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Original Article

Impact of nurse staffing on reducing infant, neonatal and perinatal mortality rates: Evidence from panel data analysis in 35 OECD countries

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ABSTRACT

Objectives: To investigate the magnitude of effect nurse staffing had on decreasing the newborn mortality rates in member countries of Organisation for Economic Co-operation and Development (OECD).
Methods: The statistical technique of panel data analysis was applied to explore the possibility of association between the number of nurses' density per 1,000 population and infant, neonatal and perinatal mortality rates (IMR, NMR and PMR) per 1000 births. The observations of 35 OECD countries were collected over the period of 2000 through 2016.

Results: There were significant associations between nurse staffing and IMR, NMR and PMR i.e. a 1% increase in nurse-staffing level reduced IMR, NMR and PMR by 0.98%, 0.97% and 0.96%, respectively. Furthermore, the role of nursing-related services in declining the average of newborn mortality rates were investigated at the highest level in Slovenia (−5.50), Sweden (−3.34), Iceland (−2.51), Czech Republic (−1.86), Japan (−1.64) and Finland (−1.64). Moreover, if the current relationship between nurse-staffing level and newborn mortality rates are disturbed with nursing shortage (e.g. in Slovak Republic and Israel), then it takes about 17 years for the mortality rates to reduce and restore back to the previous equilibrium.

Conclusions: A higher proportion of nurses' density per 1,000 population is associated with lower newborn mortality rates. In addition, the nursing-related services of Slovenia, Sweden, Iceland, Czech Republic, Japan and Finland with the highest impact on improving the health level of newborns would be good patterns for other developed countries in maternity and child health care.

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What is known?

- The association between the nursing-related services and lower risk-adjusted mortality has been proved in previous studies, but there is a lack of cross-national studies to analyze the possible role of practicing nurses in reducing newborn mortality rates.

What is new?

- Our findings verified that the long-run elasticity of nurse-staffing level on IMR, NMR and PMR were −0.98, −0.97 and −0.96, respectively.
- Among OECD countries, the highest effect of practicing nurses on improving health level of newborns were estimated in Slovenia, Sweden, Iceland, Czech Republic, Japan and Finland.
- If the long-run relationships between nurse staffing and newborn mortality rates are disturbed with nursing shortage e.g. observed in Slovak Republic and Israel, it lasts for 17 years to restore back to long-run equilibriums.

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1. Introduction

According to the global measurements of health care performance, infant and neonatal mortality rates (IMR and NMR), i.e. the rate of newborn deaths per 1,000 live births of one year and less

than four weeks of age, as well as perinatal mortality rate (PMR), i.e. early neonatal mortality, are the most predominant indicators of mothers' and newborns' health level. In member countries of Organisation for Economic Co-operation and Development (OECD), about 70% of total number of baby deaths which occur during less

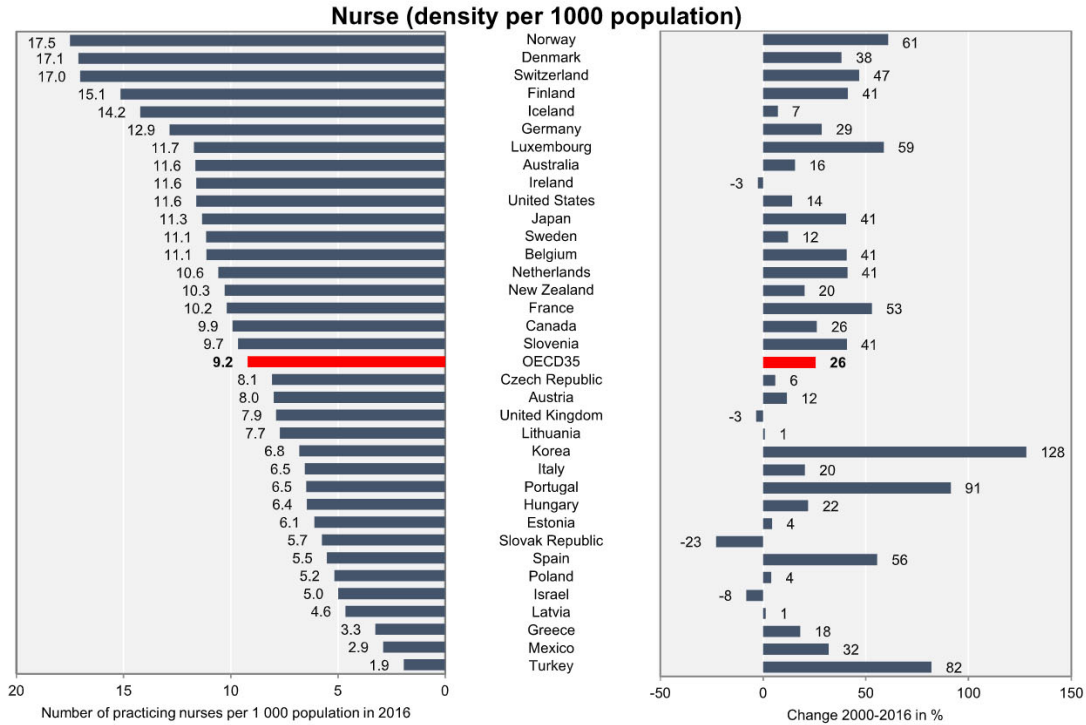


Fig. 1. Number of practicing nurses' density per 1,000 population, 2016 and change 2000–2016. Source: OECD [24].

