Evaluating the Effect of a Policy Change to Hospital Productivity: 80 Hours Work Restriction on Medical Residents

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Evaluating the Effect of Medical Resident Work-hour Reform on Hospital Productivity: 80 Hours Work Restriction on Medical Residents

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Abstract
This paper uses a two-year panel dataset on hospitals from the American Hospital Association (AHA) to evaluate the effect a policy change has on the marginal product of medical residents. A weighted 2SLS approach is used to estimate a semi-parametric production function. A policy restricting medical residents to work no more than 80 hours a week is found to result in a net loss of 14 inpatient days per resident annually, which is not statistically different from zero. In addition, the model presented in this paper performs better than past models when estimating first-order effects of inputs in the hospital production function.

Section 1: Introduction

On May 1, 2003, the Council of Teaching Hospitals restricted the maximum number of hours worked by a resident to 80 hours a week. Noncompliance of this policy results in a loss of accreditation for the violating residency program. In this study, the role of a medical resident in the hospital production function is estimated using a semi-parametric model. The relationship between physicians and medical residents enter the production function non-parametrically. The estimator presented in this paper produces more precise estimates of first-order effects in production than those found in fully parametric models currently in the literature. Further, the model identifies changes in the marginal product and elasticity of substitution between inputs of the production function as a result of work-hour restrictions placed on medical residents.

The economic literature has numerous studies investigating the role and the demand for physician services (Cockx and Brasseur 2003), but medical residents have seldom been studied. The literature on medical residents is concentrated on the choice of medical specialization (Arcidiacono and Nicholson 2003; Nicholson and Souleles 2002; Nicholson 2003). These studies find that the choice of medical specialization is very sensitive to expected future incomes in each specialization. The authors claim that the large wage gap between specializations can be attributed to existing barriers to entry in the non-primary medicine specializations by limiting the number of total medical residents in these fields.

Once the choice of specialization has occurred, then a medical resident becomes an input into the hospital production function. The medical resident enters separately from physicians in the production function because of a difference in experience, which may lead to differences in productivity. Early studies use a Cobb-Douglas production function to estimate the relationship between the inputs and number of patients served (Lave 1970; Reinhardt 1971). Both models recognized that physicians and medical residents are two separate inputs and treats them as such in the production function. Jensen and Morrisey (1986) overcome some of the functional restriction of the Cobb-Douglas by using a Translog production function. The Translog function incorporates second-order and interaction terms, which are absent in the Cobb-Douglas model. The authors find the elasticity of substitution between physicians and nurses to be close to zero and the marginal product of the last medical resident to not be statistically different from zero. The model presented in this study departs from the previous literature in two ways. First, the model relaxes structural constraints placed upon the estimation of the hospital production function by a fully parameterized model. Physicians and medical residents enter the production function non-parametrically to allow for richer non-linear effects on hospital production. Secondly, the model introduces instruments for the hospital inputs to remove simultaneity bias ignored by previous studies.

The remainder of the paper is organized in the following fashion. Section 2 summarizes the events leading to the restriction in medical resident work hours. Section 3 develops the empirical model of hospital production. Section 4 describes the estimation strategy. Section 5 gives a description of the data. The results of the estimation are described in Section 6. Section 7 concludes the paper with a concise description of the results and provides suggestions for public policy.

Section 2: Background

In 1984, an 18-year old woman died from an apparent adverse reaction to the medicine given to her while in a New York City hospital. The court ruled that the excessively long work hours of the resident in care of this patient were to blame.

> In October 1987, the Ad Hoc Advisory Committee on Emergency Services of New York State Department of Health adopted the following recommendations as a result to the court hearing:
> - 24 hour supervision of acute care inpatient units by experienced attending physicians
> - improved working conditions and greater ancillary support for residents
> - 12-hour work limits for residents and physicians in emergency departments
> - in areas other than the emergency room, a scheduled work week for residents not exceeding an average of 80 hours per week over a four-week period and not exceeding 24 hours consecutively, with at least one 24 hour period of non-working time per week (Conigliaro et. al. 1993).

These regulations are known as the New York State Health Code Section 405 Regulations and were implemented on July 1, 1989. In May 2003, the Council of Teaching Hospitals adopted these same regulations nationalizing the policy. The American Medical School Association (AMSA) has lobbied for resident hour reform, and, at this time, has bills in both the House of Representatives and the Senate. The role of medical residents should be of interest to policy makers because the wages and education given to the residents is funded through Medicaid.

The concern surrounding restrictions on medical resident work hours also exists in the international arena. The international community has taken a lead in labor reform for medical residents through the introduction of work hour restrictions as described in Table 1. Denmark has the most stringent restriction at 45 hrs/wk, and is followed by the European Union at 48 hrs/wk. The least stringent restriction is found in Australia at 75 hrs/wk, which is still more conservative than the current restriction in the United States of 80 hrs/wk.

