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Abstract

This is the first study to specify a physician practice cost function with practice costs as the unit of analysis. Our study is based on the data of 3,706 physician practices for the years 2006 to 2008. We propose a model using physician practices as the unit of observation and considering the endogenous character of physician input. In doing so, we apply a translog functional form and include a comprehensive set of variables (e.g., degree of specialisation and case-mix) that have not been previously used in this context. A system of four equations using three-stage least squares is estimated. We find that a higher degree of specialisation and participation in disease management programs and gatekeeper models leads to a decrease in costs, whereas quality certification increases costs. Costs increase with the number of physicians, most likely because of the existence of indivisibilities of expensive technical equipment. Smaller practices might not reach the critical mass to invest in certain technologies, which leads to differences in the type of health care services provided by different practice types.

Keywords: physician practice cost function, three-stage least squares, specialization, economies of scale

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1. Introduction

For inpatient care, many prospective payment systems in developed countries rely on information from studies on hospital cost functions (Busse et al., 2006). There is a large body of literature on hospital cost functions and productivity that began in the 1960s. Recent studies in this sector have focused on specific aspects, such as the influence of research activity on hospital costs and the length of stay (Bonastre et al., 2011; Farsi and Filippini, 2008). Additionally, countries increasingly maintain their own hospital cost panels to facilitate the country-specific design of prospective payment systems (Schreyögg et al., 2006). However, relatively little is known about the behaviour of physician practice costs and productivity. Physician payment systems are seldom based on information from physician cost functions. Payment rates are often based on very small cost samples or are simply driven by political considerations. The danger of this approach is that it may lead to unintended incentives of physician payment rates. Thus, understanding the behaviour of physician practice costs and productivity is important, both for providing evidence-based physician payment systems and to enable decision makers to set incentives in the intended manner.

Studies on physician practice cost functions or productivity are scarce, and they have limitations regarding data and methodology. In addition to data limitations, most studies are limited by the inappropriate treatment of physician inputs. Because of the self-employed status of physicians who own a practice, we cannot directly observe a wage for the time that a self-employed physician spends working in his or her practice. Although Escarce and Pauly (1998) have developed a theoretical model, which has been estimated empirically by Gunning and Sickles (2011), to address this latter limitation, several challenges remain unsolved. In particular, previous studies use physicians rather than practices as the unit of observation and are confined to a cross-sectional perspective only. Moreover, important components for cost functions that are regularly used for the estimation of hospital cost functions, e.g., measures of specialisation and case-mix, have not been considered thus far.

In this paper, we propose and estimate a comprehensive physician practice cost function to address limitations of previous papers. We propose a model: (1) using physician practices as the unit of observation, (2) considering the endogenous character of physician input building on the model proposed by Escarce and Pauly

(1998). Thus, we estimate a system of four-equations using three-stage least squares (3) using panel specifications throughout the equations and (4) employing a number of variables commonly used for hospital cost function estimations, e.g. case-mix, to improve the specification of the physician practice cost function.

The paper is structured as follows. The second section presents previous literature and identifies research gaps. The third section presents the data that we use. The fourth section elaborates on our model and estimation strategy. The fifth section presents and discusses our findings, and the final section draws a range of conclusions.

2. Previous Literature

In general, there are three types of studies that deal with physician practice costs and productivity in the outpatient sector. The first type of study estimates production functions of physician practices. The production study by Reinhardt (1972) is the seminal work in this field. The main objective of Reinhardt's paper was the investigation of influence factors (e.g., the organisational form of the practice) on the average productivity of the physician. Thurston and Libby (2002) revisited Reinhardt's (1972) study and estimated a generalised linear production function proposed by Diewert (1971), which allowed the estimation of q-complementarities of different types of inputs (e.g., physician and non-physician labour input or capital).

The second type of study focuses on efficiency or productivity of physicians or physician practices. Early studies of this type, such as those by Frech and Ginsburg (1974) and Marder and Zuckerman (1985), performed a survivor analysis to detect the most efficient practice size. Various other studies focusing on efficiency estimated physician production frontiers (DeFelice and Bradford, 1997; Gaynor and Pauly, 1990) or used other methods to estimate the efficiency of different practices (Ozcan, 1998; Rosenman and Friesner, 2004) and to detect factors that influence efficiency, such as compensation arrangements, the organisational form of the practice (i.e., solo vs. group practices) or the practice's specialisation (i.e., single vs. multispecialty practices). Further studies analysed the effect of these factors on the productivity of physicians (Pope and Burge, 1996).