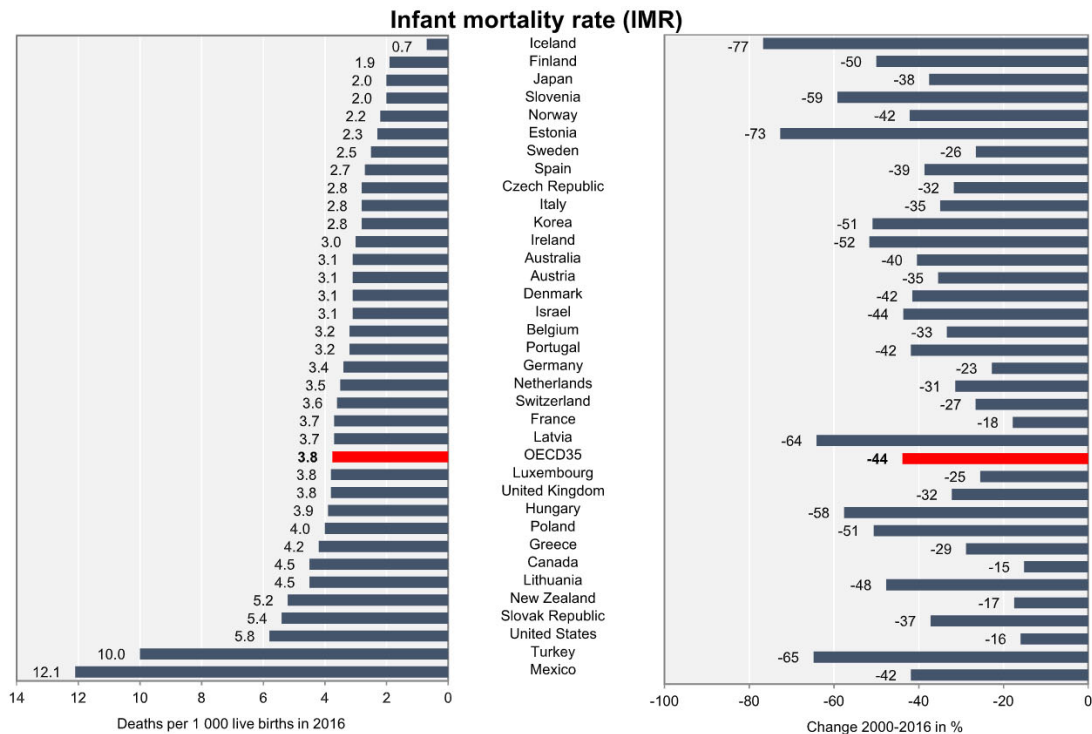


Fig. 2. Number of infant deaths per 1,000 live births, 2016 and change 2000–2016. Source: OECD Health Statistics [27].

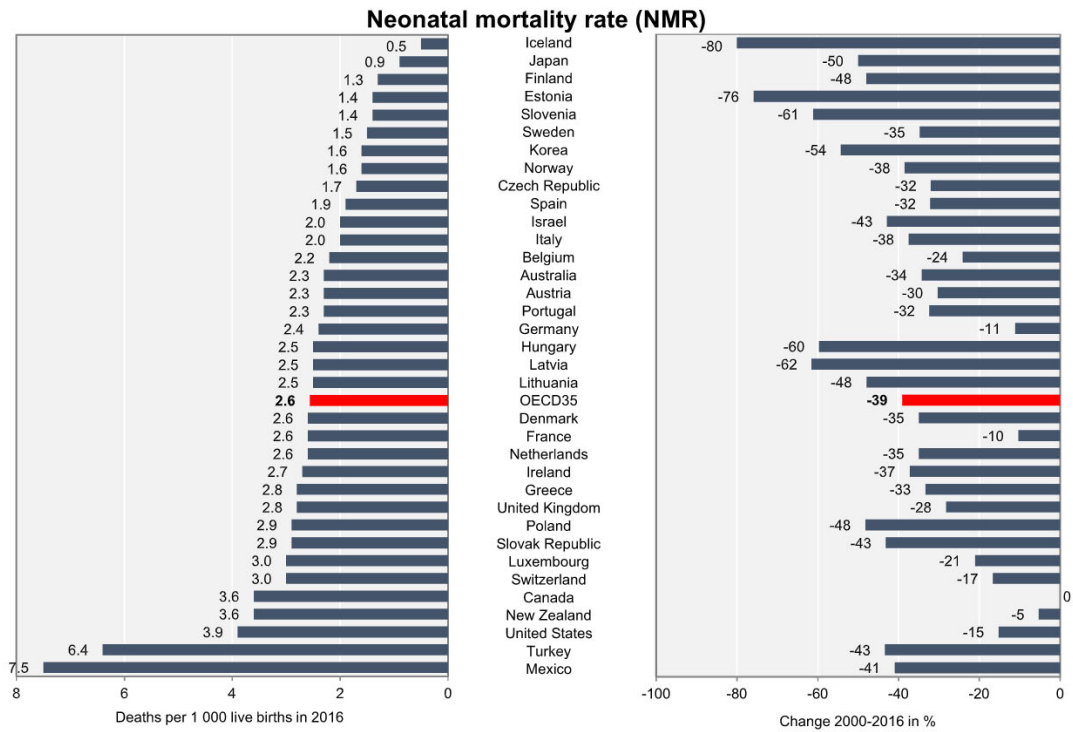


Fig. 3. Number of neonatal deaths per 1,000 live births, 2016 and change 2000–2016. Source: OECD Health Statistics [27].

