

Online Appendix

Operational Overload: The Impact of Workload on High-Skilled Workforce Attrition

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1. Summary Statistics

Following the discussion of Section 4.2.3, we also provide the summary statistics for all 420 nurses who worked during the observation period in Table A1.

Table A1: Summary statistics

	N	Mean	SD
Main Variables			
Quit	59859	0.017	0.128
Nurse Responsibility	59859	0.027	0.038
Overtime Shifts	59859	0.357	0.657
Emotional Fatigue	59859	0.079	0.288
Cumulative Workload	59859	4427.777	2387.401
Control Variables			
Patient Nurse Ratio	59859	0.660	0.069
Bed Occupancy Rate	59859	0.741	0.115
Unit Experience	59859	163.416	129.600
Shift Workload	59859	337.404	365.401
Robustness Check Variables			
Emotional Fatigue 4 weeks	59859	0.147	0.398
Avg Shifts Stayed	59859	63.588	77.603
Num New Admit	59859	0.044	0.204
Total Shifts Prior Month	59859	15.970	7.244
Avg Workload Prior Month	59859	343.772	133.93
Instrument Variables			
Lagged Arrival Rate	59859	1.224	1.328
Peer Scheduled Absences	59859	0.347	0.665
Peer Unscheduled Absences	59859	44.001	21.801

2. VIF Collinearity Diagnostics

After obtaining the main result in Section 5.1 Table 2, we conduct a variance inflation factor (VIF) check for variables in our main specification. Multicollinearity can inflate standard errors and distort coefficient estimates, potentially leading to unreliable regression results. By performing this VIF analysis, we ensure that our independent variables do not exhibit high multicollinearity. Based on commonly accepted

thresholds (i.e., VIF values greater than 5 or 10), our results confirm that multicollinearity is not a significant concern in our result.

**Table A2. Robustness Check (2)
VIF Collinearity Diagnostics (1)**

Variable	VIF	SQRT VIF	Tolerance	R-Squared
Nurse_Responsibility	1.050	1.020	0.956	0.044
Overtime_Shifts	1.080	1.040	0.925	0.075
Emotional_Fatigue	1.000	1.000	0.996	0.004
Cumulative_Workload	1.130	1.060	0.887	0.113
Mean VIF	1.060			

VIF Collinearity Diagnostics (2)

Variable	VIF	SQRT VIF	Tolerance	R- Squared
Nurse_Responsibility	3.920	1.980	0.255	0.745
Overtime_Shifts	1.060	1.030	0.941	0.059
Emotional_Fatigue	1.020	1.010	0.977	0.023
Cumulative_Workload	1.080	1.040	0.929	0.071
Patient_Nurse_Ratio	1.140	1.070	0.878	0.122
Bed_Occupancy_Rate	1.270	1.130	0.787	0.213
Unit_Experience	1.130	1.060	0.885	0.115
Shift_Workload	3.770	1.940	0.265	0.735
Mean VIF	1.800			

6.1 Robustness Check on Alternative outcome variable Y_{jt}

Table A3. Robustness Check (6.1)

	Quit 4-7 Weeks	Quit 4-8 Weeks	Quit 4-9 Weeks
Nurse_Responsibility	-8.005** (3.139)	-7.945** (2.832)	-5.749** (2.544)
Overtime_Shifts	0.556** (0.085)	0.461** (0.077)	0.325** (0.073)
Emotional_Fatigue	0.444** (0.190)	0.434** (0.165)	0.585** (0.149)
Cumulative_Workload	-0.000382** (0.000100)	-0.000451** (0.0000904)	-0.000402** (0.0000852)
Cumulative_Workload_Square	3.72e-08** (1.02e-08)	3.86e-08** (9.38e-09)	2.89e-08** (8.99e-09)
RN Fix Effect: (Nurse ID)	Yes	Yes	Yes
Time Control: (Year, Month)	Yes	Yes	Yes
Shift Control: (Patient Nurse Ratio, Bed Occupancy Rate, RN Unit Experience, Shift Workload)	Yes	Yes	Yes
Number of Observations	17599	17606	18033
LR Chi2	2431.0	3023.2	3638.5

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.2 Further Analysis on H1 Nurse_Responsibility_{jt}

There are alternative explanations for the findings of H1 nurse responsibility: a nurse with higher responsibility may care for patients who have been in the ICU for a longer period. Or alternatively, a nurse with lower responsibility may care for newly admitted patients with intense and acute needs. To address this concern, we constructed corresponding variables, then tested the correlations of these variables with H1 nurse responsibility, and eventually incorporated the new variables as control variables in the robustness check.

