped. An examination of the excluded patient records showed no systematic differences in the characteristics of the excluded patients.

FIGURE 1. VA HOSPITALS INCLUDED IN SAMPLE

D. *Sample*

During our study period (fiscal years 2003 through 2006, i.e., October 1, 2002 through September 30, 2006) the VA operated 143 hospitals with acute inpatient care units located across the United States. Many VA hospitals are located in rural, nonmetropolitan areas; these hospitals are quite small and, in particular, have very small in-patient facilities, often focusing on outpatient services. After deleting nursing units that had fewer than 100 patient days (i.e., about three patients per day) or fewer than two RNs per shift, our final dataset includes 907,993 patients who were admitted to 151 acute care units (excluding intensive care units) in 76 hospitals. The hospitals that were deleted as a result of these exclusion rules are all in rural areas or very small metropolitan areas and the final sample accounts for 90 percent of all acute care stays in the VA system in fiscal years 2003–2006. Figure 1 shows the geographic location of the hospitals included in our final sample.

II. Empirical Strategy and Specification

Our empirical objective is to identify the effects of nurse staffing on patient outcomes as measured by patient length of stay in the hospital. We estimate this relationship using fixed effects regression analyses. Our basic estimating equation is:

$$(1) \quad Y_{ijt} = \alpha_1 \mathbf{S}_{jt} + \alpha_2 \mathbf{HC}_{jt} + \alpha_3 \mathit{IPadmit}_{jt} + \mathbf{U}_{jy} + \beta_1 \mathbf{M}_t + \beta_2 \mathbf{P}_{it} + \mu_{ijt},$$

where i indexes patients, j indexes hospital unit, t indexes month, and y indexes the year. Y_{ijt} is a measure of the residual length of hospital stay (as defined in Section IIA) for a patient cared for on unit j. The first four terms on the right hand side of

equation (1) relate to the hospital unit. $\mathbf{S}_{jt}$ and $\mathbf{HC}_{jt}$ measure, respectively, staffing intensity and the human capital attributes of the nursing staff in month t of the unit j. The total number of inpatient admissions to the unit ($IPadmit_{jt}$) is included to control for monthly variation in capacity utilization. $\mathbf{U}_{jy}$ is a vector of annual unit fixed effects; $\mathbf{M}_t$ is a vector of 47 month dummies (November 2002 through September 2006) that measure time-varying effects that are common to all units. Patient-level variables, $\mathbf{P}_{it}$, are the Elixhauser index of comorbidities and the patient's age. The random, unobserved error component is denoted as μ_{ijt}. Robust standard errors are clustered at the level of the nursing unit. As noted in Section I, our sample includes more units than hospitals (i.e., there are some instances in which a hospital contributes more than one unit to the sample). We check the robustness of our findings to alternative clustering methods, i.e., clustering of errors at both the hospital and the geographical (e.g., Metropolitan Statistical Area) level. The Appendix includes a glossary of all variables used in the regression tables.

To estimate the regression in equation (1), we employ detailed panel data on nurses and patients to relate changes in nurse staffing within individual hospital units to the outcomes of patients receiving care on those same units. The panel nature of our data enables us to include annual nursing unit fixed effects, denoted U_{jy}. These fixed effects control for any characteristics of the nursing unit that might influence patient outcomes and which are unlikely to vary within a year. Examples of this type of slowly changing unit characteristics include the manager of the unit, the nonnurse labor characteristics of the unit (e.g., attributes of the physician staff or other hospital personnel),[7] and certain nonlabor inputs (e.g., number of beds, technology).

By identifying our effects from within-unit variation in nurse staffing, we can be reasonably sure that our estimates are independent of these time-invariant factors (e.g., unit capacity, unit culture, the skills of managers and other clinicians working on the unit). Though there are likely to exist time-varying factors at the unit level (other than nurse staffing) affecting patients' lengths of stay, these factors would need to be closely correlated with monthly changes in nurse staffing in order to confound our analyses. For example, the composition of the physician staff changes as doctors take vacation, are transferred to other VA facilities, and residents begin or end their program on the unit. We think it is reasonable to assume that these physician staff changes are largely uncorrelated with nursing staff changes and in our empirical model are absorbed into the error term.[8] In the paragraphs that follow, we present information, data, and statistical analyses to convince the reader that the changes in nurse staffing from which we identify our effects provide sufficient variation and are exogenous to other time-varying inputs in the care production process.

[7] We do not have data on the characteristics of the physicians in the unit but the absence of this information does not bias our results. In the VA hospitals, physician teams are assigned to nursing units but, importantly, these assignments do not vary on a monthly basis (although they might change every year or two), and hence will not covary with within-unit monthly variation in nurse staffing.

[8] Even if a particular physician is absent during a month, the characteristics of the physicians on the team in the unit do not vary on a month-to-month basis because patients are cared for by other members of the physician's team and practice styles within physician groups tend to be homogeneous (Wennberg and Gittlesohn 1973). More recent work by Doyle, Ewer, and Wagner (2010) demonstrated that patient outcomes in the VA were invariant to physician team assignment.

A. *Dependent Variable: Residual Patient Length of Stay in the Hospital*

For each patient admitted to an acute care nursing unit in a VA hospital during the time period October 1, 2002 through September 30, 2006, we calculate the individual's length of stay in the hospital. It is a commonly used measure in studies of hospital performance (e.g., Doyle, Ewer, and Wagner 2010; Evans and Kim 2006), can be calculated and compared for all patients, and is a particularly good measure for the VA.[9] A patient's length of stay in the hospital, when adjusted for the patient's admitting diagnosis and other patient characteristics, is a relatively inclusive measure of cost and quality of care. Because length of stay is increased by delays in delivery of appropriate care and errors in care delivery, a shorter length of stay indicates that the hospital provided better care. Deficits in nursing care can increase a patient's length of stay through three mechanisms: (i) errors in routine care including errors of omission (e.g., delayed or missed feedings, inadequate hygiene, missed treatments) and errors related to medications; (ii) failure to recognize and respond to abnormal symptoms and emergencies; and (iii) failure to convey accurate and useful information to physicians.[10]

Because length of stay may vary greatly depending on factors particular to the patient and independent of hospital care, we define our dependent variable as log (patient's actual length of stay) minus log (DRG-specific Medicare expected length of stay).[11] Thus, we relate the deviation from expected length of stay of each patient to characteristics of the nursing staff for the unit to which the patient was admitted. Residual LOS is preferred to actual LOS because any organizational decisions that are conditioned on the characteristics of patients on the unit are less likely to be related to patients' residual LOS. Thus, this specification limits the potential for reverse causality that could occur if nurse staffing were adjusted to compensate for variations in the severity of the conditions of patients in the unit. Table 1 shows that the mean length of stay in our sample is 5.92 days and the mean residual length of stay is 0.9 days.

B. *Human Capital of the Nursing Staff*

Hours of Nurse Staffing.—Our first set of measures of general human capital describes staffing intensity: the number of hours worked during the month by RNs,

[9] Outside of the VA, Medicare pays a fixed amount based on the patient's admitting diagnosis. Since costs, but not revenues, accrue to the hospital for every day that the patient occupies a bed, the hospital might have an incentive to discharge the patient early. In the VA, however, each hospital is paid based on the number of enrollees in the hospital's region. Premature discharges would not occur because the hospital would bear the full financial risk if the patient subsequently required additional care.

[10] In regressions not reported here, residual LOS is positively and significantly correlated with measures of complications (decubitus ulcers, infections, failure to rescue, and postoperative pulmonary embolism or deep vein thrombosis) that have been shown (Zhan and Miller 2003) to be sensitive to nurse staffing. We did not find a significant correlation between nurse staffing and complication rates among patients in acute care units; this is not surprising since these events are extremely rare among non-ICU patients.

[11] We used the Medicare average length of stay for each DRG as the expected length of stay as it is computed based on a model of the extent to which patient characteristics affect length of stay. This variable is relatively precise since it is estimated on a very large sample. In a regression of length of stay on expected length of stay, the within R^2 is only 0.06, indicating that there remains a substantial amount of within-unit variation in residual length stay, after accounting for expected length of stay.