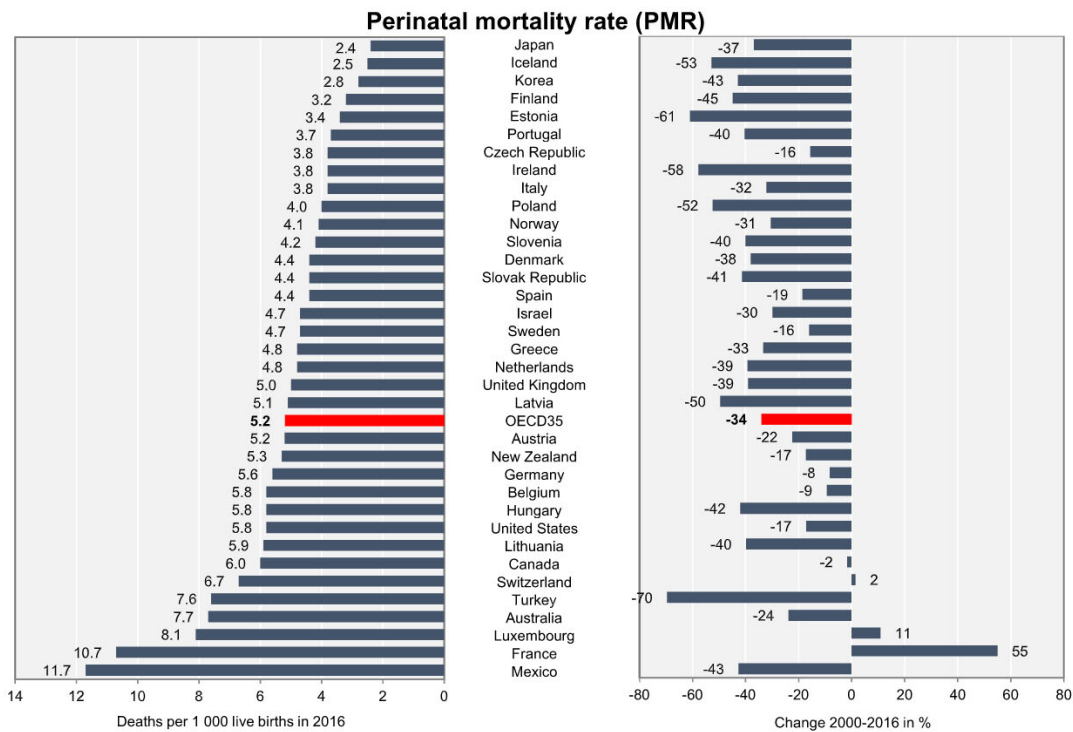


Fig. 4. Number of perinatal deaths per 1,000 live births, 2016 and change 2000–2016. Source: OECD Health Statistics [27].

than one year of birth are neonatal deaths i.e. happen in less than four weeks of birth, whereas birth defects, prematurity, sudden infant death syndrome (SID), infections as well as accidents are reported as the major causes of neonatal mortality [1].

In the most of developed countries, the average of IMR, NMR and PMR in 2016 were quite low about 3.76, 2.56 and 5.19 deaths per 1,000 live births, respectively, except in Turkey and Mexico. Since 2000, there has been a significant decrease in the trend of newborn

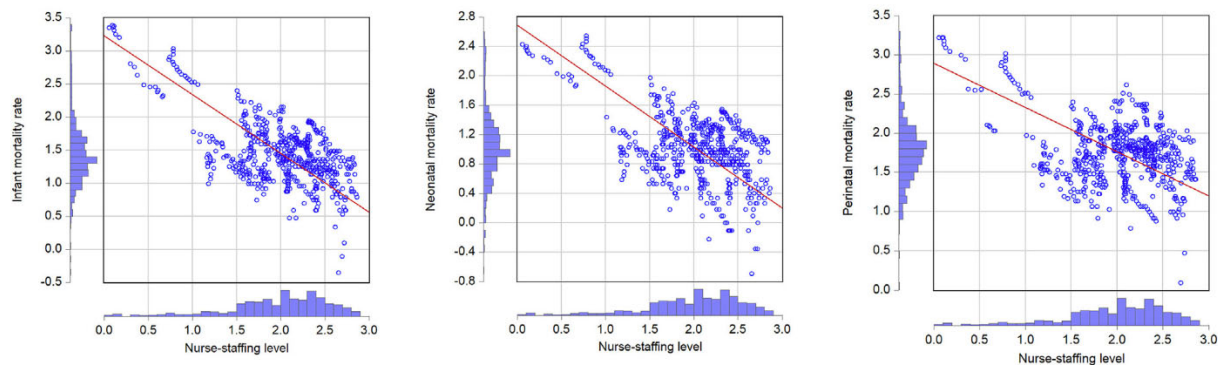


Fig. 5. Cross plot of logarithms of infant, neonatal and perinatal mortalities per 1,000 live births and nurse density per 1,000 population in 35 OECD countries 2000–2016.

mortality observed in all OECD countries, particularly in Turkey, Mexico, Latvia, Estonia, Hungary, Lithuania and Poland contributed to differences in characteristics and effectiveness of health care systems, economic and social conditions, education level together with mothers and newborns lifestyles – see Ref. [1,2].