Firstly, we constructed two additional variables. *Avg_Shifts_Stayed_{jt}*: The average shifts those patients have stayed in the ICU until shift t and under care by nurse j at shift t. *Num_New_Admit_{jt}*: The number of newly admitted patients, under care by nurse j at shift t.

Secondly, we verify the correlation of these variables with H1. $\text{Corr}(\text{Nurse_Responsibility}_{jt}, \text{Num_New_Admit}_{jt}) = 0.144$, $\text{Corr}(\text{Nurse_Responsibility}_{jt}, \text{Avg_Shifts_Stayed}_{jt}) = -0.015$. These findings suggest that nurses with higher responsibility are slightly more likely to care for newly admitted patients, either those in their first ICU shift or the early stages of their ICU stay. This pattern contradicts the concern that higher-responsibility nurses are shielded from intensive or acute care activities. Instead, correlations show that when a nurse takes on a greater share of patient responsibility in a shift, they may be more involved in managing newly admitted patients and the complexity that comes with early ICU care.

Thirdly, we run the two regressions¹ as robustness checks. In the first regression, we add *Avg_Shifts_Stayed_{jt}* as an additional control. In the second regression, we add *Num_New_Admit_{jt}* as an additional control. These two regressions address the potential endogeneity concerns from newly admitted patients' care demand and early ICU stay patients' care demand towards H1 *Nurse_Responsibility_{jt}*. The regression results remain consistent after we control for the additional variables.

Table A4. Robustness Check (6.2)

	(1)	(2)
Nurse_Responsibility	-7.961*** (2.834)	-7.885*** (2.873)
Overtime_Shifts	0.461*** (0.0771)	0.461*** (0.0771)
Emotional_Fatigue	0.434*** (0.165)	0.434*** (0.165)
Cumulative_Workload	-0.000450*** (0.0000905)	-0.000451*** (0.0000905)
Cumulative_Workload_Square	3.85e-08*** (9.40e-09)	3.86e-08*** (9.38e-09)
Avg_Shifts_Stayed	-0.000226 (0.000567)	

¹ Since *Avg_Shifts_Stayed_{jt}* and *Nun_New_Admit_{jt}* are similar proxies for how intense a nurse's shift is, we separately incorporate them in the two regressions.

Num_New_Admit		-0.0248 (0.203)
Fix Effect RN: Nurse ID	Yes	Yes
Fix Effect Time: Year, Month	Yes	Yes
Fix Effect Shift: Patient Nurse Ratio, Bed Occupancy Rate, RN Unit Experience, Shift Workload	Yes	Yes
Number of Observations	17606	17606
chi2	3023.3	3023.2

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.3 Robustness Check on H4, emotional fatigue

Table A5. Robustness Check (6.3)
Alternative window period of the Emotional Fatigue variable

	Xtlogit
Nurse_Responsibility	-8.087*** (2.837)
Overtime_Shifts	0.459*** (0.077)
Emotional_Fatigue_4_weeks	0.317** (0.154)
Cumulative_Workload	-0.000448*** (0.0000903)
Cumulative_Workload_Square	3.90e-08*** (9.36e-09)
Fix Effect RN: Nurse ID	Yes
Fix Effect Time: Year, Month	Yes
Fix Effect Shift: Patient Nurse Ratio, Bed Occupancy Rate, RN Unit Experience, Shift Workload	Yes
Number of Observations	17606
chi2	3020.6

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.4 Robustness Check on H4, Cumulative Workload

6.4.1 Cumulative Workload with decay rate 0.05

Table A6. Robustness Check (6.4.1)
Alternative decay parameter of the Cumulative_Workload variable

	Xtlogit
Nurse_Responsibility	-7.978*** (2.828)

Overtime_Shifts	0.439*** (0.077)
Emotional_Fatigue	0.396** (0.164)
Cumulative_Workload_New	-0.000573*** (0.000164)
Cumulative_Workload_New_Square	0.000000120*** (3.58e-08)
RN Fix Effect: (Nurse ID)	Yes
Time Control: (Year, Month)	Yes
Shift Control: (Patient Nurse Ratio, Bed Occupancy Rate, RN Unit Experience, Shift Workload)	Yes
Number of Observations	17606
LR Chi2	3008.9

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.4.2 Cumulative Workload by care activity types

If zooming into nurses' patient flowsheet documentation, there are two types of care activities: routine and acute. The difference between routine and acute care activities is determined by two separate tabs in the patient flowsheet documentation, which enable us to accurately distinguish workload types.

Routine care activities include standard tasks that nurses are required to perform for all ICU patients throughout each shift. Examples include regular patient assessment, documentation of vital signs, and basic patient care. Acute care activities represent tasks involving higher physical workload and greater emotional intensity, typically required only by critically ill patients. These activities encompass complex procedures and intensive interventions such as managing renal replacement therapy (CVVH and Dialysis), administering transfusions, and operating advanced life-support equipment (e.g., ECMO). Since not all patients require the acute care activities, many nurses may not perform the acute workload during their shifts.