TABLE 1—SUMMARY STATISTICS, FISCAL YEARS 2003–2006

Variable name	Mean	Standard deviation		
		Overall	Between units	Within units
Patient-level variables ($N = 907{,}993$)				
LOS	5.92	8.19	1.42	8.10
Residual LOS	0.90	7.95	1.22	7.88
Patient age	65.81	12.86	2.27	12.70
Elixhauser index	1.46	1.09	0.23	1.07
Unit-level variables ($N = 6687$)				
RN regular hours	4.86	1.93	2.05	0.69
RN overtime hours	0.16	0.15	0.13	0.08
LPN hours	1.74	1.08	1.03	0.34
UAP hours	1.29	0.94	0.87	0.36
Contract hours	0.20	0.63	0.54	0.34
Average RN unit tenure	4.41	1.98	1.94	0.44
Average RN net facility tenure	2.23	2.07	2.01	0.47
Average RN total experience	10.08	2.56	2.49	0.61
Percent RN hrs 0–1 years unit tenure	0.28	0.18	0.17	0.07
Percent RN hrs 1–2 years unit tenure	0.16	0.12	0.10	0.07
Percent RN hrs 2–3 years unit tenure	0.12	0.10	0.08	0.06
Percent RN hrs 3–4 years unit tenure	0.09	0.09	0.07	0.05
Percent RN hrs 4–5 years unit tenure	0.07	0.08	0.06	0.05
Percent RN hrs 5–6 years unit tenure	0.06	0.08	0.06	0.05
Percent RN hrs 6–7 years unit tenure	0.05	0.09	0.07	0.06
Percent RN hrs 7–8 years unit tenure	0.07	0.11	0.08	0.07
Percent RN hrs 8–9 years unit tenure	0.05	0.10	0.08	0.06
Percent RN hrs 9–10 years unit tenure	0.04	0.08	0.07	0.05
Percent RN hrs >10 years unit tenure	0.02	0.06	0.05	0.03
Experienced departure and no hire	0.16	0.37	0.12	0.35
Any departure no hire	0.23	0.42	0.13	0.40
Hire and no experienced departure	0.25	0.43	0.15	0.41
Hire and no departure	0.19	0.39	0.12	0.37
Experienced departure and hire	0.13	0.33	0.13	0.30
Any departure and hire	0.18	0.39	0.17	0.35
Internal hire and no experienced departure	0.03	0.18	0.07	0.17
External hire and no experienced departure	0.22	0.42	0.14	0.39
Internal hire and experienced departure	0.02	0.14	0.06	0.13
External hire and experienced departure	0.11	0.32	0.12	0.29
Admissions	152.71	48.58	46.88	16.17
Complication rate	0.014	0.01	0.007	0.014

Note: Variables defined in glossary in the Appendix.

LPNs, and UAPs assigned to the unit. We divide the aggregate number of hours in the month for each type of nurse by the number of patient days to adjust for within-unit variation in patient census.[12] A priori, it was not theoretically obvious that there would be an optimal ratio of RNs to LPNs to UAPs. Consequently, in our baseline specification we opted for flexibility and entered clinician hours per bed days as linear terms and tested for interactions. Coefficients on the interactions between RN hours, LPN hours, and UAP hours were small and statistically insignificant, and so we dropped the interaction terms from the model.

[12] Dividing nursing hours by the number of patient days is a common specification in studies of nurse staffing (e.g., Needleman et al. 2002) and is akin to the use of teacher-student ratios in the education literature (see Krueger 2003).

In our data, within unit month-to-month variation in nurse staffing levels is driven in part by nurse absences and whether and how these absences are covered by other nurses. As noted in Section I, nurse absences precipitate some combination of the following actions: (i) coverage of the absence by contract nurses, (ii) coverage by overtime hours supplied by currently employed VA nurses,[13] or (iii) no coverage resulting in the unit being short-staffed. The total number of contract nursing hours deployed on the unit during a given month is available in the VA's accounting data and we include this variable in our regression. Overtime hours worked by nurses assigned to the same unit on which the absence occurs will cause no net variation in total nurse staffing.

Two characteristics of a nurse absence are likely to influence how that absence is covered on the unit: the expected duration of the absence, and whether the absence was planned in advance. For example, the duration of medical leave and other types of leave typically exceeds one month. Nursing units are unlikely to scramble on a daily basis to cover for nurses on this type of leave; in these cases, nurse managers are more likely to arrange for contract nurses for coverage. In instances of unanticipated separations, nurse managers are also likely to use contract nurses until a replacement nurse can be hired. A second category of absences is characterized by short duration; for example, a nurse might call in sick the night before his or her shift. These absences are more likely (than multimonth leaves) to be covered by overtime or not covered at all (leaving the unit short-staffed). Absences due to holidays are short in duration but known in advance and may be covered by staff overtime or contract nurses. Vacations are typically longer than a day but less than a month, and these absences are known in advance, and so may also be covered by a combination of overtime and contract nurse hours.

Table 1 shows that RN hours (regular plus overtime) account for 61 percent of total nursing hours while LPN hours, UAP hours and contract hours account for 21 percent, 16 percent, and 2 percent of total nursing hours, respectively; these numbers are comparable to staffing patterns in hospitals outside of the VA (Furukawa, Raghu, and Shao 2011). Note that a substantial portion of the total variation in monthly staffing levels occurs within units over time (e.g., RN regular hours $=$ 36 percent, contract hours $=$ 54 percent).

Experience of the Nursing Staff.—Detailed data were available to construct several measures of the experience of RNs working on the hospital units in our sample; these experience variables are nested and enable us to model the importance of the specificity of the nurses' human capital.[14] Beginning with the most general human capital, we computed each RN's total experience to include time worked at the VA and time worked in other health care delivery organizations prior to VA employment. Second, we computed the number of months the nurse had worked at the hospital at which she or he was currently assigned. Third, we computed our most

[13] Overtime hours by VA nurses, regardless of where they worked, are charged back to the nurse's assigned unit. The majority of overtime is worked on the unit the nurse regularly works on. This accounting feature may introduce noise into our measure of hours worked possibly generating an attenuation bias.

[14] At the time of the study, the VA had very limited data on LPN tenure. Including LPN tenure in our model would have resulted in a drastic reduction in the sample with unknown biases.

specific measure of human capital—the number of months worked on the unit to which the RN was currently assigned.

Each of the human capital variables described in the preceding paragraph are computed at the individual nurse level and must be aggregated to the unit-month level to be included in the regression. Experimentation with a variety of combination methods led us to using the average RN tenure weighted by hours worked. Thus, our unit tenure variable is computed as the weighted average of the unit tenure of nurses working on the unit during the month where the weights are the number of hours worked by each nurse on the unit in that month. Data on the prior experience of contract nurses was unavailable and hence our tenure variables reflect solely the experience of RNs employed by the VA.

To test for existence of diminishing or increasing returns to unit tenure, we employ a piecewise linear function of unit tenure. In this specification, tenure is modeled as a set of indicator variables describing the hours-weighted distribution of tenure on the unit in each month (e.g., the set includes variables measuring the percent of total RN hours in the month supplied by RNs who have been on the unit 1–2 years, 2–3 years, 3–4 years, 4–5 years, 5–6 years, 6–7 years, 7–8 years, 8–9 years, 9–10 years and at least 10 years; the left out category is less than 1 year of unit tenure).

Average unit tenure and the distribution of RN tenure varies from month-to-month as a result of new nurses joining the unit and/or experienced nurses being absent from the unit (e.g., vacations, sick days, personal leaves) or departing the unit (e.g., turnover and retirement). For example, if a relatively junior (senior) nurse works overtime hours to cover for a senior (junior) nurse who is on vacation, then average unit tenure will decrease (increase) in proportion to the number of vacation hours and the difference in experience between the vacationing and the overtime nurse. Temporary absences covered by contract nurses could cause average unit tenure to increase or decrease depending on the relative experience level of the absent nurse compared to other nurses on the unit. Permanent replacement of a retiring nurse with a newly hired nurse will result in a much larger one-time downward shift in average unit tenure.

Table 1 shows that average unit tenure for RNs is 4.41 years and RNs have 2.23 additional years of tenure in the current hospital; there is substantial within-nursing unit variation in these variables. Figure 2 shows the month-to-month within-unit residual variation (after controlling for the annual unit fixed effect and the month time dummy) in LOS, residual LOS, and the various measures of nurse staffing. Reassuringly, these figures do not show any obvious trends and the results of Box-Pierce tests confirm that all of the series are "white noise."