Section 3: Econometric Model

In this paper the production function is defined semi-parametrically as the sum of a linear function and a non-specified g function,

$$\ln Y = \alpha + X\theta + g(P, R, PL) + u \quad (1)$$

where the inputs of the g function are the number of physicians P, the number of residents R and a policy dummy variable PL. The policy dummy variable takes the value of 1 after Section 405 has been made law and zero otherwise. The linear portion of equation (1) is a Translog function of the remaining labor inputs, which include the number of registered nurses RN and the number of licensed nurses LPN. The dependent variable Y is the hospital output measured as the total number of inpatient days. The regression constant α represents a productivity constant. The hospital-time specific error u captures unobservable quality differences between hospital and across time. The error term is assumed to have a mean of zero and a standard deviation of σ^2.

Specifying the production function in this manner has several advantages. First, the relationship between physicians and residents is isolated from the other inputs. Physicians and medical residents are close substitutes, but have a unique relationship in that physicians serve as instructors to medical residents. Second, the non-specified function allows for flexibility in the substitution patterns of these inputs, which could be constrained with a structural function. The relationship between registered nurses and licenses nurses is not the main concern of this paper, but is still important to capture. For this reason, the use of a Translog function, as described in equation 2,

$$X\theta = \theta_1 \ln(RN) + \theta_2 \ln(LPN) + \theta_3[\ln(RN)]^2 + \theta_4[\ln(LPN)]^2 + \theta_5[\ln(RN)][\ln(LPN)] \quad (2)$$

allows us to capture the relationship between these inputs beyond first order effects. The Translog function incorporates second order terms and interaction of the inputs. Defining the production in this manner does force the researcher to assume physicians/medical residents are additively separable from registered nurses and licensed nurses.

Lastly, two controls are used to separately identify the effect of the policy on production. A dummy variable for time is used to capture any technological advances between the time periods of the two samples. The dummy variable takes the value of 1 in 1987 and zero otherwise. A dummy variable for the state of New York is used to separate a state effect from the policy effect. The policy only affects the state of New York, therefore, a state dummy variable is needed to capture variation between states so that the policy dummy variable will not also include these variations.

Instruments

Olley and Pakes (1996) recognize that firms choose their level of production and the number of inputs simultaneously, thus, inputs are econometrically endogenous. If one assumes each hospital maximizes profit subject to input wages and market demand for health services then each input can be written as a function of exogenous variables.

$$L_{ih} = f(w_i, w_{-i}, d_h, u_h) \quad (3)$$

where w_i is the wage of L_{ih}, w_{-i} are the wages of other inputs, d_h are demand shifters for hospital services, and u_h is a hospital specific component unobserved by the econometrician. These components of the labor demand function can be used as instruments for the inputs in the production function. [1]

[1] There exist an equilibrium problem in the labor market. The labor market for health professionals is much larger than the consumer market that each hospital serves. Without perfect information, health professionals are not able to solve local consumer demand functions and make wage offers to all hospitals in the different consumer markets. Therefore, the labor market need not clear.

The observable characteristics of agents in an MSA serve as instruments. Specifically, the characteristics of income per capita, population, and percentage with group health insurance, percentage of private health insurance, and percentage with a secondary health insurance per MSA are good instruments because they are correlated with the inputs as demand shifters, but are uncorrelated with the unobserved hospital specific error. Other agent characteristics such as sex, race, and age were considered as potential instruments, but were not highly correlated with the inputs.

Wage data is the source of another instrument. The mean wage per MSA for registered nurses and licensed practical nurses serve as instruments. The wages of physicians and medical residents could not be used as instruments because the PUMS data source for these wages classifies physicians and medical residents in the same category.

Lastly, a variable capturing the level of competition within a city is created from the cost data of each hospital. The instrument is constructed by dividing the total operation cost of each individual hospital TC_{ht} by the total operation cost of all hospitals within a city. The set of hospitals within city (i) is represented by H_i .

$$C_{ht} = \frac{TC_{ht}}{\sum_{k \in H_i} TC_{kt}} \quad (4)$$

The competition variable C_{ht} describes the level of concentration of health services hospital (h) has within a group of hospitals H_i . The competition variable is continuous between zero and unity. A value of one would represent a monopoly.

Section 4: Estimation strategy

The challenge of estimating this production function is simultaneously handling the endogeneity of the inputs and estimate the non specified function, $g(\cdot)$. To confront this difficulty, the parameters and $g(\cdot)$ of the production function are estimated simultaneously using two stage least squares with weights (2SLSW). As proposed by Ichimura (1993), the non-specified function for each hospital is assigned a numerical value by solving equation (1) for $g(\cdot)$.

$$\widetilde{Y}_{ht} \equiv \ln(Y_{ht}) - X_{ht}\theta - u_{ht} = g_{ht}(P_{ht}, R_{ht}, Pl_{ht}) \quad (1')$$

A kernel function places weights on each of these numerical values to estimate g(•).

$$\frac{\sum_{j\neq i}^{n}\tilde{Y}_j K\left(\frac{\ln(P_i)-\ln(P_j)}{b_p},\frac{\ln(R_i)-\ln(R_j)}{b_r},\frac{Pl_i-Pl_j}{b_{pl}}\right)}{\sum_{j\neq i}^{n}K\left(\frac{\ln(P_i)-\ln(P_j)}{b_p},\frac{\ln(R_i)-\ln(R_j)}{b_r},\frac{Pl_i-Pl_j}{b_{pl}}\right)}=\hat{g}_i(P_i,R_i,Pl_i) \quad (5)$$

The kernel function is equal to a tri-variate normal probability density function where the off diagonal elements in the covariance matrix are equal to zero. The bandwidths b_p, b_r, and b_{pl} are equal to the standard deviations of log (P), log(R), and PL, respectively. The variable n is the total number of observations.