As nurses play a critical role in providing health care services in hospital and long-term care along with primary and home care settings, whereas nurses obviously outnumber physicians in the most of OECD countries, it is substantial to compute the effects of nurse staffing on improving the health level of mothers and newborns among different health care systems of OECD countries. Despite the significant rise in the average number of nurse density per 1,000 population from 7.3 in 2000 to 9 in 2015, in Slovak Republic, followed by Ireland, Israel and United Kingdom the number of nurses per capita has declined since 2000 i.e. the size of nurse staffing rose slower than population growth. Thus, there are growing concerns about potential future shortages of nurses in the process of aging reformation and retirement of current generation of nurses observed in many OECD countries [3].

In response to shortages of practicing nurses and physicians to ensure proper care delivery and to enhance the quality of newborn care in health facilities, it is critical for governments, policy makers and researchers to look for more efficient care services aimed to

advance the health level of mothers and newborns [4]. To do this, the first step is to estimate the impact of nurse staffing on improving newborn health outcomes among different health care systems of developed countries [5].

To our knowledge, nursing literature has strongly argued the association between nurse staffing and lower risk-adjusted mortality [6–8], reviewed in Ref. [9]. Besides, the results of multinational studies have drawn the same conclusion with patient mortality [9–18], failure to rescue [10,12] and safety failures [13,19–23]. However, there is a lack of empirical research to measure the possible role of practicing nurses in reducing newborn mortality rates in national level.

The aim of this study is to provide empirical information about the relationship from nursing characteristics to reducing newborn mortality rates. To do this, the most comprehensive source of cross-national statistics across developed countries is applied in this study. The statistical technique of panel data analysis is conducted to measure the association between nurses' density per 1,000 population and improving the quality of newborn care services among 35 OECD countries during the period of 2000–2016.

Table 1

Panel unit root test results (35 OECD countries, 2000–2016).

Null hypothesis: Unit root Method	Level			1st Difference Intercept
	Intercept	Intercept and trend	None	
Nurse				
Levin, Lin & Chu t-stat	–1.95*	–2.40**	10.80	–9.39**
Im, Pesaran and Shin W-stat	1.97	0.66	–	–8.35**
ADF – Choi Z-stat	72.66	65.98	18.52	195.59**
PP – Choi Z-stat	144.96**	84.02	15.40	203.84**
IMR				
Levin, Lin & Chu t-stat	–5.82**	–5.59**	–11.30**	–19.59**
Im, Pesaran and Shin W-stat	1.62	–4.98**	–	–19.21**
ADF – Choi Z-stat	61.663	157.69**	282.60**	423.75**
PP – Choi Z-stat	74.81	194.27**	386.50**	572.20**
NMR				
Levin, Lin & Chu t-stat	–4.24**	–9.35**	–9.48**	–27.23**
Im, Pesaran and Shin W-stat	0.92	–5.89**	–	–23.83**
ADF – Choi Z-stat	60.47	147.65**	253.60**	500.45**
PP – Choi Z-stat	64.50	184.15**	327.00**	605.34**
PMR				
Levin, Lin & Chu t-stat	–2.29*	–9.19**	–9.59**	–23.73**
Im, Pesaran and Shin W-stat	0.39	–5.23**	–	–20.84**
ADF – Choi Z-stat	84.62	143.62**	224.10**	446.24**
PP – Choi Z-stat	87.70	153.40**	351.70**	617.45**

Notes: Null hypothesis was no integration and the optimum lag lengths were selected by Schwarz Information Criterion (SIC) from 0 to 3; * $P < 0.05$ and ** $P < 0.01$; OECD = Organisation for Economic Co-operation and Development; IMR = infant mortality rates; NMR = neonatal mortality rates; PMR = neonatal mortality rates.

Table 2
Pedroni co-integration test (35 OECD countries, 2000–2016).

Co-integration test between	Pedroni's criteria	Unweighted		Weighted		Conclusion
		Statistic	P	Statistic	P	
Nurse & IMR	Panel v-Statistic	2.21	0.013	1.86	0.031	Co-integrated
	Panel rho-Statistic	-1.86	0.031	-2.25	0.012	
	Panel PP-Statistic	-2.68	0.003	-3.65	0.000	
	Panel ADF-Statistic	-2.94	0.001	-4.06	0.000	
	Group rho-Statistic	-0.75	0.225			
	Group PP-Statistic	-4.58	0.000			
	Group ADF-Statistic	-5.02	0.000			
Nurse & NMR	Panel v-Statistic	0.82	0.206	0.72	0.235	Co-integrated
	Panel rho-Statistic	-1.51	0.065	-1.80	0.035	
	Panel PP-Statistic	-2.15	0.015	-3.55	0.000	
	Panel ADF-Statistic	-1.19	0.115	-3.47	0.000	
	Group rho-Statistic	-0.77	0.218			
	Group PP-Statistic	-4.78	0.000			
	Group ADF-Statistic	-4.77	0.000			
Nurse & PMR	Panel v-Statistic	-1.15	0.876	-0.78	0.781	Co-integrated
	Panel rho-Statistic	0.32	0.627	0.13	0.555	
	Panel PP-Statistic	-1.62	0.052	-1.57	0.057	
	Panel ADF-Statistic	-2.39	0.008	-1.87	0.030	
	Group rho-Statistic	1.18	0.881			
	Group PP-Statistic	-1.63	0.050			
	Group ADF-Statistic	-1.83	0.033			

Notes: Null hypothesis was no co-integration and the optimum lag lengths were selected by SIC (from 0 to 9); OECD = Organisation for Economic Co-operation and Development; IMR = infant mortality rates; NMR = neonatal mortality rates; PMR = perinatal mortality rate.