The third type of study estimates physician cost functions. Early studies of this type, such as those of Pope and Burge (1995), have been characterised by problems with data and methodology. One common problem of these studies is that they deal with the lack of a price for the labour input of a self-employed physician by the inclusion of physician time as a proxy for price. Escarce and Pauly (1998) were the first to take into account the problem of the endogenous character of physician labour input in the estimation of physician cost functions. As in previous studies (Gaynor and Pauly, 1990) the authors assume that physicians (i.e., practice owners) maximise their utility depending on net income and leisure. They showed that under this assumption, physician labour input is endogenous, and conventional measures of marginal costs and economies of scale are problematic. The authors proposed a framework for a more precise estimation of physician cost functions. They illustrated their model based on the American Medical Association (AMA) Physician Socioeconomic Monitoring Survey (SMS). Escarce and Pauly (1998) stated that the results of their study should not be the basis for policy implications, as the usefulness of the SMS for the estimation of physician practice cost functions is limited for a number of reasons. For instance, it is based on a telephone survey and focuses on physicians rather than practices. Other physician practice cost surveys suffer from similar shortcomings. Gunning and Sickles (2011) re-estimated the results based on an update of the SMS for 1998.

Both studies have a number of limitations. First, they were based on the individual physician as the unit of observation, although a given practice may have several physicians, and there may be substitution effects between the owner and other employed physicians of the same practice. Second, previous studies were not able to use output data at the practice level, which led to a downward bias of coefficients. Third, the employed information in the cost function estimation was largely limited by the dataset used. Because of the lack of output data, case-mix measures could not be developed. Thus, it is likely that certain variables effectively absorb the effect of unmeasured severity and again lead to downward bias. Additionally, other variables such as specialisation, which is commonly used in hospital cost function estimations, could not be used. Finally, the mentioned studies were confined to cross-sectional estimations.

Our proposed model to estimate a physician practice cost function goes beyond the works of Escarce and Pauly (1998) and Gunning and Sickles (2011) in several ways. First, this is the first study to estimate a physician practice cost function. Thus, we incorporate the level of the physician practice and its characteristics as well as the level of the physicians and their characteristics. Second, we employ a panel specification to improve the efficiency of our estimates. Third, we estimate separate models for general practitioners and specialists, as there is reason to believe that cost functions vary systematically between them. Fourth, we include measures to control for case-mix and specialisation, which we expect to improve the consistency of the estimates. Finally, we employ additional covariates at the practice level that are commonly used in hospital cost functions.

3. Data

The data for our study were obtained from the survey of practice costs and the medical care structure of the Research Institute of the National Association of Statutory Health Insurance Physicians of Germany. The Association of Statutory Health Insurance Physicians represents all physicians in Germany with an authorisation to treat patients with statutory health insurance, who constitute about 85% of the German population. The Institute's survey contains detailed information on inputs (i.e., physician labour input, subdivided into different categories as working hours inside and outside the practice; full-time equivalents of different types of staff; area of the practice and the technical equipment), on outputs (i.e., the quarterly number of cases treated for all patients with statutory health insurance and the share of privately insured patients treated) and on revenues and costs of different cost categories (e.g., staff costs, rental charges, laboratory costs, depreciation or insurance fees), each of which is measured at the practice level. In addition, the survey contains detailed information on practice characteristics, including the year of founding of the practice, the organisational form of the practice, participation in disease management programs or quality certification. It also contains physician characteristics for the owners of the practice for the years 2006 through 2008.

To obtain the data, the Research Institute sent questionnaires to 30,000 physician practices and ensured that the relative number of questionnaires sent to physicians in specific regions and of specific specialties corresponded to the respective relative number of physicians in specific regions and of specific specialties. Among the regions and specialties, practices were chosen randomly. In 2010, practices were asked to provide information for 2006 through 2008. Moreover, the data were validated by a tax advisor for most practices (93.8% of all provided data). In total, 4,664 questionnaires for the entire study period (i.e., 2006 through 2008) were returned to the institute.