One would normally proceed by minimizing a loss function over the parameters,θ.

$$\min_{\theta}\sum_{i=1}^{n}(\tilde{Y}_i-\hat{g}_i)^2$$

This estimation procedure is similar to minimizing the sum of squared errors. One can achieve the same results through a different method. Given that the kernel function does not contain parameters to be estimated, equation (5) can be rewritten in the following way.

$$\begin{aligned}\sum_{j\neq i}^{n}\tilde{Y}_j w_{ij} &= \hat{g}_i(P_i,R_i)\\ \sum_{j=1}^{n}w_{ij} &= 1\end{aligned} \quad (5')$$

Next, one can construct an nxn weight matrix where (i) indexes the rows and (j) indexes the columns. Each row contains the weights necessary to estimate g_i(•) and the sum of the weights in each row equal 1. The matrix can be read in the following way, w_{12} represents the weight placed on g_2(•) to estimate g_1(•).

$$W=\begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1n}\\ w_{21} & w_{22} & & \\ \vdots & & \ddots & \\ w_{n1} & & & w_{nn}\end{bmatrix}$$

The estimated vector, $\hat{g}(P,R,Pl)$ is constructed by multiplying the weight matrix, W, by the vector g(•). The error term drops out of equation (6) because the weight matrix simply takes a weighted average of the error, which has mean zero.

$$W\tilde{Y}=W(\ln(Y)-X\theta-u)=W(\ln(Y)-X\theta)=\hat{g}(P,R,Pl) \quad (6)$$

Replacing g(•) in equation (1) with $\hat{g}(P, R, Pl)$ and solving for the dependent variable reveals a simple linear regression equation.

$$(I - W)\ln(Y) = (I - W)X\theta + u \quad (7)$$

$$(I - W)\ln(Y) = V \quad (I - W)X = \widetilde{X}$$

$$V = \widetilde{X}\theta + u \quad (7')$$

Instrumental variables and two stage least squares techniques can be used on equation (7') in the traditional fashion to remove the endogeneity in X.

$$\hat{X} = Z(Z'Z)^{-1}Z'\widetilde{X} = Z(Z'Z)^{-1}Z'(I - W)X$$

$$\hat{\theta}_{2SLS} = (\hat{X}'\widetilde{X})^{-1}\hat{X}'V$$

The estimator gives consistent estimates of $\hat{\theta}_{2SLS}$.[2]

Section 5: Data

The data are from four sources: the American Hospital Association (AHA), March Current Population Surveys, Public Use Microdata Samples (PUMS), and Centers for Medicare & Medicaid Services (CMS). The AHA data provides annual hospital characteristics on the number of inpatient days, physicians, medical residents, registered nurses, licensed nurses, hospital beds, and other cost characteristics. A sample of both teaching and non-teaching hospitals was obtained for the years of 1987 and 1991. 1987 is selected as the starting year because it is sufficiently before the enactment of Section 405 in 1989 that the hospitals would not have adjusted their production decisions in anticipation of the law. These two samples provide a two-year panel dataset.

The number of inpatient days has been selected as a measure of output for each hospital. Inpatient days are not a perfect measure of production because it cannot be considered a completely homogenous good. Hospitals provide a wide range of services each at a different cost. Therefore, the level of care is not completely captured by the number of inpatient days.

[2] In the appendix I show how 2SLS and IV work in this framework.

To remedy this problem, I use the case mix index, as suggested by Jensen and Morrisey (1986), to weight the number of inpatient days for each hospital. The case mix index is a weighted sum of Medicare cost for different diagnostic service in a hospital. These sums are then normalized into an index where the average cost of health care service receives a value of 1. The level of care is captured by the cost of providing the service. Each hospital with a Medicare provider number is assigned a case mix value. Multiplying the case mix value by the number of inpatient days allows one to adjust output between hospitals into a more homogenous good. The case mix index is highly correlated with itself from year to year with a correlation coefficient of .97. Therefore, the 1992 case mix index is used to substitute the case mix indices of 1987 and 1991, which were not available. The case mix index is provided by CMS.