2. Data description

The number of practicing professional nurses' density per 1,000 population, which defined as the determinant of health care performances, covered nursing professionals who deliver clinical and hospital care services directly to patients including general care nurses, specialist nurses, clinical nurses, district nurses, nurse anesthetists, nurse educators, nurse practitioners and public health nurses were collected from OECD [24] as the index of nurse-staffing level [25,26]. The nursing data is available at Health Care Resources Package for 35 OECD countries from 2000 to 2016.

The column chart of practicing nurse's ratio for 35 OECD countries in years 2016 and change from 2000 to 2016 is available in Fig. 1. In 2016, the highest number of practicing nurses per 1,000 population was recorded in Norway (17.49), followed by Denmark (17.10), Switzerland (17.02), Finland (15.14) and Iceland (14.22) among the other OECD countries. Interestingly, out of 35 OECD countries, there was a significant rise in the number of practicing nurses in 31 countries from 2000 to 2016 and Korea with 128.2%, Portugal with

91.4%, Turkey with 82.1%, Norway with 60.9% and Luxembourg with 58.9% had the highest growth during this period. At the other end of the range, the lowest level of practicing nurses in 2016 was recorded in Turkey, where on average, only 1.93 practicing nurses per 1,000 inhabitants; Mexico (2.98), Greece (3.25), Latvia (4.64) and Israel (4.99) had the lowest number of nurses in OECD countries. Furthermore, there was a reduction in the trends of nurse staffing during 2000–2016 period in Ireland (-2.5%), United Kingdom (-3.3%), Israel (-8.1%) and Slovak Republic (-22.8%). The average amounts of practicing nurses' ratios in 2000 and 2016 were 7.34 and 9.22 with the ranges of 13.26–1.06 and 17.49–1.93, respectively.

The number of newborn deaths aged *under one year of age* together with *under 28 days of age* that happened each year both expressed per 1,000 live births are defined as IMR and NMR without considering birthweight or minimum threshold of gestation period. Perinatal mortality per 1,000 total births is described as the ratio of child deaths within one week of birth (early neonatal deaths) plus fetal deaths of minimum gestation period 28 weeks or minimum fetal weight of 1,000g. The observations of IMR, NMR and

Table 3
Dynamic long-run models: panel fixed-effect with cross-section weights (35 OECD countries, 2000–2016).

Dependent Variable	Variable	Coefficient	Std. Error	t	P	r ²	Durbin-Watson
IMR	Constant	0.4828	0.09	4.82	0.000	0.992	2.58
	Nurse(-1)	-0.1407	0.03	-3.80	0.000		
	IMR(-1)	0.8381	0.02	38.30	0.000		
Long-run elasticity of effect nurse had on IMR: $-0.1407/(1-0.8381) = -0.9789$							
NMR	Constant	0.5840	0.09	6.05	0.000	0.986	2.55
	Nurse(-1)	-0.1935	0.03	-5.07	0.000		
	NMR(-1)	0.7791	0.02	30.85	0.000		
Long-run elasticity of effect nurse had on NMR: $-0.1935/(1-0.7791) = -0.9727$							
PMR	Constant	0.6166	0.09	6.29	0.000	0.983	2.54
	Nurse(-1)	-0.1499	0.03	-4.57	0.000		
	PMR(-1)	0.8069	0.02	33.55	0.000		
Long-run elasticity of effect nurse had on PMR: $-0.1499/(1-0.8069) = -0.9569$							

Notes: OECD = Organisation for Economic Co-operation and Development; IMR = infant mortality rates; NMR = neonatal mortality rates; PMR = perinatal mortality rate.

Table 4

Dynamic long-run model: pooled fixed-effect with cross-section weights (35 OECD countries, 2000–2016).

Countries	Magnitude of the effect nurse had on:			
	IMR	NMR	PMR	Average
Australia	-1.1827	-0.9772	-0.9141	-1.0247
Austria	-1.8059	-1.6519	-1.3311	-1.5963
Belgium	-0.9789	-0.9901	-0.6613	-0.8768
Canada	-0.8061	-0.5732	-0.5109	-0.6301
Czech Republic	-2.4285	-1.6470	-1.5122	-1.8626
Denmark	-1.0740	-0.7967	-1.0858	-0.9855
Estonia	-1.4654	-1.4273	-0.9296	-1.2741
Finland	-1.6629	-1.6793	-1.5650	-1.6358
France	-0.7668	-0.6107	-0.8150	-0.7309
Germany	-1.0606	-0.8944	-0.7135	-0.8895
Greece	-1.5316	-1.6387	-1.0964	-1.4222
Hungary	-1.0847	-1.3608	-1.2343	-1.2266
Iceland	-3.0402	-2.6095	-1.8770	-2.5089
Ireland	-0.5678	-1.5568	-1.2940	-1.1395
Israel	-0.2379	No significant	No significant	-0.2379
Italy	-0.8248	-1.5712	-1.0707	-1.1556
Japan	-1.7175	-2.0580	-1.1547	-1.6434
Korea	-0.9777	-1.0120	-0.9142	-0.9680
Latvia	-0.5443	-0.3575	-0.6738	-0.5252
Lithuania	-0.4531	-2.2298	-1.7688	-1.4839
Luxembourg	No significant	-0.6339	-0.2847	-0.4593
Mexico	-0.9433	-0.9865	-1.0019	-0.9772
Netherlands	-1.0282	-0.9373	-1.3173	-1.0943
New Zealand	No significant	No significant	-0.4876	-0.4876
Norway	-1.0927	-1.0972	-0.6403	-0.9434
Poland	-1.5128	-1.8684	-1.1697	-1.5170
Portugal	-0.7740	-0.5611	-0.6078	-0.6476
Slovak Republic	No significant	No significant	No significant	0.0000
Slovenia	-5.3534	-6.3165	-4.7989	-5.4896
Spain	-0.9846	-0.9403	-0.3663	-0.7637
Sweden	-4.3460	-5.1244	-0.5560	-3.3422
Switzerland	-0.6877	-0.4915	No significant	-0.5896
Turkey	-0.8830	-0.8859	No significant	-0.8845
United Kingdom	-0.9594	-0.3824	-0.5338	-0.6252
United States	-1.4608	-1.4006	-1.1526	-1.3380
OECD35	-1.3824	-1.4771	-1.0980	-