C. *Team Capital and Nursing Team Disruptions*

Our empirical strategy, as described thus far, does not account for the team aspect of production; that is, our empirical modeling of input composition (hours worked by type of nurse) and experience (e.g., unit tenure) would capture the basic effects of human capital in other service settings. However, as described in Section I, the production of nursing services involves a moderate amount of teamwork. When

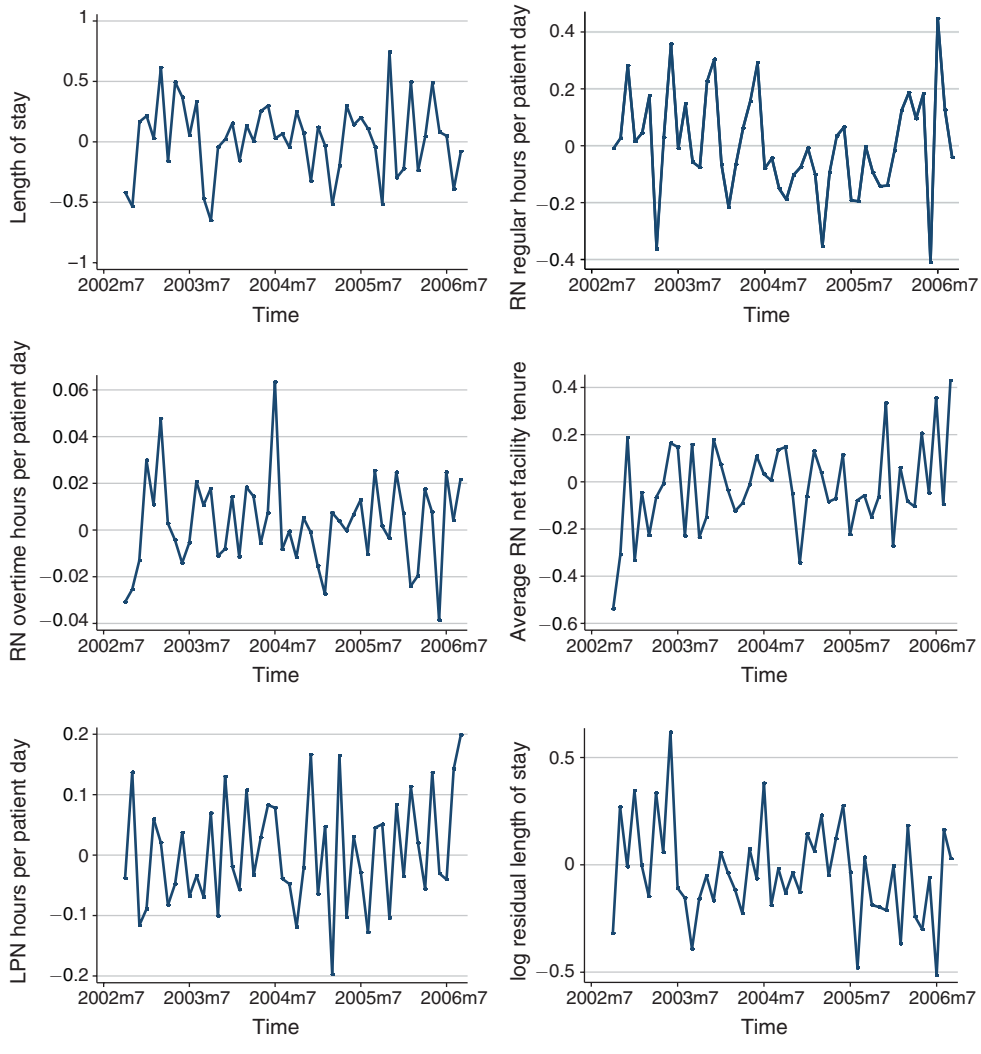

FIGURE 2. MONTH-TO-MONTH WITHIN-UNIT VARIATION

Note: These plots show the month-to-month within-unit residual variation after controlling for the annual unit fixed effect and the month time dummy.

(*Continued*)

teams are disrupted by changes in the composition of the staff, we hypothesize a loss of team capital, and a negative effect on patient outcomes.

While we do not measure team capital directly (the relationships and shared knowledge among team members), we construct three variables related to discrete changes in the composition of nursing teams to serve as proxies for shocks to team capital. We model three types of mutually exclusive changes to the nursing staff: departure and no hire (contraction of the staff), hire and no departure (expansion of the staff), and contemporaneous hire and departure (replacement). To model departures, we create an indicator variable for the unit month equal to one when an experienced nurse (at least one year of unit tenure) is *newly* absent from the unit for the

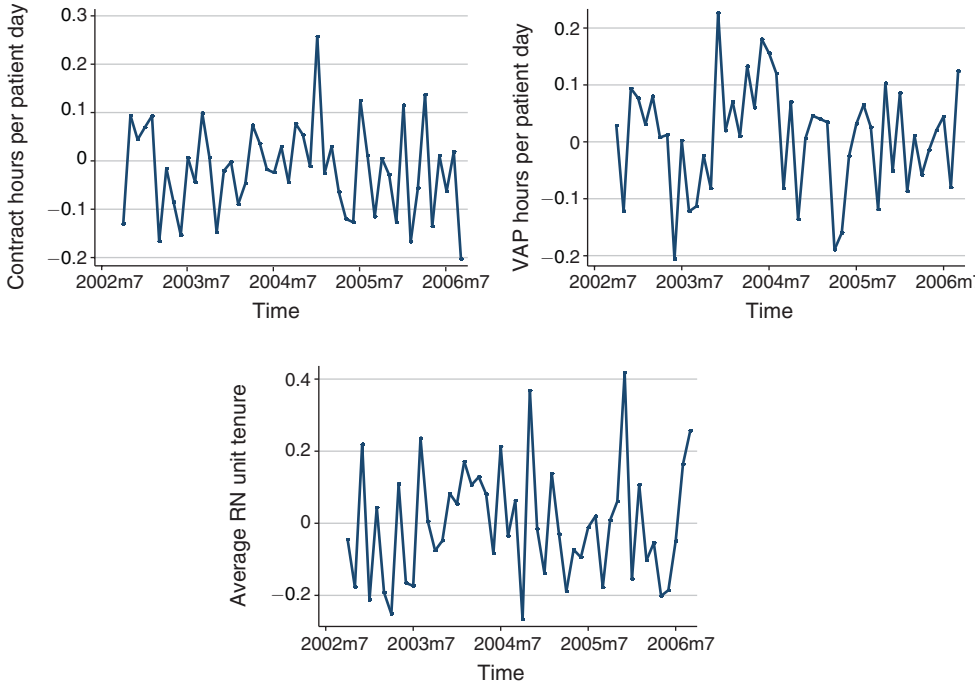

FIGURE 2. MONTH-TO-MONTH WITHIN-UNIT VARIATION (*Continued*)

Note: These plots show the month-to-month within-unit residual variation after controlling for the annual unit fixed effect and the month time dummy.

entire month during which the patient was admitted—that is, the nurse was working on the unit in the previous month but does not work any hours on the unit in the current month.[15] Next, to model new hires, we create an indicator equal to one if a new nurse joined the unit in the prior month. Our three disruption variables are equivalent to the three possible combinations of these two indicator variables.

While these events seem neat and clean in the abstract, identifying these events in the data is quite challenging and requires further assumptions. First, it is necessary to define the window of time for the potential overlap of departures and new hires (replacement). It is quite plausible that the hiring of a new nurse to replace a departing nurse might be separated in time by more than one month (e.g., a nurse is hired in the current month to replace a nurse who departed two months earlier), particularly if the departure is unexpected.[16] On the other hand, when there are multiple departures and hires within a given window of time, there are multiple potential "replacements" for each departure. The potential for nonunique matching of departures and hires is increasing in the length of the overlap window. Based

[15] By *newly* absent, we mean that this nurse was not absent from the unit in the previous month. If the nurse was absent for two months in a row, the indicator variable would be equal to one only in the first month of the absence. In constructing the variables in this manner, we are attempting to more precisely measure the effects of a negative shock to team human capital.

[16] Conversely, with planned departures (e.g., retirements), a replacement nurse might be hired *in advance* of the departure to allow for on-the-job training to be delivered by the departing nurse.

on the results of analyses in which we varied the length of window, and different algorithms for matching departures and hires, we chose a window of overlap equal to one month. Hence, departures and new hires in the same unit that occur more than one month apart are modeled as staff contractions and expansions, respectively, rather than replacements. To the extent that our choice of window length causes us to misidentify replacement events as staff expansions or contractions, we would expect to find significant lag effects for the expansion and contraction indicators.

Table 1 shows that changes to the nursing team on the unit are quite common; in 29 percent of the unit-months, an experienced nurse leaves the unit (either for a short-term leave or a separation); this is the sum of two events; an experienced departure and no hire (16 percent) or an experienced departure and hire (13 percent). Hires are also quite common; in 25 percent of the unit months, there is a hire with no experienced departure and in 13 percent of the months there is a hire coupled with an experienced departure. Finally, we note that internal hires (i.e., transfers between units) are rare; in 3 percent of the unit-months there is an internal hire and no experienced departure and in 2 percent of the unit-months there is an internal hire and an experienced departure.