The instruments used in this project are obtained from the March CPS for the years of 1987 and 1991 as well as the 5% PUMS for the years of 1980 and 1990. The March CPS provides the percentage of households with group health insurance, with private health insurance, and with secondary health insurance in each MSA. The March CPS also provides average income for each MSA. Wages in 1987 and 1991 for the inputs are not readily available through AHA. Instead, the average earnings by MSA from the 5% PUMS in 1980 and 1990 is used. Physicians and medical residents are classified the same in the PUMS. For this reason, the average earnings of physicians are not used. The wages of medical residents are known, but have little variation over specialization or hospital. Therefore, medical resident wages are poor instruments. All measurements of income were adjusted into 1991 dollars using the CPI index provided by the US Bureau of Labor Statistics.

Section 6.1: Estimation Results

The performance of the semi-parametric model is compared against two alternative definitions of the production function, the Cobb Douglas Production function and the Translog Production function. The results of the Cobb Douglas production function are located in Table 4. Prior models assume that the endogeneity bias of the inputs is very small and statistically not significant. The Hausman test, using the instruments described earlier, finds that at least one variable is endogenous at α=.10 in the OLS regressions of the Cobb-Douglas function. The marginal product for a medical resident in this framework is close to zero. The Cobb-Douglas appears to perform poorly when estimating first-order effects of the inputs on production.

In contrast to the Cobb-Douglas production function, Jensen and Morrisey (1986) use a Translog production function where the inputs are physicians, residents, registered nurses, and hospital beds. An F-test is used to test the null hypothesis that input interactions and second order terms in the Translog function have coefficients equal to zero against the alternative that at least one is different from zero. The F-statistic is equal to 34.135, which rejects the null hypothesis at the 1% level of significance. This finding indicates that physicians and nurses are not additively separable.

The Jensen and Morrisey model contains mild multicollinearity in that the number of hospital beds can be well explained by the other inputs. When simply regressing the other inputs on the number of hospital beds, one finds an R^2 close to 80%. A hospital bed is capital that is fixed in the short-run, and variable in the long-run. Therefore, hospitals can choose various combinations of labor inputs that are variable in the short run to fit the quasi-fixed number of hospital beds. As described by the OLS 1 regression in Table 5, the marginal product of a medical resident is positive and statistically different from zero when hospital beds are removed from the production function. This result differs from Jensen and Morrisey (1986) who find medical residents have a marginal product of zero. In addition, the authors do not use any instruments to correct for bias in the estimated parameters.

Section 6.2: Estimation Results of Semi-parametric Production Function

The estimates of the parameters in the semi-parametric production function are found in table 6. All the inputs of production are found to be endogenous by the Hausman test when adjusting the number of inpatient days using the case mix index. Three variables are found to be endogenous when not adjusting the number of inpatient days. These results would suggest the OLS bias is larger than previously found in the literature. Table 7 displays the dominance the semi-parametric model has in estimating the marginal product of physicians and residents over the two parametric models, Cobb-Douglas and Translog. Both fully parametric models perform well when estimating the marginal product of physicians, but fail to produce realistic estimates of the marginal product of medical residents, where the highest value found is 1.6320 inpatients per day. The Translog production function rejects that nurses and physicians are additively separable, but the semi-parametric model does a much better job estimating the first order effects of medical residents. The marginal product values found by the semi-parametric production function more closely resemble the actual reported patient loads found in several residency programs of 10-15 patients. The 2SLS semi-parametric estimates provide marginal product values of 9.47 and 14.31, for physicians and medical residents, respectively, after adjusting inpatient days by the case mix index.

It is important to note that the adjusted inpatient days have given more weight to hospitals that provide more services such as teaching hospitals. Sloan and Valavona (1985) make the point that costs are found to be relatively higher at teaching hospitals than at non-teaching. In particular, teaching hospitals have higher costs because medical residents order more tests than are necessary as a learning experience. These additional tests do improve the quality of care, but also increase the cost of care. For these reasons it is expected that teaching hospitals would receive higher case mix index values. Therefore, the results presented in this study are focused on the activities at teaching hospitals and not hospitals in general.

The marginal product of a physician is found to be lower than that of a medical resident in the estimation results. These results are also driven by the characteristics of teaching hospitals. Physicians at teaching hospitals must dedicate a portion of their time to non-productive activities as teaching and research; thus, their marginal products are lower relative to medical residents, who do not have additional non-productive responsibilities.

The elasticity of substitution between physicians and medical residents is calculated, using both adjusted inpatient days and unadjusted inpatient days. A 1% increase in the number of physicians leads to a 4.768 (.23) decrease in the number of medical residents using case mix adjusted inpatient days. A 1% increase in the number of physicians leads to a 4.396 (.33) decrease in the number of medical residents using inpatient days as the dependent variable. Both values are evaluated at the mean, and the standard errors are in parentheses. In addition, the elasticity of substitution between physicians and registered nurses is -9 (1.31).

Section 6.3: How would hospitals react to a national restriction of resident work hours?

In this section, a counterfactual experiment is performed to evaluate the effects of a nationwide restriction on medical resident work hours. Using the estimated parameters, the marginal product for physicians and residents in each hospital is calculated setting the policy dummy variable, PL, equal to 1 for all hospitals. Next, the process is repeated but PL is equal to zero for all hospitals. The marginal product of physicians (residents) when PL is equal to zero is subtracted from the marginal product of physicians (residents) when PL is equal to one. This procedure obtains marginal product values for both physicians and residents in each hospital prior and post the implementation of the policy. These marginal product values can now be used to perform hypothesis testing.