Note: Dynamic long-run models for individual countries were the same as panel models in Table 3; OECD = Organisation for Economic Co-operation and Development; IMR = infant mortality rates; NMR = neonatal mortality rates; PMR = perinatal mortality rate.

PMR were collected from OECD Health Statistics [27] for 35 OECD countries over the period 2000–2016.

The column chart of newborn mortality rates for 35 OECD countries in years 2016 and change from 2000 to 2016 are available in Figs. 2–4. Obviously, the rates of newborn deaths in OECD countries were quite low, except in Turkey and Mexico (as well as PMR in France). Among the 35 OECD countries, the lowest newborn mortality rates in 2016 were observed in Iceland (0.70), followed by Finland (1.90), Japan (2.00) and Slovenia (2.00) for infant mortality, Iceland (0.50), Japan (0.90), Finland (1.30) and Estonia (1.40) for neonatal mortality along with Japan (2.40), Iceland (2.50), Korea (2.80) and Finland (3.20) for perinatal mortality.

Since 2000, there has been a drop in the trend of newborn mortality rates observed in almost all OECD countries except in Switzerland (1.5%), Luxemburg (11.0%) and France (55.1%) with positive perinatal mortality growth and the highest reduction of newborn mortality rates were estimated in Iceland (-76.7%), followed by Estonia (-72.6%), Turkey (-64.8%) and Latvia (-64.1%) for infant mortality, in Iceland (-80.0%), Estonia (-75.9%), Latvia (-61.5%) and Slovenia (-61.1) for neonatal mortality, as well as in Turkey (-69.6%), Estonia (-60.9%), Ireland (-57.8%) and Iceland (-52.8%) for perinatal mortality. Overall, the average changes in IMR, NMR and PMR in OECD countries during 2000–2016 period were -40.2%, -39.1% and -34.0%, respectively.

Fig. 5 relates the level of nurse staffing to newborn mortality rates (all in logs) within orthogonal non-parametric regression curve, and histogram of marginal distributions. As can be seen, there exists a clear inverse relationship from the level of practicing nurses to all newborn mortality rates. However, this finding may be spurious because of the possibility of stochastic trends in panels of our series. Thus, to provide statistical conclusion about the possible effect of nurse-staffing level on IMR, NMR and PMR, the information of unit root test and co-integration analysis in the form of panel data analysis are needed. The summary of descriptive statistics for variables is available in Appendix A.

3. Panel data analysis

Due to the nature of our data that statistically defined in cross-sectional time-series framework (35 countries during 2000–2016 period), we have the possibility to evaluate the association between nurse-staffing level and IMR, NMR and PMR in long-run using the statistical technique of panel data analysis. The instruction of panel data analysis starts with providing the essential information about the stationary process of our panel series from unit root test and continues with co-integration analysis to examine the association between the non-stationary variables. In co-integration analysis, if the existence of a co-integration relationship between the panel series is confirmed statistically, the significant coefficient of this relationship can be measured by dynamic long-run analysis. In the final step, the sensitivity of the long-run equilibrium between the co-integrated series may be analyzed with panel error correction model.

3.1. Unit root test

Unit root test is the first step in time-series analysis to identify the plausible effects of time variation on panel series i.e. whether series are stationary (mean and variance are constant in long-term) or non-stationary and possesses a unit root (mean and variance vary during time). Statistically, the null hypothesis of unit root test is the presence of stationarity based on intercept and trend stationarity according to different test models. Statistics and probabilities of several types of unit root test are available in Table 1. Due to significant statistics in level and 1st difference of integration tests, the result of unit root test verifies that nurse staffing variable was non-stationary i.e. its integration was sensitive to the trend presentation, while newborn mortality rates were stationary. Thus, the results of integration test open the way to co-integration analysis to investigate whether there existed a meaningful association between nurse-staffing level and newborn mortality rates in long-run or not.

3.2. Co-integration analysis

In this step, we examine the existence of long-run relationship between the level of nurse staffing and newborn mortality series in the form of co-integration analysis. The results of Pedroni panel co-integration test [28,29] based on Engle-Granger model are reported in Table 2 and confirm that nurse staffing series and IMR, NMR and PMR were significantly co-integrated in the long-run.

3.3. Dynamic long-run analysis

Based on the results of Pedroni co-integration test, there existed a significant relationship between nurse-staffing level and newborn mortality rates in long-run. The aim of this step is to calculate the magnitudes of these relationships based on dynamic long-run analysis in panel and pooled data frameworks. Results of

Table 5
Panel error correction model (35 OECD countries, 2000–2016).