Because we have access to the characteristics of individual nurses, we are able to deepen our analysis of disruptions along two dimensions. First, we contrast the effects of departures by experienced nurses with the effects of departures by inexperienced nurses. Second, we contrast the effects of internal hires with those of external hires. Human capital theory predicts smaller disruption effects for less experienced nurses and internal hires.

We expect disruptions (i.e., staff expansions, contractions, and replacements) to create negative shocks to the specific human capital of team members thus impacting shared understanding and working relationships, and thereby affecting coordination and communication. Conceptually, the effects of staff changes that operate through decrements to team capital are separate from, and in addition to, the effects of staff changes that operate through changes to the human capital of individual team members.

D. *Exogeneity of Changes in Nurse Staffing*

In this section, we address potential challenges to the exogeneity of our measures of monthly changes in nurse staffing. First is a possible concern about the endogeneity of nurse absences and separations. This might be a concern with annual data since nurses could arguably observe and respond to annual changes in the quality of care on their unit; however, our identification strategy is based on month-to-month changes in staffing and patient outcomes. We believe it is highly unlikely that nurses observe month-to-month changes in the quality of care, as measured by residual length of stay, which might lead them to request transfers, call in sick, or quit.[17] Nevertheless, we estimated models of the determinants of unit-to-unit mobility and separations from the VA and present the results in

[17] During the nurse's first six months at a VA hospital, he/she is considered to be on probation and can be terminated for poor performance. After the first six months, it is extremely unlikely to observe terminations for poor performance.

TABLE 2—DETERMINANTS OF RN UNIT-TO-UNIT MOBILITY OR RN SEPARATIONS FROM THE VA

	Inter-unit mobility		Separations	
	(1)	(2)	(3)	(4)
Individual characteristics				
Tenure on unit	−0.0005***	−0.0005***	−0.0026***	−0.0026***
	(0.0001)	(0.0001)	(0.0002)	(0.0002)
Bachelor's degree	0.0004	0.0004	0.0258***	0.0258***
	(0.0010)	(0.0010)	(0.0034)	(0.0034)
RN age	−0.0001***	−0.0001***	0.0000	0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Unit characteristics				
log residual LOS[a]	−0.0000		0.0046	
	(0.0032)		(0.0047)	
RN hours	0.0020**	0.0020**	0.0022***	0.0021***
	(0.0008)	(0.0008)	(0.0007)	(0.0007)
LPN hours	−0.0022	−0.0021	−0.0015	−0.0016
	(0.0014)	(0.0014)	(0.0016)	(0.0016)
UAP hours	0.0007	0.0007	−0.0030**	−0.0030**
	(0.0014)	(0.0013)	(0.0012)	(0.0012)
Contract hours	0.0002	0.0002	−0.0003	−0.0003
	(0.0006)	(0.0007)	(0.0011)	(0.0011)
Avg. patient age	−0.0000	−0.0000	0.0003	0.0004
	(0.0002)	(0.0002)	(0.0004)	(0.0003)
Avg. Elixhauser	0.0004	0.0003	−0.0023	−0.0016
	(0.0031)	(0.0031)	(0.0039)	(0.0039)
Complication rate[b]		0.0418		−0.0933***
		(0.0350)		(0.0340)
Constant	0.0045	0.0050	−0.0120	−0.0156
	(0.0120)	(0.0118)	(0.0235)	(0.0230)
R^2	0.0028	0.0029	0.1587	0.1588
Observations	141,258	141,258	141,258	141,258

Notes: Each observation is a nurse-month. In columns 1 and 2, the dependent variable equals one if the nurse is working in a different unit in month $t + 1$ compared to the unit he/she worked in month t, while in columns 3 and 4, the dependent variable equals one if the nurse left the VA in month $t + 1$. Unit characteristics are measured at month t. All regressions include time dummies for each month, and an annual unit fixed effect. Robust standard errors in parentheses. Variables definitions are provided in the glossary in the Appendix.

[a]log of average residual length of stay for patients admitted to this unit in month t.

[b]Average complication rate for patients admitted to this unit in month t.

***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

Table 2. The Appendix includes a glossary of all variables used in the regression tables. In columns 1 and 2, the dependent variable equals one if the RN was working on a different unit in month $t + 1$ compared to the unit he/she worked in month t. In columns 3 and 4, the dependent variable equals one if the RN left the VA in month $t + 1$. The estimates in Table 2 indicate that RN separations and transfers observed in our sample are correlated with the nurses' individual characteristics, (i.e., unit tenure, education, and age), but are not more likely to occur

in response to higher residual length of stay or complications in the month prior to these events.[18]

A second possible concern is that nursing hours per patient day may be negatively correlated with average length of stay. This could happen if the nursing unit is very busy, patients are triaged for admission based on the severity of their illness (i.e., less severely ill patients are asked to wait), and the unit manager is unable to adjust nursing hours in response to the unanticipated increase in admissions. In these cases, when units are very busy and disproportionately populated by very sick patients, there might exist a negative spurious correlation between nursing hours per patient day and patients' average length of stay.

The following analysis demonstrates that this type of negative spurious correlation does not exist in our data. Note that this spurious correlation will exist only to the extent that patients are triaged for admission based on the severity of their illness, and the extent to which unit managers are unable to adjust nurse staffing. To test for this, we divided patient admissions in our sample into four categories: (i) Patient is severely ill and unit is busy; (ii) Patient is severely ill and unit is not busy; (iii) Patient is not severely ill and unit is busy; and (iv) Patient is not severely ill and unit is not busy. A patient was defined as being severely ill if his Elixhauser index was above the median value. A unit was defined as busy if the number of bed days on the unit during the month was more than one standard deviation above the annual average number of bed days on the unit. We found that the percentage of severely ill patients was the same (16 percent) in busy months and non-busy months and therefore any negative correlation between nurse staffing and average residual length of stay cannot be driven by triaging in favor of more severely ill patients.

A third potential concern is that management may adjust nursing staff based on unit performance, i.e., reallocating staff from units that are performing well to poorly performing units, and making up the staff hours shortfall by allocating contract staff, who have less human capital, to the better performing units. In fact, the rate of transfers between like units is exceedingly small (mean = 0.7 percent) so this concern is likely to have an imperceptible impact on our results. But, in order to further address this concern we estimate a regression on a sample that is restricted to units that are the only one of their type in the hospital (e.g., the only medical unit, the only surgical unit, etc.) lessening the likelihood of internal transfers. As discussed in Section III, and shown in column 2 of Table 5A, the regression results are qualitatively unaffected by restricting the sample to units with a single medical or surgical unit.

E. *Short-Term versus Long-Term Effects*

Our use of monthly data enables us to avoid the potential endogeneity of nurse staffing. While beneficial, this identification strategy limits us to estimating short-term effects (i.e., effects that occur within, at most, a period of one month). Temporary staffing changes (e.g., to cover sick days, vacations, and holidays) are unlikely to have substantial long-term effects beyond what we measure in this study.

[18] The negative coefficient on complications in column 4 is rather puzzling with no obvious explanation.

However, the accumulation over several months of the productivity effects of permanent staffing changes could be substantial. There is also the possibility that the productivity effects of temporary staffing changes could be larger or smaller in units with more frequent permanent staffing disruptions (e.g., high turnover)—that there is an interaction effect.

Estimating longer-term effects of nurse staffing on productivity is beyond the scope of this paper. However, to shed some light on the potential importance of these longer-term effects, we estimated one specification that included lagged values of our team disruption indicators. Coefficients on these lag variables may capture potential decrements to team function that could occur in the second month following the loss of an experienced team member and/or the addition of a new team member. Note that any medium and long-term effects of permanent staffing changes that operate through individual specific human capital (i.e., individual knowledge and skills proxied by experience) will be captured in our monthly measures of tenure.

III. Results

A. *Staffing and Human Capital*

Column 1 of Table 3 shows the results of estimating equation (1). Higher staffing levels for each type of nursing input is associated with statistically significant reductions in residual length of stay. Moreover, the magnitude of the effect is increasing in the level of nursing skill; we estimate that a one hour increase in staffing per patient bed day by RNs, LPNs, and UAPs is associated with significant decreases in residual length of stay equal to 3.4, 2.9, and 1.5 percent, respectively.

Overtime hours worked by RN staff nurses are also associated with significant reductions in residual length of stay. In contrast, staffing by contract nurses is unrelated to patient outcomes. While the presence of a contract nurse adds to the intensity of staffing of the unit, these additional resources are not productive on the margin in improving patient outcomes as measured by residual length of stay. We conjecture that the difference in coefficients for employee RN hours (either regular hours or overtime hours) and contract RN hours is related to differences in the nurses' specific human capital. In comparison to staff nurses working overtime, contract nurses have no, or very little, prior familiarity with the procedures, practices, and equipment in the unit as well as with their nursing colleagues. A prior study (Aiken et al. 2007) reported no significant differences in education and prior experience between staff RNs and contract RNs. Our finding that overtime hours do not have a weaker effect than regular work hours is further support for this conjecture.