However, not all practices completed the questionnaire for all years, as in some instances the practices were founded in 2007 or 2008. After plausibility checks were conducted, an average of 4,339 physician practices remained in the sample. As the responses of many practices were incomplete, we performed a missing values imputation for some variables. All values are presumed to be missing at random (MAR). We account for the missing values by using multiple imputation, as single imputation leads to an underestimation of the variance of the subsequent estimates based on the imputed sample (Briggs *et al.*, 2002). Similar to other studies, we performed five imputations (Grieve *et al.*, 2010; Wagner *et al.*, 2001). We chose to use the Monte Carlo Markov Chain (MCMC) (Schafer, 1997) as the method of imputation.

The final dataset consists of responses from an average of 3,706 physician practices for 2006-2008 (unbalanced panel) of 33 different specialties and two comprehensive practice types (i.e., physicians working in practices that include different types of specialties). The number of practices between the original and the final sample is different because we only imputed those variables with the highest rate of missing values. Thus, we lost some practices because of missing values. To increase the comparability of the physician practices in our sample, we divide the entire sample into the following two subcategories: general practitioners and specialists.

4. Methodology

4.1. Variables

Originally, cost functions consist of outputs and input prices. Previous studies have often added a range of other explanatory variables, e.g., patient characteristics, such as the proportion of patients with different types of insurance policies, or organisational characteristics, such as the number of physicians in the practice. The descriptive statistics of all variables included in our cost function (except of the dummy variables for different specialties) are shown in Table I.

Table I. Summary statistics

	General practitioners		Specialists	
Variable	Mean	SD	Mean	SD
Total costs	173,073.60	124,964.00	189,022.70	308,325.30
Physician time per year	2,451.59	488.33	2,393.35	472.81
Outputs				
Cases treated per year	4,688.62	2,648.48	4,203.79	3,508.07
Input prices				
Price for office space[a]	123.41	63.27	131.12	75.06
Price for labour[b]	42,984.95	121,508.40	44,210.12	232,155.60
Physician characteristics				
Years of experience	17.45	8.36	14.36	7.04
Female	0.27	0.44	0.38	0.48
Age	54.09	6.98	52.79	6.69
Children	0.03	0.18	0.05	0.21
Practice characteristics				
Case-mix index	1.01	0.08	0.99	0.34
Number of physicians	1.50	0.81	1.31	0.77
Number of owners	1.44	0.67	1.25	0.65
Proportion of physician FTEs	0.06	0.86	0.04	0.84
Degree of specialisation	0.10	0.05	0.18	0.10
Participation in DMPs[c]	0.81	0.39	0.15	0.36
Participation in gatekeeper models	0.42	0.49	0.01	0.12
Quality certification	0.12	0.33	0.12	0.33
Further education	6.00	4.99	7.19	5.39
Share of statutory insured patients (%)	80.10	26.77	81.39	23.47
Urban area (%)	36.68	-	31.60	-
Urbanized area (%)	39.26	-	37.82	-
Rural area (%)	24.05	-	30.58	-

a price per square metre per month; b price per month; c DMP = disease management program

The dependent variable of our cost function is the total cost of the physician practice, including estimations for rental charges if the physician owned the practice. Various independent variables are part of our cost function. The output measure is the number of cases treated for patients with statutory health insurance. Moreover, input prices for labour, i.e., for all practice staff except of the practice owner(s), and office space are included in our cost function. These prices were not part of the dataset, and they had to be calculated. In calculating the price of office space, rental charges or estimated rental charges (if the physician owned the practice) and associated costs (e.g., expenditures for heating) were divided by the area of the practice in square metres. The price for labour was created by the division of all expenses for labour by the total number of full-time equivalents of all staff categories [except the owner(s)]. The calculation of different prices for subgroups of staff was not possible, as labour costs for subgroups of staff were not part of our dataset. To control for differences in the composition of staff of different practices, we included the proportion of full-time equivalents (FTEs) of employed physicians (i.e., FTEs of employed physicians in relation to FTEs of all categories of employed staff) as a variable in our cost function. All other input prices (e.g., the prices of medical supplies or equipment) were assumed not to vary geographically. Moreover, we included the physician labour input (i.e., the time input of the owner of the practice) in our cost function as a proxy for the opportunity costs of the self-employed owner, and we address possible endogeneity bias resulting from the inclusion of this variable. Other proxies for opportunity costs, such as the hourly wage of salaried physicians in the respective market area, are problematic because of a number of reasons (Escarce and Pauly, 1998). For instance, salaried physicians and self-employed physicians may differ in unobserved characteristics.