Dependent variable	Variable	Coefficient	Std. Error	t	P	r ²	Durbin-Watson
ΔIMR	Constant	-0.0329	0.00	-5.27	0.000	0.027	2.50
	ΔNurse	-0.0718	0.19	-0.35	0.719		
	EC(-1)	-0.0585	0.01	-3.93	0.000		
ΔNMR	Constant	-0.0321	0.00	-4.48	0.000	0.028	2.55
	ΔNurse	0.0357	0.22	0.15	0.876		
	EC(-1)	-0.0659	0.01	-4.02	0.000		
ΔPMR	Constant	-0.0243	0.00	-3.85	0.000	0.027	2.91
	ΔNurse	-0.0134	0.20	-0.06	0.946		
	EC(-1)	-0.0599	0.01	-3.96	0.000		

Notes: EC means the error correction term, i.e. the residuals from the static long run panel model between the series. The optimum lag lengths were selected by SIC (from 0 to 3); OECD = Organisation for Economic Co-operation and Development; IMR = infant mortality rates; NMR = neonatal mortality rates; PMR = perinatal mortality rate.

dynamic long-run models demonstrate that the long-run elasticities of nurse staffing on IMR, NMR and PMR were -0.98, -0.97 and -0.96, respectively. In another word, one percent rise in the number of nurses' density per 1000 population would decline the rates of infant, neonatal and perinatal mortality per 1,000 child births about one percent in long-run. Results of dynamic long-run panel models are available in Table 3.

Dynamic long-run model analysis based on pooled data framework is used in this step to calculate the magnitude of the effect nurses had on distinct types of newborn deaths in every country. Result of panel fixed effect method with cross-sectional weights is available in Table 4 and Fig. 6. The highest magnitude of nurse-staffing level on infant mortality reduction per 1,000 births in long-run was estimated in Slovenia with -5.35, followed

by Sweden with -4.35, Iceland with -3.04 and Czech Republic with -2.43. By contrast, the lowest magnitudes of this relationship were investigated in Ireland (-0.57), Latvia (-0.54), Lithuania (-0.45) and Israel (-0.24). There was not any committed relationship from nurse density per 1,000 population to IMR in Luxembourg, New Zealand and Slovak Republic and for the rest of countries, the range of this long-run elasticity was between -1.81 in Austria and -0.69 in Switzerland with the average of -2.02 for OECD.

The highest magnitude of role of practicing nurses on NMR reduction in long-run was calculated Slovenia (-6.32), followed by Sweden (-5.12), Iceland (-2.61) and Lithuania (-2.23). For the rest of developed countries, the range of this magnitude was simulated between -2.06 in Japan and -0.36 in Latvia with the average

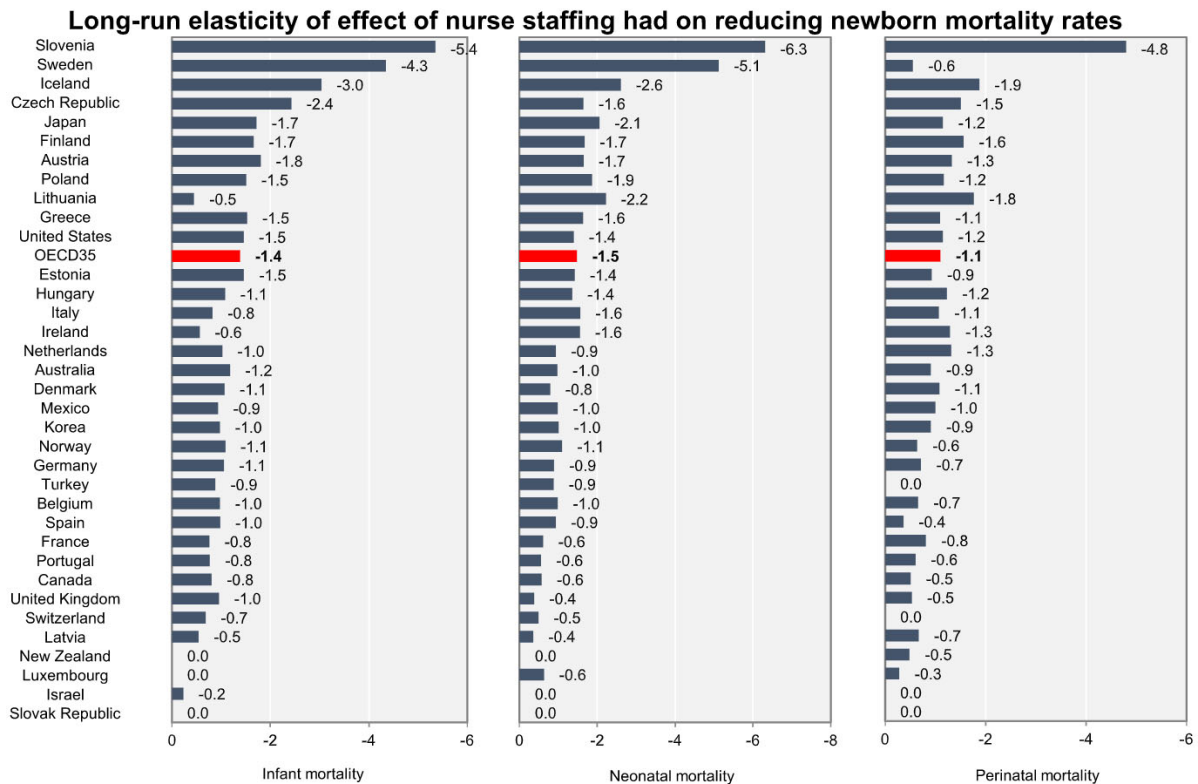


Fig. 6. Long-run elasticity of effect of nurses' density per 1000 population on newborn mortality rates (2000–2016).

of -1.48 for OECD countries, except in Israel, New Zealand and Slovak Republic which there was not any significant relationship between nurse-staffing level and NMR.