The results of the hypothesis test, where the null states that marginal product of physicians (medical residents) remains the same after the policy against the alternative that the policy has decreased the marginal product of physicians (medical residents), can be found in table 8. The policy does improve marginal product of physicians at the 99% level of confidence. The increase in marginal product for physicians allows them to produce an additional 57 inpatient days, or an additional 30 case mix adjusted inpatient days, annually. The policy does decrease marginal product of the medical resident, but when using inpatient days as the output, the change in marginal product as a result of the policy is not statistically different from zero at the 95% level. The slight fall in marginal product for medical residents decreases the number of inpatient days by only 14 days annually, and decreases the number of case mix adjusted inpatient days by 44 days annually. The fall in casemix adjusted inpatient days could be attributed to the fall in unnecessary lab work because physicians, instead of medical residents, are ordering the tests. Experience physicians ask for fewer lab tests than medical residents thus decreasing costs associated with care.

Considering only inpatient days as a measure of production suggests that placing a work limit on residents does not harm their performance in a statistically significant way, thus leading to a Pareto improvement. The overall effect the policy has on production is inconclusive. The reform leads to a net gain in production of 43 inpatient days annually, but a loss of 14 case mix adjusted inpatient days annually when comparing the change in marginal products of physicians to medical residents. The annual change for case mix adjusted inpatient days appears to be small.

Section 7: Conclusion

Past models have placed a structural relationship on physicians and residents, as well as ignored that the inputs of the hospital production function are endogenous. By not removing the bias, authors have underestimated the marginal product of physicians and residents. A downward bias on the estimate of marginal product for medical residents suggest that there exist a negative correlation between the number of medical residents and the hospital specific error in production. This correlation most likely arises from the dual responsibilities of teaching residents and providing care in teaching hospitals. Time spent teaching a medical resident is time not spent on productive activities. This reasoning would lead to a decrease in production as the number of medical residents increase in teaching hospitals relative to non-teaching hospitals of the same size.

This paper presents an alternative method to estimate the hospital production function, which does produce estimates of marginal product that more resemble real world observations. Introducing a policy change into the production function allows the model to identify changes in substitution patterns between physicians and medical residents. Section 405 is a source of variation in hospital choice of input bundles that may not be captured by a well-defined structural model. The empirical evidence has shown that Section 405 has not hurt the marginal product of medical residents in the state of New York by a statistically significant margin, and has shown that this law may improve the productivity of physicians. The increase in productivity in physicians may be due to physicians working longer hours to regain the number of inpatient days loss by the work hour restriction on medical residents. The decrease in productivity for residents maybe minimized by an improvement in scheduling on the part of each hospital due to Section 405.

Finally, the results have implications on how teaching hospitals should respond to the nationwide reduction on resident hours. The work restriction should cause an increase in demand for residency positions in non-primary medical fields. The work hour restriction should cause a decrease in the average number of hours worked by non-primary medicine resident and should have little to no affect on the average hours worked by primary medicine residents.

Residency programs have contemplated increasing the number of years in their training programs to compensate for the loss of hours due to the reform; but the results presented would suggest that each resident actually receives relatively the same length of instructional time both prior and after the policy is in effect. An increase in the years of training will only lead to an increase in cost for the residency program, and will also reduce the supply of residents entering those programs. Graduating medical students will be discouraged from entering long residency programs because they will have to forgo an additional year of a full physicians salary and/or the start of a family. These are high opportunity costs for graduating medical students, who have already acquired much debt in the form of school loans, and who may have already forgone four years to start a family.

An alternative option is to increase the number of available slots to solve scheduling difficulties. The addition of one resident increases the flexibility of scheduling by 80 hours a week. Teaching hospitals and Medicaid would have to agree to increase funding for surgery residency programs in order to increase the number of available slots. If an agreement can be made the effects would be two fold. First, more residents would be available to ease scheduling difficulties. Second, the increase in the number of surgical residents will eventually lead to an increase in the number of surgeons and a decrease in the price of surgery. I would recommend continuing the use of the current admission process and possibly opening new slots for more demanding fields of specialization, such as surgery. After all, the reform is only calling to reduce the number of hours worked by a medical resident to a maximum of two full time jobs.