To develop a physician practice cost function, we included further explanatory variables. One key variable of interest is the size of the practice. Following other studies on physician cost functions (Escarce and Pauly, 1998; Gunning and Sickles, 2011; Pope and Burge, 1995), we included the number of physicians per practice (i.e., the sum of owners and the FTEs of employed physicians) as a measure of practice size in our cost function. Moreover, we also included the square of the number of physicians as a variable. A second variable of interest is the degree of specialisation of the practice, which is defined as the degree to which a practice focuses on certain services or procedures. To determine the degree of specialisation, we used the Hirschman-Herfindahl index (HHI) which is the sum of the squared proportions of all different services or procedures executed by the practice of all services or procedures executed. Regarding the inpatient sector, previous studies (Dayhoff and Cromwell, 1993; Zwanziger *et al.*, 1996) used the HHI as a measure of the degree of specialisation. Moreover, we added a dummy variable for participation in nationwide uniformly defined disease management programs (Busse, 2004) and a dummy variable for participation in gatekeeper programs. Gatekeeper programs offer bonuses to patients if they restrict themselves to always attending a general practitioner (GP) before they may be referred to specialists, which is not mandatory in Germany. Dummy variables for the existence of quality certification and the number of days of professional development for each owner are added as proxies for higher structural quality that a practice provides.

As only patients insured by statutory health insurance could be included as output variables, we control for the relative number of patients with statutory health insurance treated by each practice. Other control variables are the geographic location [i.e., urban areas (cities with more than 100,000 inhabitants), urbanized areas (more than 150 inhabitants per square kilometre) or rural areas (less than 150 inhabitants per square kilometre)] and the specialty of the physician practice.

Finally, we also include a case-mix index variable in our cost function to control for differences in patient severity. For the calculation of the case-mix index, the resource use of each physician practice was predicted by means of a regression based on the diagnoses made by the respective practice. In doing so all 80 diagnoses of the German Risk Structure Compensation scheme were incorporated. To create the case-mix index variable, the predicted average resource use value of each practice was divided by the average of the predicted resource use of all practices of the same specialty.

4.2. Functional form and estimation strategy

Griffin *et al.* (1987) provided a detailed overview of the characteristics of different production functions and proposed several criteria for the choice of functional forms. We applied the criteria and decided to specify the cost function as a translog functional form, which was introduced by Christensen *et al.* (1973). A disadvantage of this functional form is its inability to deal with observations that contain zero levels for any output included in the cost function (Vita, 1990). However, this is not of relevance in our case, as we estimate a single-output cost function with no zero values for output. The translog functional form and variations of this function have been applied in hospital cost studies (Bilodeau *et al.*, 2000; Conrad and Strauss, 1983; Cowing *et al.*, 1983) and in physician cost studies (Escarce and Pauly, 1998). As an alternative, we estimate other functional forms, such as the Leontief function, which was proposed by Diewert (1971) and applied to hospitals by Li and Rosenman (2001) and to physician practices by Gunning and Sickles (2011). However, because of the skewed distribution of the dependent variable, the translog functional form is identified as the most appropriate form for our dataset. Linear homogeneity in input prices is generated by imposing constraints on the sum of certain coefficients prior to the estimation, and symmetry is achieved by construction[1]. As proposed by Escarce and Pauly (1998), we jointly estimate a cost function and an equation of physician labour input. The cost function is:

$$\ln C_{it}\,(y_{it},\, p_{it},\, T_{it}) = \alpha_0 + \sum_{k=1}^{2} \alpha_k \ln p_{k,it} + \alpha_3 \ln y_{it} + \alpha_4 \ln T_{j,it} +$$

$$0.5 \sum_{k=1}^{2} \sum_{l=1}^{2} \alpha_{kl} \ln p_{k,it} \ln p_{l,it} + \gamma_k \ln y_{it} \sum_{k=1}^{2} \ln p_{k,it} + \quad (1)$$

$$0.5\ \delta \ln y_{it} \ln y_{it} + \sum_{k=1}^{m} \zeta_k Z_{k,it} + u_t + \varepsilon_{it}$$

, where C_{it} is physician practice costs for practice i at time t, $p_{k,it}$ is the price for input, k, y_{it} is the number of cases treated for all patients with statutory health insurance, $T_{j,it}$ is physician time of physician j, $Z_{k,it}$ are our variables of interest and a set of further control variables, u_t is a year fixed effect and ε_{it} is the error term of the practice.