Slovenia with -4.80 , followed by Iceland with -1.88 , Lithuania with -1.77 and Finland with -1.56 had the highest magnitudes of the effect nurse staffing had on decreasing perinatal mortality per 1,000 live births in long-run. By contrast, Canada (-0.51), New Zealand (-0.49), Spain (-0.37) and Luxembourg (-0.28) had the lowest magnitudes of association between nurses and PMR, whereas there was no evidence for the possibility of such a relationship in Israel, Slovak Republic, Switzerland and Turkey in long-run. The magnitude of this relationship for the rest of OECD had a range from -1.15 in Czech Republic to -0.53 in United Kingdom with the average of -1.10 for OECD countries.

Overall, nurse-staffing level had the highest effect on declining the average of newborn mortality rates in Slovenia (-5.50), followed by Sweden (-3.34), Iceland (-2.51), Czech Republic (-1.86), Japan (-1.64) and Finland (-1.64). By contrast, the lowest effect of nurses on dropping the trend of newborn mortality rates in long-run were estimated in Latvia (-0.52), New Zealand (-0.49), Luxembourg (-0.46) and Israel (-0.24) and there was not any evidence for concluding the existence of association between these series in Slovak Republic.

3.4. Panel error correction model

As the results of panel data analysis confirmed the existence of meaningful association between nurse staffing and infant, neonatal and perinatal mortalities in long-run, it would be interesting to analyze if an external factor such as nursing shortage disrupt the long-run equilibrium between these variables, what would be the speed of correcting back to long-run steady state. To examine this, the result of panel error correction model is presented in Table 5 and proves that if the long-run relationship between practicing nurses level and newborn mortality rates are disturbed with nursing shortage, then it takes at least 17 years ($1/0.0585$) for IMR, 15 years for NMR ($1/0.0659$) and 17 years ($1/0.0599$) for PMR to restore back to the previous long-run equilibrium with nurse staffing.

4. Discussion

There has been much interest in measuring the possible role of nursing-related services due to the level of nurse staffing in proficiency of mothers and newborns care management. To our knowledge, there is a lack of cross-national studies to examine the association between practicing nurses and reducing newborn mortality rates in OECD countries. Across the traditional statistical approaches used in nursing research which typically have relied on stochastic models [9], this article considered the effects of time variation on the relationship between professional nurses' density per 1,000 population and newborn mortality rates, including IMR, NMR and PMR, using the most comprehensive source of cross-national observations across OECD countries. The statistical technique of panel data analysis was conducted to calculate the magnitudes of the role of nurse staffing in reducing newborn mortality rates using a panel of 35 OECD countries during the period of 2000–2016.

Result of unit root test verified that nurse staffing series were nonstationary which opened the way to dynamic long-run analysis based on panel and pooled estimations. According to the results of co-integration analysis and panel dynamic long-run models, there were meaningful associations between the level of nurse staffing and IMR, NMR and PMR in the long-run and the elasticity of these relationships in OECD countries were -0.98 , -0.97 and -0.96 ,

respectively. Overall, the impact of practicing nurses on decreasing the average of newborn mortality rates in the long-run were recorded at the highest level in Slovenia, Sweden, Iceland, Czech Republic, Japan and Finland. On the other hand, the lowest effect of nurse staffing on declining the long-run trend of newborn mortality rates were estimated in Latvia, New Zealand, Luxembourg and Israel. In addition, the result of panel error correction model verified that if the long-run association between nurse-staffing level and newborn mortality rates are disturbed with nursing shortage, e.g. in Slovak Republic and Israel, then it takes at least 17 years for mortality rates to restore back to the previous long-run equilibriums.

In all, the results of this study highlight the significant association between higher levels of nurse staffing and lower newborn mortality rates in developed countries. Moreover, as the effects of nurse staffing on improving the health level of newborns are at the highest level in Slovenia, Sweden, Iceland, Czech Republic, Japan and Finland among the other OECD countries, the recommendation for the other countries is to pattern the hospital nursing characteristics in mothers and newborns care management of this group of countries. A principal direction of future research is to explore what factors drive the efficiency of nursing care on newborn health as well as analyze if the current trends continue across the countries to monitor the possible effect of nursing shortage.

Due to the lack of data, the missing of relevant control variables like the level of nursing education, years of work experience etc. in statistical analysis was the limitation of this study. As the lack of data availability is the biggest obstacle in nursing research, it is recommended by OECD and the Commission on Information and Accountability for Women's and Children's Health in WHO along with other relevant organizations, in co-operating with researchers, to support countries in collecting and analyzing cross-national observations, which can be used to further study the interaction between nursing characteristics and health outcomes [30–32].

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Declaration of competing interest

The authors have declared that no conflicts of interest exist.

CRediT authorship contribution statement

Arshia Amiri: Conceptualization, Methodology, Software, Data curation, Writing - original draft, Visualization, Investigation, Writing - review & editing. **Katri Vehviläinen-Julkunen:** Validation, Writing - review & editing. **Tytti Solankallio-Vahteri:** Validation, Writing - review & editing. **Sirpa Tuomi:** Validation, Writing - review & editing.

Appendices. Supplementary data

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