We recalculated the cumulative routine workload and the cumulative acute workload, utilizing hypothesis 4's cumulative workload's embedded exponential decay function.

$$Cumulative_Routine_Workload_{jt} = \sum_{t'=t-56}^{t'=t-1} Routine_Workload_{jt} * e^{-\lambda*(t-t')}$$

$$Cumulative_Acute_Workload_{jt} = \sum_{t'=t-56}^{t'=t-1} Acute_Workload_{jt} * e^{-\lambda*(t-t')}$$

To replace Hypothesis 4, we used the cumulative routine workload, cumulative acute workload, and their quadratic terms in the following table as a robustness check. In Table 7, we observe a U-shaped relationship between the nurse's routine care activities and voluntary attrition, which is consistent with Hypothesis 4. While moderate levels of routine care may be engaging and stabilizing, excessive routine burden leads to burnout. In contrast, acute workload exhibits a weak inverted U-shaped pattern ($p < 0.1$), suggesting that some exposure to high-severity care may increase the risk of attrition, but those consistently handling

complex cases may be more resilient, thereby reducing the risk of attrition. The remaining results on Hypotheses 1-3 remain consistent and statistically significant.

Relevant managerial implications: Based on the U-shaped finding on routine care, managers should evenly distribute routine care to nurses and monitor their workload across shifts to prevent disengagement from underload and burnout from overload. Based on the inverted U-shaped finding on acuity care, managers should be careful in identifying nurses with moderate exposure to acute tasks across shifts, who may be at greatest risk of stress. These findings highlight the importance of balancing the immediate staffing needs within shift, with the long-term goal of nurse retention across shifts. In particular, there's value in tracking both routine and acute workloads longitudinally to inform daily shift assignment and avoid chronic workload imbalance.

**Table A7. Robustness Check (6.4.2)
Cumulative Workload by Care Activity Types**

	Xtlogit
Nurse_Responsibility	-7.676*** (2.836)
Overtime_Shifts	0.483*** (0.0787)
Emotional_Fatigue	0.408** (0.166)
Cumulative_Routine_Workload	-0.000462*** (0.0000951)
Cumulative_Routine_Workload_Square	4.72e-08*** (1.02e-08)
Cumulative_Acute_Workload	-0.000698 (0.000481)
Cumulative_Acute_Workload_Square	-0.000000591* (0.000000312)
Fix Effect RN: Nurse ID	Yes
Fix Effect Time: Year, Month	Yes
Fix Effect Shift: Patient Nurse Ratio, Bed Occupancy Rate, RN Unit Experience, Shift Workload	Yes
Number of Observations	17606
chi2	3064.0

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.4.3 Trim at the 5th percentile of $Cumulative_Workload_{jt}$

To address whether nurses with very few care activities intentionally used paid leave before resigning, potentially contributing to the U-shaped relationship, we trimmed the cumulative workload variable at the 5th percentile and re-ran the regression. The results confirm that the U-shaped relationship for cumulative workload remains consistent, and the coefficients for Hypotheses 1-3 remain stable.

Table A8. Robustness Check (6.4.3)
Trim Cumulative Workload at 5th Percentile

	Xtlogit
Nurse_Responsibility	-7.601*** (2.876)
Overtime_Shifts	0.477*** (0.0773)
Emotional_Fatigue	0.463*** (0.166)
Cumulative_Workload	-0.000567*** (0.0000969)
Cumulative_Workload_Square	4.86e-08*** (9.81e-09)
Fix Effect RN: Nurse ID	Yes
Fix Effect Time: Year, Month	Yes
Fix Effect Shift: Patient Nurse Ratio, Bed Occupancy Rate, RN Unit Experience, Shift Workload	Yes
Number of Observations	16869
chi2	2985.0

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.4.4 Cumulative Workload with external and internal factors

This robustness check focuses on the H4, Cumulative Workload in the past month. A nurse’s total amount of workload in the past month may be influenced by external factors (e.g., manager assignment or patient conditions) or internal factors (such as the nurse's own decisions to work or take days off).

To gain a deeper understanding, we introduced two additional variables: the total number of shifts worked in the past four weeks (*Total_Shifts_Last_Month_{jt}*), and the average number of care activities per shift in the past four weeks (*Avg_Workload_Last_Month_{jt}*). The first variable captures shift frequency (more of a nurse’s own decision), the second variable captures shift intensity (more of manager assignment or patient condition).