Our baseline specification includes three measures of the experience of RNs: total experience as an RN (both VA and non-VA); experience at the current VA hospital net of tenure in the current nursing unit, and tenure on the current nursing unit. Of these three, only tenure on the current nursing unit is significantly related to residual LOS: an increase of one year in average unit tenure of RNs on the unit is associated with a 1.33 percent reduction in the adjusted length of stay. These findings suggest a comparatively important role for *specific* human capital in the productivity of the registered nursing staff.

Table 3—Nurse Human Capital and Patient's Residual Length of Stay

			Below median age	Above median age	Surgical patients	Medical patients
	(1)	(2)	(3)	(4)	(5)	(6)
RN regular hours	−0.0345***	−0.0350***	−0.0332***	−0.0356***	−0.0238***	−0.0362***
	(−0.0028)	(−0.0028)	(−0.0036)	(−0.0037)	(−0.0048)	(−0.0031)
RN overtime hours	−0.0440**	−0.0425**	−0.0516**	−0.0363	0.0035	−0.0532**
	(−0.0185)	(−0.0184)	(−0.022)	(−0.0269)	(−0.0397)	(−0.0214)
LPN hours	−0.0295***	−0.0292***	−0.0249***	−0.0339***	−0.0387***	−0.0279***
	(−0.0055)	(−0.0055)	(−0.0064)	(−0.0067)	(−0.0096)	(−0.0062)
UAP hours	−0.0151***	−0.0151***	−0.0144***	−0.0156***	−0.0168**	−0.0147***
	(−0.004)	(−0.004)	(−0.0051)	(−0.0055)	(−0.0079)	(−0.0046)
Contract hours	0.0021	0.002	0.0002	0.0038	−0.0023	0.0037
	(−0.0049)	(−0.0048)	(−0.0065)	(−0.0058)	(−00074)	(−0.0054)
Avg. RN unit tenure	−0.0133***		−0.0168***	−0.0100*	−0.0247***	−0.0110***
	(−0.0038)		(−0.0051)	(−0.0053)	(−0.008)	(−0.0041)
Avg. RN net facility tenure	−0.0003	0.0005	0.002	−0.0026	0.0131	−0.0024
	(−0.0042)	(−0.0042)	(−0.005)	(−0.006)	(−0.0092)	(−0.0043)
Avg. RN experience	−0.0006	0.0002	0.0026	−0.0038	−0.0034	−0.0003
	(−0.0029)	(−0.0028)	(−0.0035)	(−0.0042)	(−0.0065)	(−0.003
Percent RN hours with:						
1–2 years unit tenure		−0.0740***				
		(−0.0244)				
2–3 years unit tenure		−0.1140***				
		(−0.9326)				
3–4 years unit tenure		−0.1067***				
		(−0.0412)				
4–5 years unit tenure		−0.0845**				
		(−0.0409)				
5–6 years unit tenure		−0.1129**				
		(−0.0439)				
6–7 years unit tenure		−0.1135***				
		(−0.0424)				
7–8 years unit tenure		−0.1802***				
		(−0.0478)				
8–9 years unit tenure		−0.2174***				
		(−0.0501)				
9–10 years unit tenure		−0.2515***				
		(−0.0651)				
> 10 years unit tenure		−0.1936**				
		(−0.0914)				
Constant	−0.1700***	−0.1423***	−0.2265***	−0.0573	−0.0753	−0.1479***
	(−0.0389)	(−0.0397)	(−0.0511)	(−0.0566)	(−0.0725)	(−0.041)
R^2	0.0199	0.0199	0.0172	0.0156	0.0148	0.021

Notes: Dependent variable is log(patient's residual length of stay in hospital). $N = 907{,}993$. All regressions include patient age, Elixhauser comorbidity index, number of patient admissions, time dummies for each month, and unit fixed effects that vary by year. Robust standard errors, reported in parentheses, are clustered by nursing unit. Variable definitions are provided in the glossary in the Appendix.

***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

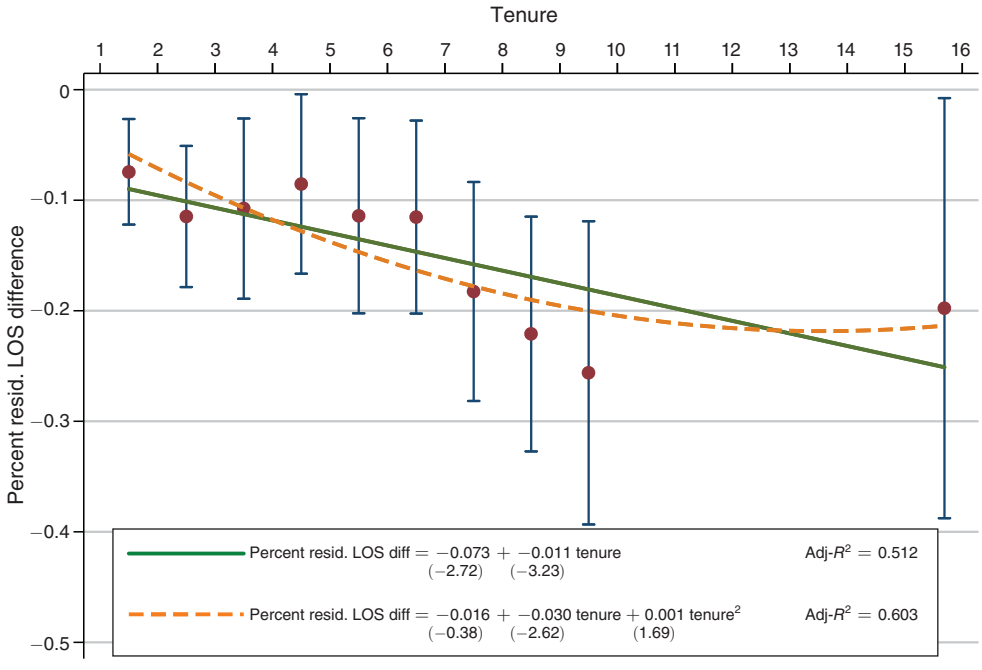

FIGURE 3. COEFFICIENTS AND 95 PERCENT CONFIDENCE INTERVALS ON LINEAR PIECEWISE TENURE FUNCTION FROM COLUMN 2 IN TABLE 3

In column 2 of Table 3, we replace average RN unit tenure with a piecewise linear function of tenure (measuring the percentages of RN hours in different tenure categories) where the excluded category is percent of RN hours with less than one year of tenure on the unit. All of the coefficients on these tenure variables are negative and significant. Each of the coefficients can be interpreted as showing the impact of replacing nurses with less than one year of experience with nurses who have the experience level associated with the particular coefficient, holding constant the rest of the tenure distribution. For example, a 10 percentage point increase in the share of RN hours with 1–2 years of unit tenure is associated with a 0.7 percent reduction in length of stay. A similar increase in the 2–3 year tenure category is associated with a 1.1 percent reduction in length of stay.

In Figure 3, we plot the coefficients from the piecewise linear tenure function from column 2.[19] The figure also shows regression lines that were fitted to the coefficients using either a linear or quadratic specification for tenure. It is notable that the return to tenure plateaus in the three to seven year range and then increases, followed by a leveling off at the 10+ category. This is in contrast to the results in the education literature where it has been found that returns to teacher tenure level off after one or two years (Rockoff 2004; Rivkin, Hanushek, and Kain 2005).

[19] Using information on the percentages of RN hours in each of the annual categories that comprise the 10+ tenure category and assigning the midpoint of each interval as the average value of tenure in that category, (e.g., the 10–11 category is assigned a value of 10.5), and assigning 20 to the open-ended interval, we calculated that the mean value of tenure associated with the 10+ category is 15.69. The coefficient on the open-ended category is therefore plotted in Figure 3 as being associated with a tenure value of 15.69.

In sum, the results in column 2 show that residual length of stay is lower in units that are staffed by RNs whose average unit tenure exceeds one year, and this beneficial effect does not diminish with additional years of unit tenure.