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Appendix
2SLS and IV in a semi-parametric framework

Our original equation is found below

$$(I - W)\ln(Y) = (I - W)X\theta + u$$

Let our dependent variable and explanatory variables be define as found below.

$$(I - W)\ln(Y) = V \quad (I - W)X = \widetilde{X}$$

Substituting these values into the first equation, we get a simple linear equation with no constant

$$V = \widetilde{X}\theta + u$$

Now using a set of suitable instruments Z, we project the explanatory variable onto Z making them exogenous

$$\hat{X} = Z(Z'Z)^{-1}Z'\widetilde{X} = Z(Z'Z)^{-1}Z'(I - W)X$$

Then the unbias linear estimator of the parameters can be found as

$$\begin{aligned}
\hat{\theta}_{2SLS} &= (\hat{X}'\hat{X})^{-1}\hat{X}'V \\
&= (X'(I-W)'Z(Z'Z)^{-1}Z'Z(Z'Z)^{-1}Z'(I-W)X)^{-1}X'(I-W)'Z(Z'Z)^{-1}Z'(I-W)\ln(Y) \\
&= (X'(I-W)'Z(Z'Z)^{-1}Z'(I-W)X)^{-1}X'(I-W)'Z(Z'Z)^{-1}Z'(I-W)\ln(Y) \\
&= (\hat{X}'\widetilde{X})^{-1}\hat{X}'V
\end{aligned}$$

When Z and X are of the same dimensions then our equation is just identified and we can reduce the 2SLS to an IV estimator.

$$\begin{aligned}
\hat{\theta}_{2SLS} &= (\hat{X}'\widetilde{X})^{-1}\hat{X}'V \\
&= (X'(I-W)'Z(Z'Z)^{-1}Z'(I-W)X)^{-1}X'(I-W)'Z(Z'Z)^{-1}Z'(I-W)\ln(Y) \\
&= (Z'(I-W)X)^{-1}Z'Z(X'(I-W)'Z)^{-1}X'(I-W)'Z(Z'Z)^{-1}Z'(I-W)\ln(Y) \\
&= (Z'(I-W)X)^{-1}Z'(I-W)\ln(Y) = \hat{\theta}_{IV}
\end{aligned}$$

TABLE 1

	Total Hours Duty per Week	Maximum Hours on Duty	Maximum Consecutive Shifts	Minimum Rest Hours	Minimum Continuous Off-Duty Hours
Australia	75 hrs/wk (Western and Victoria) 70 hrs/wk (Tasmania) 68 hrs/wk (South)	24 consecutive hours for a shift (Capital Territory)	N/A	N/A	N/A
Denmark	45 hrs/wk	N/A	N/A	11-8 hrs between shifts	55 hrs/wk
United Kingdom	72 hrs/wk	16 hrs a shift	12 regular shifts in a row	8 hrs between regular shifts 12 hrs after being on-call	N/A
European Union	48 hrs/wk including overtime	Night work must not exceed 8 hrs on average	N/A	N/A	N/A
Germany	56 hrs/wk	24 consecutive hrs max	12 consecutive on-call duty periods	10 consecutive hrs off after working more than 7.5 hrs	12 consecutive hrs when on-call
Netherlands	48 hrs avg/wk over 13 wks and 60 hrs max/wk	24 consecutive hrs max	5 shifts worked consecutively/wk for a max 13 wks in 26	10 consecutive hours between shifts	9 hrs rest for shifts < 15 hrs and 24 hrs rest for shifts >15 hrs

TABLE 2

DESCRIPTIVE STATISTICS				
VARIABLES	**MEAN**	**STD**	**MAX**	**MIN**
DEPENDENT				
INPATIENT DAYS	65337.7	72341.16	713754	128
CM*INPATIENT DAYS	95223.03	110605.61	918760	770.88
EXPLANATORY				
PHYSICIANS	12.8746	3.7563	832	2
RN	139.5601	3.3326	2507	1
LPN	25.0393	3.6450	390	1
RESIDENTS	5.7240	7.3721	909	1
BEDS	226.8910	2.5449	1979	6
POLICY	0.0755	0.2642	1	0
NY	0.1105	0.3136	1	0
TIME	0.2705	0.4443	1	0
INSTRUMENTS				
INCOME PER CAPITA	13582.01	2217.48	20702	5768.6
POP. OF SMSA (100,000)	41.66	55.68	194.80	1
RN WAGE IN 1991 $	20138.24	5227.27	29307	9183.1
LPN WAGE IN 1991 $	13756.66	3654.62	24655	4909.8
GROUP HEALTH INSURANCE	0.6106	0.0846	0.8029	0.3310
SECONDARY HEALTH INSURANCE	0.5277	0.2793	0.9270	0.0549
PRIVATE HEALTH INSURANCE	0.5197	0.2748	0.9278	0.0632