Since *Total_Shifts_Last_Month_{jt}* and *Avg_Workload_Last_Month_{jt}* are moderately correlated (corr = 0.3285, $p < 0.001$), we addressed potential multicollinearity by presenting three model specifications. Column (1) includes both variables simultaneously. Column (2) includes only *Avg_Workload_Last_Month_{jt}*, Column (3) includes only *Total_Shifts_Last_Month_{jt}*.

Table A9’s results are informative. Column (1) suggests that both higher shift intensity and higher shift frequency are associated with increased attrition risk. Column (2) shows that shift intensity, with external factors such as patient acuity and manager assignment, contributes to attrition risk. In contrast, Column (3) finds that the shift frequency, a proxy for time off or rest, is not significantly associated with attrition risk.

Table A9. Robustness Check (6.4.4)

	(1)	(2)	(3)
Nurse_Responsibility	-7.407*** (2.836)	-7.808*** (2.837)	-7.784*** (2.830)
Overtime_Shifts	0.483*** (0.0776)	0.469*** (0.0773)	0.465*** (0.0771)
Emotional_Fatigue	0.433*** (0.167)	0.475*** (0.167)	0.398** (0.167)
Cumulative_Workload	-0.000796*** (0.000137)	-0.000525*** (0.0000976)	-0.000559*** (0.000114)
Cumulative_Workload_Square	5.01e-08*** (9.99e-09)	4.40e-08*** (9.74e-09)	3.98e-08*** (9.43e-09)
Avg_Workload_Prior_Month	0.00155*** (0.000503)	0.000897** (0.000447)	
Total_Shifts_Prior_Month	0.0698*** (0.0249)		0.0348 (0.0221)
Fix Effect RN: Nurse ID	Yes	Yes	Yes
Fix Effect Time: Year, Month	Yes	Yes	Yes
Fix Effect Shift: Patient Nurse Ratio, Bed Occupancy Rate, RN Unit Experience, Shift Workload	Yes	Yes	Yes
Number of Observations	17606	17606	17606
chi2	3035.0	3027.2	3025.7

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.5 Instrument Variable Approach

Table A10. Robustness Check (6.5.1)

	Xtlogit
Nurse_Responsibility	-70.73** (33.83)
H1_Residual	64.23* (33.71)
Overtime_Shifts	52.54*** (9.649)
H2_Residual	-52.00*** (9.667)
Emotional_Fatigue	0.722*** (0.181)
Cumulative_Workload	-0.00380*** (0.000622)

H4_Residual	0.000361 (0.000303)
Cumulative_Workload_Square	0.000000105*** (2.92e-08)
H4_Residual_Square	2.68e-08 (2.34e-08)
Fix Effect RN: Nurse ID	Yes
Fix Effect Time: Year, Month	Yes
Fix Effect Shift: Patient Nurse Ratio, Bed Occupancy Rate, RN Unit Experience, Shift Workload	Yes
Number of Observations	17606
chi2	3037.2

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

7. Re-ran main analysis with refined dataset

The following re-run the main results using the smaller subset of the dataset as discussed in Section 7.

Table A11: Summary statistics

	N	Mean	SD
Main Variables			
Quit	9438	0.058	0.233
Nurse Responsibility	9438	0.049	0.031
Overtime Shifts	9438	0.346	0.628
Emotional Fatigue	9438	0.087	0.287
Cumulative Workload	9438	4359.153	2154.677
Control Variables			
Patient Nurse Ratio	9438	0.657	0.069
Bed Occupancy Rate	9438	0.731	0.108
Unit Experience	9438	163.649	117.807
Shift Workload	9438	631.767	286.830
Mediating Variable			
Help Available	9438	0.723	0.448

Table A12. Main Result

	(1) Base	(2)	(3)	(4)	(5)
Nurse_Responsibility		-11.200*** (3.347)	-10.670*** (3.351)	-10.630*** (3.350)	-10.500*** (3.345)
Overtime_Shifts			0.459*** (0.098)	0.453*** (0.099)	0.489*** (0.099)
Emotional_Fatigue				0.409* (0.217)	0.455** (0.218)
Cumulative_Workload					-0.000462*** (0.000124)

Cumulative_Workload_Square					4.25e-08*** (1.36e-08)
Fix Effect RN: Nurse ID	Yes	Yes	Yes	Yes	Yes
Fix Effect Time: Year, Month	Yes	Yes	Yes	Yes	Yes
Fix Effect Shift: Patient Nurse Ratio, Bed Occupancy Rate, RN Unit Experience, Shift Workload	Yes	Yes	Yes	Yes	Yes
Number of Observations	9438	9438	9438	9438	9438
chi2	1591.3	1603.4	1624.5	1628.1	1642.5

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$