In columns 3 through 6 we explore the generalizability of the results by estimating the model in column 1 on four different subsamples: patients who are below the median age of 65 (column 3), patients who are above median age (column 4), patients with a surgical diagnosis (column 5), and patients with a medical diagnosis (column 6). Analyzing the below-median-age sample is particularly important because the non-VA patient population is younger than the VA patient population. The results for the below-median-age population in column 3 are almost identical to our baseline results in column 1 indicating that our findings are relevant for a younger, non-VA, patient population. The estimates of our models for surgical (column 5) and medical (column 6) patients are very similar; two points of differentiation are that unit tenure has a larger impact on surgical patients, and overtime hours is insignificant for this group.

To summarize, while the size of the estimated effects is small, our main results in Table 3 support our hypotheses that the human capital of the nursing staff has significant effects on patient outcomes. First, residual length of stay is negatively associated with the general human capital of the nursing staff (as measured by larger estimated effects for licensed nurses (RNs and LPNs) compared to the unlicensed personnel (UAPs)). Second, residual length of stay is negatively associated with the specific human capital of the nursing staff (as measured by the tenure of RNs on the units, and the fact that the use of contract RNs does not reduce length of stay). Third, tenure effects are nonlinear.

B. *Team Disruptions*

The results in Table 3 indicate that RN experience on the unit, and the specific skills and knowledge gained through that experience, significantly improves patient outcomes. We hypothesize that RN unit experience may have an additional, but indirect, effect on productivity deriving from improved coordination, communication, and mentoring among members of experienced nursing teams. These team behaviors may lead to increases in the productivity of individual team members and/or the productivity of the team as a whole, and hence we label these productivity effects as team production externalities. While we do not observe these positive externalities directly, we can partially identify them in our data by analyzing changes in the productivity of a nursing unit that are associated with disruptions to the nursing team. In the regressions reported in Table 4, average unit tenure captures the direct effect of average unit experience on the productivity of nurses working on the unit during a particular month; the team disruption variables measure the *additional* productivity effects resulting from changes in the membership of the nursing team.

The models reported in Table 4 build on our baseline specification (column 1 of Table 3). In column 1 of Table 4, we add three team disruption indicators: an experienced RN departed the unit but there was no hire (departure and no hire); an experienced RN did not depart but there was a new hire (hire and no departure); and an experienced RN departed and there was a new hire (departure and hire). The results show that all three events are associated with an increase in residual length of stay, though the coefficient on the joint event is imprecisely estimated. We note that

TABLE 4—IMPACT OF PRODUCTION EXTERNALITIES

	(1)	(2)	(3)	(4)
RN regular hours	−0.0348***	−0.0349***	−0.0348***	−0.0348***
	(0.0028)	(0.0028)	(0.0028)	(0.0028)
RN overtime hours	−0.0449**	−0.0441**	−0.0444**	−0.0449**
	(0.0186)	(0.0185)	(0.0186)	(0.0186)
LPN hours	−0.0293***	−0.0293***	−0.0293***	−0.0293***
	(0.0055)	(0.0055)	(0.0054)	(0.0055)
UAP hours	−0.0153***	−0.0151***	−0.0152***	−0.0153***
	(0.0040)	(0.0040)	(0.0040)	(0.0040)
Contract hours	0.0022	0.0022	0.0024	0.0022
	(0.0049)	(0.0049)	(0.0049)	(0.0049)
Avg. RN unit tenure	−0.0124***	−0.0124***	−0.0124***	−0.0124***
	(0.0038)	(0.0038)	(0.0038)	(0.0038)
Avg. RN net facility tenure	−0.0003	−0.0003	−0.0004	−0.0003
	(0.0042)	(0.0042)	(0.0042)	(0.0042)
Avg. RN experience	−0.0004	−0.0004	−0.0005	−0.0005
	(0.0029)	(0.0029)	(0.0029)	(0.0029)
Departure and no hire[a]	0.0075*	0.0023	0.0069*	0.0071*
	(0.0039)	(0.0035)	(0.0038)	(0.0038)
Hire and no departure[a]	0.0078**	0.0065*		
	(0.0034)	(0.0037)		
Departure and hire[a]	0.0073	0.0064		
	(0.0046)	(0.0042)		
Internal hire and no departure[a]			−0.0045	
			(0.0078)	
External hire and no departure[a]			0.0086**	
			(0.0034)	
Internal hire and departure[a]			0.0198**	
			(0.0087)	
External hire and departure[a]			0.0023	
			(0.0050)	
Internal hire				0.0050
				(0.0061)
External hire				0.0067**
				(0.0033)
Constant	−0.1790***	−0.1775***	−0.1779***	−0.1776***
	(0.0387)	(0.0388)	(0.0386)	(0.0387)
R^2	0.0199	0.0199	0.0199	0.0199

Notes: Dependent variable is log(patient's residual length of stay in hospital). $N = 907{,}993$. All regressions include patient age, Elixhauser comorbidity index, number of patient admissions, time dummies for each month, and unit fixed effects that vary by year. Robust standard errors, reported in parentheses, are clustered by nursing unit. Variable definitions are provided in the glossary in the Appendix.

[a] In columns 1, 3, and 4, departures are restricted to RNs who had at least one year of unit tenure. In column 2, departures include RNs with less than one year of unit tenure.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

the magnitudes of these three coefficients are very similar, and this finding suggests that after controlling for tenure effects, hires and departures are equally disruptive.[20]

[20] In results not reported here, we included one-period lags of the three disruption indicators used in column 1; all three lagged variables were insignificant.

Table 5A—Robustness Checks

	Stay within month (1)	Single type unit (2)	Vacation months (3)	Hospital SE (4)	MSA SE (5)
RN regular hours	−0.0334***	−0.0322***	−0.0255***	−0.0345***	−0.0345***
	(−0.0028)	(−0.0038)	(−0.0058)	(−0.0036)	(−0.0037)
RN overtime hours	−0.0491**	−0.0542**	−0.0324	−0.0440**	−0.0440**
	(−0.0197)	(−0.0252)	(−0.0376)	(−0.0187)	(−0.0183)
LPN hours	−0.0254***	−0.0293***	−0.0433***	−0.0295***	−0.0295***
	(−0.0055)	(−0.0068)	(−0.0114)	(−0.0058)	(−0.0058)
UAP hours	−0.0125***	−0.0110*	−0.0106	−0.0151***	−0.0151***
	(−0.0042)	(−0.0057)	(−0.0078)	(−0.0034)	(−0.0034)
Contract hours	0.0017	0.003	0.0121	0.0021	0.0021
	(−0.0048)	(−0.0071)	(−0.0074)	(−0.0056)	(−0.0053)
Avg. RN unit tenure	−0.0137***	−0.0120**	−0.0162**	−0.0133***	−0.0133***
	(−0.0038)	(−0.0048)	(−0.0078)	(−0.0039)	(−0.0039)
Avg. RN net facility tenure	0.0002	−0.0017	−0.009	−0.0003	−0.0003
	(−0.0042)	(−0.0055)	(−0.0087)	(−0.0038)	(−0.0035)
Avg. RN experience	−0.00004	0.0006	0.0014	−0.0006	−0.0006
	(−0.0029)	(−0.0038)	(−0.0063)	(−0.0027)	(−0.0025)
Constant	−0.1871***	−0.1164**	−0.0522	−0.1700***	−0.1700***
	(−0.0371)	(−0.0528)	(−0.0763)	(−0.0488)	(−0.0506)
R^2	0.0184	0.0204	0.018	0.0199	0.0199
Observations	799,476	523,237	233,347	907,993	907,993

Notes: Dependent variable is log(patient's residual length of stay in hospital). These regressions use the specification in column 1 of Table 3. All regressions include patient age, Elixhauser comorbidity index, number of patient admissions, time dummies for each month, and unit fixed effects that vary by year. Robust standard errors, reported in parentheses, are clustered by nursing unit. Variable definitions provided in the glossary in the Appendix.

***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

In column 2, we loosen our criteria for the departure indicator to include departures of RNs with less than one year of unit tenure. Notably, the coefficient on the indicator variable "departure and no hire" is only 30 percent of the magnitude of the coefficient on the same variable in column 1 and is insignificant. Our interpretation of this finding is that inexperienced nurses have had less time to build the working relationships that underlie team capital and hence when these nurses depart the impact on team functioning is minimal.