TABLE 3

DESCRIPTIVE STATISTICS FOR HOSPITAL IN THE STATE OF NEW YORK								
	1987				1991			
VARIABLES	**MEAN**	**STD**	**MAX**	**MIN**	**MEAN**	**STD**	**MAX**	**MIN**
DEPENDENT								
INPATIENT DAYS	142559	113803.7	695950	1235	133077.2	116361.9	695950	1235
CM*INPATIENT DAYS	180485.7	148696.3	838132.6	4386.49	171255.84	146145.17	838132.59	4386.49
EXPLANATORY								
PHYSICIANS	57.13	80.2	538	2	48.34	75.44	523	2
RN	310.37	315.77	1709	7	259.27	292.51	1709	7
LPN	49.52	43.57	280	2	44.07	41.10	280	2
RESIDENTS	120.76	150.78	804	2	116.32	156.5819	804	2
BEDS	396.48	312.42	1789	15	351.5714	303.92	1789	15
INSTRUMENTS								
INCOME PER CAPITA	13487.36	1802.04	17585	9214.2	14330.66	2099.7	20702	6846.8
POP. OF SMSA (100,000)	113.99	91.95	194.80	1	106.19	92.94	194.80	1
RN WAGE IN 1991 $	21356.47	6680.68	28629	10822	25257.89	3985.23	28629	15838
LPN WAGE IN 1991 $	14806.17	4285.48	19917	6317.2	17212.32	2807.93	19917	10877
GROUP HEALTH INSURANCE	.5784	.1051	.8232	.409	.5816	.1130	.8232	.4092
SECONDARY HEALTH INSURANCE	.4939	.2792	.9612	.0677	.6746	.1267	.9612	.4852
PRIVATE HEALTH INSURANCE	.4722	.2602	.9245	.0846	.6414	.1146	.9245	.4976

TABLE 4

COBB DOUGLAS PRODUCTION FUNCTION								
DEPENDENT	INPATIENT DAYS				INPATIENT DAYS *CM			
	OLS		2SLS		OLS		2SLS	
Variables	1	2	1	2	1	2	1	2
Constant	7.5825*** (.0248)	4.9789*** (.0241)	7.1213*** (1.1749)	5.4860*** (2.3093)	7.5294*** (.0350)	4.8553*** (.0373)	6.6114*** (2.3741)	4.8121*** (1.8040)
Physicians	.0938*** (.0061)	.0128*** (.0034)	.0422 (.1984)	-.0295 (.1937)	.1004*** (.0085)	.0128** (.0056)	.1438 (.1644)	.1203 (.1494)
Residents	.0086 (.0063)	-.0133*** (.0035)	.0965 (.1283)	.1244 (.1268)	.0023 (.0075)	-.0082 (.0051)	-.0486 (.1521)	-.0189 (.1431)
Registered Nurses	.5563*** (.0078)	.0619*** (.0057)	.6775*** (.1353)	.3859 (.4171)	.5907*** (.0064)	.1510*** (.0090)	.7991*** (.2585)	.2294 (.3551)
Licensed Nurses	.1484*** (.0071)	.0060 (.0041)	.1276 (.1018)	.0573 (.1185)	.1160*** (.0086)	-.0028 (.0060)	.0450 (.1664)	.0047 (.1549)
Time	-.0513*** (.0220)	-.1579*** (.0120)	-.2760* (.1554)	-.3608*** (.1557)	-.0650** (.0340)	-.1826*** (.0208)	-.1861 (.2490)	-.3590* (.2091)
Policy	.3514*** (.0456)	.2663*** (.0257)	.4766 (.6609)	.5676 (.7800)	.3057*** (.0518)	.2647*** (.0319)	.2856 (.4622)	0.5742 0.5024
Residents x Policy	-.0285 (.0177)	-.0279*** (.0097)	-.1462 (.2538)	-.2070 (.2799)	-.0320* (.0178)	-.0484*** (.0121)	-.0473 (.1939)	-.2668 (.2066)
Hospital beds		1.0739*** (.0081)		.6351 (.5192)		1.0736*** (.0130)		.9325** (.4273)
R^2	.7235	.9186			.7874	.9269		
Hausman Test			3.190*[a]	5.226*[b]			2.3149	1.887
N	8061	7410	3443	3197	3725	3562	1502	1458

*Significant at the 90% level
**Significant at the 95% level
***Significant at the 99% level
[a]one endogenous variable
[b]two endogenous variables