The equation for physician labour input is:

$$\ln Tj_{,it}\,(y_{it},\, p_{it}) = \beta_0 + \sum_{k=1}^{2} \beta_k \ln p_{k,it} + \beta_3 \ln y_{it} +$$

$$\frac{1}{2} \sum_{k=1}^{2} \sum_{l=1}^{2} \beta_{kl} \ln p_{k,it} \ln p_{l,it} + \theta_k \ln \mathrm{y}it \sum_{k=1}^{2} \ln p_{k,it} +$$

$$\frac{1}{2} \lambda \ln y_{it} \ln y_{it} + \sum_{l=1}^{m} \varsigma_l Z_{l,it} + \sum_{k=1}^{m} \varphi_k X_{k,it} + u_t + \varepsilon_{it} \quad (2)$$

, where $Tj_{,it}$, $p_{k,i,t,}$, y_{it}, $Z_{k,it}$, u_t and ε_{it} are the same variables as in our cost function. The variables included in $X_{k,it}$ are the instrumental variables of our estimation. We choose

[1] Linear homogeneity in input prices and symmetry were achieved by the following restrictions: $\alpha_{kl} = \alpha_{lk}$;
$\sum_{k=1}^{2} a_k = 1$; $\sum_{l=1}^{2} \alpha_{kl} = 0$; $\sum_{k=1}^{2} \gamma_k = 0$ for all k, l

the variables years of experience, age, sex and a dummy variable for the interaction of being female and being between ages 35 and 44 as a proxy for having young children. All of these variables are expected to influence physician time and to not be correlated with costs.

We estimate the physician cost function and labour equation in a system of four equations, including factor demand functions of labour input and office space, to improve the efficiency of the estimates. The four equations are estimated using three-stage least squares (3SLS). To account for correlation within physician practices, the regression is conducted using a sandwich variance estimate (Lin and Wei, 1989). As shown by Hardin (2002), this estimator is also robust for two-stage models.

To obtain measures for marginal costs, we derived our cost function with regard to the output variable and multiplied the result by the quotient of C_{it} and Y_{it}. We calculated economies of scale as follows:

$$S = \frac{1 - \frac{\partial \ln C_{it}}{\partial \ln T_{j,it}}}{\frac{\partial \ln C_{it}}{\partial \ln y_{it}}} \qquad (3)$$

,where S is the maximal rate of increase in the practice's output as all inputs (including the time of the owner) increase proportionally. A value of S greater than unity implies that a proportional increase in all inputs leads to a larger than proportional increase in outputs.[2]

5. Results and Discussion

Results of our regression analyses of general practitioners are presented in Table II, and results for specialists are presented in Table III. For both subgroups, at least two instrumental variables each meet the criteria proposed in the literature that the F-statistic be higher than 10 for the first equation and lower than 10 for the second equation (Staiger and Stock, 1997). Marginal costs are estimated to be 16.41 € for

[2]For further details please see Escarce and Pauly (1998).

general practitioners and 19.09 € for specialists. Economies of scale for both subgroups are greater than unity. For general practitioners, the value for S is 0.702, which indicates that a 10% increase in output leads to a 14.24% increase in cost. For specialists, the value is 1.860, which indicates that a 10% increase in output leads to a 5.37% increase in cost. Thus, specialists could reduce their cost per case if they increased the number of cases treated.