In column 3, we report the results of a regression in which we disaggregate the hiring indicator variables to separately examine the effects of internal hires (i.e., transfers from another nursing unit) compared to external hires (i.e., hires from outside the VA). As shown in Table 1, internal hires are quite infrequent. In the cases when there are no experienced departures, only 12 percent of the hires are internal; when experienced departures occur, only 15 percent of the hires are internal. The results in column 3 show that, in cases when there is no contemporaneous departure of an experienced nurse, external hires are positively and significantly associated with an increase in residual length of stay, but internal hires are not. However, we obtain the opposite results for cases in which an experienced nurse departs: the coefficient on internal hires is positive and significant while the coefficient on external

TABLE 5B—ROBUSTNESS CHECKS

	Stay within month (1)	Single type unit (2)	Vacation months (3)	Hospital SE (4)	MSA SE (5)
RN regular hours	−0.0337***	−0.0325***	−0.0252***	−0.0348***	−0.0348***
	(−0.0028)	(−0.0038)	(−0.0059)	(−0.0036)	(−0.0037)
RN overtime hours	−0.0496**	−0.0554**	−0.034	−0.0449**	−0.0449**
	(−0.0198)	(−0.0252)	(−0.0379)	(−0.0183)	(−0.0178)
LPN hours	−0.0253***	−0.0291***	−0.0432***	−0.0293***	−0.0293***
	(−0.0055)	(−0.0068)	(−0.0113)	(−0.0058)	(−0.0058)
UAP hours	−0.0127***	−0.0112**	−0.0109	−0.0153***	−0.0153***
	(−0.0042)	(−0.0056)	(−0.0078)	(−0.0033)	(−0.0033)
Contract hours	0.0017	0.0031	0.0119	0.0022	0.0022
	(−0.0048)	(−0.0071)	(−0.0074)	(−0.0057)	(−0.0054)
Avg. RN unit tenure	−0.0128***	−0.0115**	−0.0167**	−0.0124***	−0.0124***
	(−0.0039)	(−0.0048)	(−0.0079)	(−0.0039)	(−0.0039)
Avg. RN net facility tenure	0.0001	−0.0018	−0.0088	−0.0003	−0.0003
	(−0.0042)	(−0.0055)	(−0.0087)	(−0.0038)	(−0.0035)
Avg. RN experience	0.0001	0.0009	0.0009	−0.0004	−0.0004
	(−0.0029)	(−0.0037)	(−0.0063)	(−0.0027)	(−0.0025)
Departure no hire	0.004	0.008	0.0088	0.0075*	0.0075*
	(−0.0041)	(−0.0052)	(−0.0091)	(−0.0039)	(−0.0043)
Hire no departure	0.0056*	0.0076*	−0.0003	0.0078***	0.0078***
	(−0.0034)	(−0.0043)	(−0.0077)	(−0.0029)	(−0.0028)
Departure and hire	0.0075	0.0038	−0.0031	0.0073	0.0073
	(−0.0047)	(−0.0061)	(−0.0112)	(−0.0044)	(−0.0045)
Constant	−0.1939***	−0.1234**	−0.0474	−0.1790***	−0.1790***
	(−0.0371)	(−0.0523)	(−0.0754)	(−0.0495)	(−0.0517)
R^2	0.0184	0.0205	0.018	0.0199	0.0199
Observations	799,476	523,237	233,347	907,993	907,993

Notes: Dependent variable is log(patient's residual length of stay in hospital). These regressions use the specification in column 1 of Table 4. All regressions include patient age, Elixhauser comorbidity index, number of patient admissions, time dummies for each month, and unit fixed effects that vary by year. Robust standard errors, reported in parentheses, are clustered by nursing unit. Variable definitions provided in the glossary in the Appendix.

***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

hires is not statistically significant. We were concerned that the cell sizes for the events of "internal hire and no departure" and "internal hire and departure" were quite small (sample mean = 0.03 and 0.02, respectively) and we therefore combined these two events to create an indicator for "internal hire" and also created a combined indicator for "external hire." Column 4 shows that internal hires have an insignificant effect on length of stay while external hires have a positive and significant effect.

In summary, the results in Table 4 provide evidence of the multiple mechanisms through which specific human capital may affect productivity in the context of team production. Controlling for the average experience of nurses on the unit, the departure of an experienced regular staff nurse has an additional negative effect on the productivity of the unit (i.e., an increase in residual length of stay); this effect is not observed when an inexperienced staff nurse departs. The arrival of a new nurse

on the unit is also associated with lowered productivity but this effect is significant only if the nurse is hired externally. While the size of the estimated effects in Table 4 is small, the results are highly suggestive that nursing team disruptions negatively impact patient outcomes.

C. *Robustness Checks*

We conducted a number of robustness checks and present these in Table 5A, which uses the baseline specification, Table 3 column 1, and Table 5B (which uses the specification that includes the team disruption variables, Table 4, column 1). In the first robustness check, shown in column 1 of each table, we restrict the sample to patients whose stay on the unit occurs entirely within the month, thereby eliminating patients whose stay may have started at the end of one month and ended at the beginning of another month. The nurse staffing in adjacent months may differ because of vacations and leaves. In the second robustness check, shown in column 2, we restrict the sample to units that are the only one of their type in the hospital in order to control for spillovers between units of the same type (e.g., management temporarily reallocating staff from units that are performing well to poorly performing units). In the third robustness check, shown in column 3, we restrict the sample to the months in which the regular staff RNs and especially RNs with seniority are likely to take vacations (August, December, January). During popular vacation months, most of the staffing changes are likely to be targeted at providing coverage for temporary absences generated by vacationing nurses, and hence the coefficient on average unit tenure would be identified by purely exogenous factors such as weather and holidays. If the coefficient on average tenure in vacation-month regressions were to differ substantially from the coefficient we obtain for our full sample, it would raise concerns about the exogeneity of staffing changes in nonvacation months. Finally, in columns 4 and 5, we cluster the standard errors by hospital and by Metropolitan Statistical Area, respectively. Clustering standard errors by hospital allows for correlation across units within the hospital and clustering by MSAs allows for correlation across hospitals within a geographical area.

Tables 5A and 5B show that our main results are robust. RN hours, LPN hours and UAP hours are significant in all regressions and the coefficient on UAP hours is smaller than those on the licensed nursing personnel. The coefficient on contract hours is insignificant and the unit tenure coefficient is significant in all regressions, supporting our earlier findings regarding the importance of specific human capital. Importantly, when we restrict to vacation months in column 3, the coefficient on unit tenure is not substantially different from the coefficient we obtain for our full sample (column 1 of Tables 3 and 4). The coefficients on overtime hours in Tables 5a and 5b are significant in all regressions except column (3) where the sample is restricted to vacation months and is only 25 percent the size of the baseline sample. Finally, with regard to the team disruption indicators in Table 5B, the magnitudes of the coefficients on "experienced nurse departure" are similar to those reported in Table 4 (with the exception of column 1) but the coefficients are less precisely estimated. The indicator for hires (without departures) is significant in all regressions except when the sample is restricted to vacation months during which we might expect a marked

TABLE 6—COST-BENEFIT ESTIMATES[a]

	Cost (1)	Days saved (2)	Benefit of days saved[e] (3)
A. RN unit tenure increases by 4.3 years[b]	$18,196[c]	7.88	$19,944
B. Change daily 8 hour shift from UAP to RN	$5,280	1.00	$2,531
C. Change 420 hours from contract to RN overtime[d]	$10,920	4.34	$10,985

[a] Monthly estimates.
[b] Difference between the 90th and 10th percentiles of average RN unit tenure.
[c] Includes additional wages and fringe benefits.
[d] This is the average number of contract hours for unit-months with nonzero contract hours.
[e] Based on VA's estimate of $2,531 cost per patient day.

reduction in hiring activity. In sum, our main findings regarding the importance of general and specific human capital are robust to the alternative specifications in Tables 5A and 5B.

D. *Cost-Benefit Calculations*

To gauge the magnitude of our estimated effects, we conducted cost-benefit calculations for three scenarios and report these in Table 6. First, we estimate the net benefit to the hospital of maintaining a higher average RN tenure on the unit. We do this by computing the additional costs (in wages) and the savings (reduced patient bed days) associated with a unit at the 90th percentile of RN unit tenure (6.55 years) compared to a unit at the 10th percentile of RN unit tenure (2.25 years). We multiply the additional hourly wage and fringes that would be paid to more senior nurses ($5.63) by the average number of RN hours per bed day (4.86) and then multiply this product by the average number of monthly bed days (665). The total cost is calculated to be $18,196 and is reported in column 1 of Table 6. We use the regression coefficient on unit tenure in column 1 of Table 3 combined with the change in tenure (4.3 years), the mean value of residual length of stay (0.9 days), and the average number of monthly admissions (153) to calculate the hospital days that will be saved each month. The result, shown in column 3, is 7.88 bed days. The total cost of a day in a VA hospital is estimated to be $2,531; thus, the cost savings associated with this reduction in patient bed days is estimated to be $19,944. The monthly net benefit to the unit from such length of stay reductions equals $1,748. Hence the unit would have an annual net cost saving of $20,976 if average tenure could be increased by 4.3 years.