TABLE 5

TRANSLOG PRODUCTION FUNCTION (OLS)				
DEPENDENT	INPATIENT DAYS		INPATIENT DAYS * CM	
VARIABLES	1	2	1	2
Constant	8.23*** (.1204)	3.8775*** (.0964)	8.1265*** (.0848)	6.6882*** (.0741)
Physician	-.238*** (.0449)	-.1235*** (.0215)	.3677*** (.0533)	.1179*** (.0364)
Registered Nurse	.2583*** (.068)	.4124*** (.0270)	.2671*** (.0368)	.7735*** (.0307)
Licensed Nurse	.36245*** (.045)	.0599*** (.0224)	.0409 (.0343)	.0663** (.0307)
Medical Resident	.2425*** (.05)	-.0171 (.0279)	.1211** (.0586)	-.0265 (.0393)
PHY^2	-.0272*** (.006)	-.0162*** (.0023)	.0100 (.0062)	-.0172*** (.0042)
RN^2	.049*** (.001)	.0532*** (.0031)	.0581*** (.0023)	.0084** (.0043)
LN^2	.0508*** (.0067)	.0083*** (.0023)	.0403*** (.0051)	-.0048 (.0037)
RES^2	.0094 (.006)	.0071*** (.0024)	.0003 (.0059)	.0163*** (.0039)
PHY*RN	-.0148*** (.0012)	-.0095** (.0043)	-.0729*** (.0068)	.0545*** (.0067)
PHY*LN	.0638*** (.0045)	-.0050* (.0027)	.0298*** (.0070)	-.0027 (.0048)
PHY*RES	-.0057* (.007)	-.0004 (.0018)	-.0088* (.0046)	.0024 (.0031)
RN*LN	-.1055*** (.0012)	.0291*** (.0043)	-.0264*** (.0068)	.0355*** (.0068)
RN*RES	-.0165* (.0050)	.0049 (.0050)	.0019 (.0072)	-.0483*** (.0070)
LN*RES	-.0395*** (.0043)	-.0037 (.0025)	-.0322*** (.0061)	-.0121*** (.0041)
TIME	-.072*** (.0275)	-.1498*** (.0118)	-.1091*** (.0354)	-.1848*** (.0231)
POLICY	.1200 (.0817)	.1113*** (.0375)	.1464 (.0970)	.1746*** (.0628)
RES*POLICY	-.0073 (.0187)	-.0172*** (.0087)	-.0370** (.0189)	-.0502*** (.0123)
NY	.187*** (.063)	.1441*** (.0279)	.1721** (.0823)	.0962* (.0533)
BEDS		1.2624*** (.0408)		-.2768*** (.0209)
$BEDS^2$		.0524*** (.0029)		.2206*** (.0021)
BEDS*PHY		.0492*** (.0045)		-.0618*** (.0051)
BEDS*RN		-.1700*** (.0074)		-.1624*** (.0063)
BEDS*LN		-.0411*** (.0050)		-.0389*** (.0066)
BEDS*RES		-.0046 (.0055)		.0480*** (.0051)
R^2	.737	.9242	.7980	.9756
N	8061	7410	3725	3725

The standard errors are found in the parentheses.

*Significant at the 90% level **Significant at the 95% level ***Significant at the 99% level

TABLE 6

SEMI-PARAMETRIC ESTIMATION OF THE HOSPITAL PRODUCTION FUNCTION				
DEPENDENT	INPATIENT DAYS		INPATIENT DAYS * CM	
VARIABLES	LEAST SQUARES	2SLS	LEAST SQUARES	2SLS
RN	-.0370 (.0822)	1.2394 (1.2989)	.1631 (.1418)	.4640 (1.4102)
LPN	.6275**** (.0523)	-1.7326 (1.4248)	.3183**** (.0813)	-3.134**** (1.5335)
RN*RN	.0851**** (.0031)	-.1843**** (.0437)	.0563**** (.0043)	-.1852**** (.0394)
LPN*LPN	.0457**** (.0065)	-.0567 (.1726)	.0393**** (.0085)	-.0728 (.0832)
RN*LPN	-.1287**** (.0082)	.4296* (.2293)	-.0761**** (.0107)	.6479**** (.1091)
TIME	-.0759**** (.0305)	-.1432* (.0801)	-.1020**** (.0458)	-.1376** (.0705)
NY	.2720**** (.0395)	.1838 (.1487)	.2334**** (.0663)	.2605* (.1414)
Hausman Test	7.3931*[a]		15.1258***[b]	
N	1687	1687	1502	1502

The standard errors are found in the parentheses.
*Significant at the 90% level
**Significant at the 95% level
***Significant at the 97.5% level
****Significant at the 99% level
[a]three endogenous variables
[b]five endogenous variables

TABLE 7

MARGINAL PRODUCT OF PHYSICIANS AND MEDICAL RESIDENTS BY INPATIENT DAYS PER DAY				
DEPENDENT	INPATIENT DAYS		INPATIENT DAYS * CM	
MODELS	PHYSICIANS	RESIDENTS	PHYSICIANS	RESIDENTS
COBB DOUGLAS				
OLS (1)	1.5253	.091	8.9219	.2043
OLS(2)	.2081	-.1198	1.1420	-.7284
2SLS(1)	.6882	.991	12.8297	-4.3174
2SLS(2)	-.4797	1.3184	10.7330	-1.6790
TRANS LOG				
OLS (1)	.511	.120	9.827	1.6320
OLS(2)	3.287	-.1519	3.0283	-2.080
SEMI-PARAMETRIC				
LEAST SQUARES	1.5956	1.9101	1.8058	1.101
2SLS	8.7068*** (21.1195)	16.9233*** (14.5475)	9.4698*** (13.1027)	14.3058*** (8.0926)

T statistics are in parentheses testing the null that marginal product is zero.
***Significant at the 95% level

TABLE 8

THE EFFECT THAT THE POLICY HAS ON MARGINAL PRODUCT				
The null hypothesis is the policy has no effect on marginal product against the alternative that the policy increases marginal product.				
DEPENDT VARIABLE	INPATIENT DAYS		CM*INPATIENT DAYS	
2SLS Model	PHYSICIANS	RESIDENTS	PHYSICIANS	RESIDENTS
Mean annual improvement in marginal product	56.637***	-13.572	29.5974***	-44.0046***
T statistic	10.6035	-1.7131	4.3760	-3.4814

***Significant at the 95% level