Our second scenario for gauging the potential impact of our estimated human capital effects involves substituting an RN for an unlicensed assistive personnel (UAP) for one eight-hour shift on each day of one month. The monthly cost of this substitution is calculated by multiplying the total number of hours per month (i.e., 8 hours $\times$ 30 days $=$ 240) by the difference in the RN hourly wage and benefits ($42) and the UAP hourly wage and benefits ($20). As shown in panel B of Table 6, the cost of this substitution equals $5,280. The patient bed-days saved as a result of this staffing substitution in each month is calculated by multiplying the difference in coefficients on RN hours and UAP hours from column 1 of Table 3, the change in hours per bed day (equals 240 divided by 665—the monthly average number of bed

days), and average residual length of stay (0.9). This product is in turn multiplied by the average number of monthly admissions, (153), resulting in one day being saved, ($2,531 in dollar terms), which is less than the increased labor costs associated with this change.

Finally, in panel C, we consider the implications of substituting RN overtime hours for an equal number of contract nursing hours, specifically reducing contract hours by 420 per month (the mean number of contract hours for unit-months that have nonzero contract hours) and offsetting this with an increase in 420 overtime hours by RN staff nurses. The average hourly wage of contract nurses is $37 and the average overtime wage for RNs is $63. Using the same methodology as we employed in the calculations for panel B (substituting RN hours for UAP hours), we find that this substitution results in an increase in wage costs of $10,920 per month, and a cost savings of $10,985 from a reduction in patient days equal to 4.34. Hence, the monthly net cost savings to the unit from replacing contract nurses with overtime hours by regular staff RNs is negligible.

The calculations above should be treated with caution for a number of reasons. First, these cost-benefit analyses assume a causal interpretation of our estimated effects while our analyses can only prove an association. Second, the estimated cost per patient day includes both fixed and variable costs and it is not clear how much the fixed costs could actually be adjusted in the short term. Offsetting this, however, is the fact that our estimate of benefits only reflects hospital cost-savings associated with changes in residual length of stay, and does not incorporate any value to the patient from a shorter hospital stay. Some of the hypothetical changes are more easily implemented than others. Substituting RNs for UAPs and contract nurses is relatively straightforward though may require an expansion of the size of the RN staff. Increasing average unit tenure by boosting the retention of RNs is likely to require changes in organizational practices and could only be accomplished over the longer term. Finally, the steps that might be required to implement the scenarios described in Table 6 (i.e., reduced turnover and increased wages in scenario A) or that might result indirectly from implementation (i.e., increased turnover in scenario C) might generate additional costs or savings that are beyond the scope of this paper.

IV. Conclusion

Using detailed organizational data from a large hospital system, we estimate the productivity effects attributable to multiple forms of human capital in a team production environment. Our estimates are derived from intertemporal changes in nurse staffing within hospital units. These staff changes were generated by short-term and medium-term absences of regular staff members (e.g., vacations, sick days, personal leaves) and permanent separations (e.g., retirement and turnover) which we show to be exogenous. With regards to the productivity of general human capital, we find that patients cared for on units utilizing more licensed nursing personnel (RNs and LPNs) and fewer unlicensed aides have shorter residual length of stay.

In previous empirical studies, specific human capital has been proxied by experience and interpreted as the product of on-the-job learning. For example, through experience, workers acquire knowledge of where things are and how things are done

in their work environment. We find corroborative evidence for this form of specific human capital: increases in the average tenure of registered nurses on the unit results in significant decreases in the length of time patients stay in the hospital. In addition, we show that a nurse's unit experience is much more relevant than his or her hospital experience. Further evidence of the importance of specific human capital is the finding that substituting contract nurses for regular staff nurses is associated with significant increases in patients' length of stay.

Because we study nurse staffing in small intraorganizational units, we are able to model human capital in ways that are quite different from previous studies. The essence of team production is that it involves interaction among team members, typically of the sort involving communication, knowledge sharing, and coordination. Workers may develop tacit routines that facilitate communication and coordination with coworkers, and can build relationships with coworkers that facilitate productivity-enhancing activities such as learning and mentoring. When experienced teams are disrupted, these activities that manage interdependencies and build capability are likely to be impaired. We find evidence suggesting that production externalities of this sort occur in nursing units when teams are disrupted by the departure of experienced nurses, the absorption of new hires, and the inclusion of temporary contract nurses. Through our study of disruptions in the work of established teams, we have estimated productivity effects of the human capital that is specific to the shared knowledge, experiences, and relationships among team members. The concept of productive capability embodied in teamwork is a potential explanation for productivity differences between and within firms and is a topic we think worthy of future research.

Appendix

Table A1—Glossary of Variables

Variable name	Definition
Panel A. Dependent variables	
Residual LOS	Patient's actual length of stay on the unit minus the DRG-specific Medicare expected length of stay
Inter-unit mobility	Dummy variable = 1 if RN is working on a different unit in month $t + 1$ compared to month t
Separation	Dummy variable = 1 if RN was working in VA in month t but had left by month $t + 1$
Panel B. Independent variables	
Tenure on unit	RN's tenure on the unit
Bachelor's degree	Dummy variable = 1 if RN has bachelor's degree
RN age	Age of RN
RN regular hours	Total RN regular work hours on the unit in month t, divided by number of patient days in month t
RN overtime hours	Total RN overtime hours on the unit in month t, divided by number of patient days in month t
RN hours	Sum of RN regular hours + RN overtime hours
LPN hours	Total LPN hours on the unit in month t, divided by number of patient days in month t

(*Continued*)

Table A1—Glossary of Variables (*Continued*)

Variable name	Definition
UAP hours	Total UAP hours on the unit in month *t*, divided by number of patient days in month *t*
Contract hours	Total contract hours on the unit in month *t*, divided by number of patient days in month *t*
Avg. RN unit tenure	Average unit tenure of RNs working on the unit in month *t*
Avg. RN net facility tenure	Average of net facility tenure (facility tenure minus unit tenure) for RNs working on the unit in month *t*
Avg. RN experience	Average of total nursing experience of RNs working on the unit in month *t*
Percent RN hours with 1–2 yrs unit tenure	Percentage of RN hours on the unit in month *t* accounted for by RNs with 1–2 years unit tenure
Percent RN hours with 2–3 yrs unit tenure	Percentage of RN hours on the unit in month *t* accounted for by RNs with 2–3 years unit tenure
Percent RN hours with 3–4 yrs unit tenure	Percentage of RN hours on the unit in month *t* accounted for by RNs with 3–4 years unit tenure
Percent RN hours with 4–5 yrs unit tenure	Percentage of RN hours on the unit in month *t* accounted for by RNs with 4–5 years unit tenure
Percent RN hours with 5–6 yrs unit tenure	Percentage of RN hours on the unit in month *t* accounted for by RNs with 5–6 years unit tenure
Percent RN hours with 6–7 yrs unit tenure	Percentage of RN hours on the unit in month *t* accounted for by RNs with 6–7 years unit tenure
Percent RN hours with 7–8 yrs unit tenure	Percentage of RN hours on the unit in month *t* accounted for by RNs with 7–8 years unit tenure
Percent RN hours with 8–9 yrs unit tenure	Percentage of RN hours on the unit in month *t* accounted for by RNs with 8–9 years unit tenure
Percent RN hours with 9–10 yrs unit tenure	Percentage of RN hours on the unit in month *t* accounted for by RNs with 9–10 years unit tenure
Percent RN hours with $>$ 10 yrs unit tenure	Percentage of RN hours on the unit in month *t* accounted for by RNs with $>$10 years unit tenure
Experienced departure and no hire	Experienced RN departed during the month and there was no new hire
Hire and no experienced departure	RN joined the unit during the month and there was no experienced departure
Experienced departure and hire	Experienced RN departed and new hire joined the unit
Internal hire and no experienced departure	RN transferred from another unit and there was no experienced departure
External hire and no experienced departure	RN joined the unit from outside the hospital and there was no experienced departure
Internal hire and experienced departure	RN transferred from another unit and experienced departure also occurred in the month
External hire and experienced departure	RN joined the unit from outside the hospital and experienced departure also occurred in the month
Internal hire	RN transferred from another unit in the hospital
External hire	RN joined the unit from outside the hospital
Any departure and no hire	Any RN departed the unit during the month and there was no hire
Hire and no departure	RN joined the unit during the month and there was no departure
Any departure and hire	RN joined the unit during the month and a departure also occurred
Avg. patient age	Average age of patients treated on the unit during the month
Avg. Elixhauser	Average of Elixhauser index of patients treated on the unit during the month
Complication rate	Average rate of reported complications experienced by patients treated on the unit during the month
Admissions	Number of patients admitted to the unit during the month

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