Table II. 3SLS Regression Results – General Practitioners

Explanatory variable	Cost function		Labour input equation	
Physician time per year[a]	0.7643	***		
Output				
Cases treated[a]	0.8803	***	-0.1572	
Input prices				
Price for office space[a]	-0.3028	*	-0.6007	**
Price for labour[a]	1.3028	***	-0.5801	***
Interaction terms				
0.5*Price for office space[2a]	0.0843	***	-0.0139	
0.5*Price for labour[2a]	-0.0239	*	0.0097	
Price for office space[a]*Price for labour[a]	-0.0604	***	0.0612	*
Cases treated[a]*Price for office space[a]	0.0807	***	0.0046	
Cases treated[a]*Price for labour[a]	-0.0807	***	0.0268	
0.5*Cases treated[2a]	-0.0132		0.0040	
Physician characteristics				
Years of experience			-0.0078	**
Female			-0.1527	***
Practice characteristics				
Case-mix index	0.6880	***	0.2293	**
Number of physicians	0.5422	***	-0.1390	***
Number of physicians[2]	-0.0430	***	0.0143	***
Proportion of physician FTEs	-0.0656	***	-0.0046	
Degree of specialisation	-1.4827	***	-0.2080	
Participation in DMPs[b]	-0.0058		-0.0226	
Participation in gatekeeper models	-0.0772	***	0.0160	
Quality certification	0.0912	***	0.0866	***
Further education	0.0062	**	0.0069	***
Share of statutory insured patients	-0.0003		0.0001	
Type of region[c]				
Rural area	-0.0905	***	0.0654	***
Urbanized area	-0.0512	**	-0.0047	
Year [d]				
2007	-0.0024		0.0001	
2008	-0.0074		-0.0023	
Constant	-7.0533	***	12.3224	***

*p≤0.10; **p≤0.05; ***p≤0.01
a logged values
b DMP = disease management program
c reference category: urban area
d reference category: 2006

Table III. 3SLS Regression Results – Specialists

Explanatory variable	Cost function		Labour input equation	
Physician time per year[a]	0.2298	*		
Output				
Cases treated[a]	-0.0739	*	0.1655	***
Input prices				
Price for office space[a]	0.6426	***	0.0314	
Price for labour[a]	0.3574	***	0.0112	
Interaction terms				
0.5*Price for office space[2a]	0.0729	***	-0.0007	
0.5*Price for labour[2a]	-0.0181	***	-0.0033	
Price for office space[a]*Price for labour[a]	-0.0548	***	0.0075	
Cases treated[a]*Price for office space[a]	-0.0283	***	-0.0126	***
Cases treated[a]*Price for labour[a]	0.0283	***	-0.0015	
0.5*Cases treated[2a]	0.0444	***	-0.0051	*
Physician characteristics				
Age			0.0016	***
Children			-0.1077	***
Practice characteristics				
Case-mix index	0.0478	***	-0.0072	
Number of physicians	0.2693	***	-0.0933	***
Number of physicians[2]	-0.0060	***	0.0073	***
Proportion of physician FTEs	0.0207	**	0.0052	*
Degree of specialisation	-0.3800	***	-0.0768	*
Participation in DMPs[b]	-0.0442	***	0.0240	***
Quality certification	0.1096	***	0.0193	***
Further education	0.0037	***	0.0056	***
Share of statutory insured patients	-0.0006	***	-0.0001	
Type of region[c]				
Rural area	-0.1118	***	0.0110	**
Urbanized area	-0.0211	**	0.0110	**
Year[d]				
2007	0.0003		-0.0018	
2008	0.0083		-0.0030	
Constant	3.6762	***	6.7319	***

*p≤0.10; **p≤0.05; ***p≤0.01
a logged values
b DMP = disease management program
c reference category: urban area
d reference category: 2006
Dummy variables for the different specialties were part of the regression but are not displayed here.

The coefficient for the practice’s number of physicians is positive and highly significant ($p \leq 0.01$) for general practitioners (0.5422) and specialists (0.2693), which indicates that one additional physician increases costs by 54.22% for general practitioners and by 26.93% for specialists, whereas the coefficient for the squared number of physicians is negative and highly significant for both subgroups. Moreover, we also estimate the same regression with the number of physicians included as a dummy variable and with practices with only one single physician as the reference group. All coefficients for both samples are positive and highly significant, which indicates that costs of physician practices with two or more physicians are always higher than the costs of practices with a single physician. To analyse the effect of size on cost in further detail, we estimate further regressions with the organisational form of the practice (rather than the number of physicians) as one independent variable and find that group practices have significantly higher costs than solo practices. Prior studies (Escarce and Pauly, 1998; Gunning and Sickles, 2011) found no significant effect of physician practice size on cost, which may be the result of their focus on cost per physician rather than practice cost.

We encountered at least three different reasons for the differences in the costs of practices of different sizes. First, the costs of larger practices may be higher because of indivisibilities of certain assets. To invest in indivisible technical equipment, practices need to reach a critical mass of (a) capital and (b) cases treated, as indivisibilities are associated with scale effects (Auquier, 1980; You, 1995). Indeed, as mentioned above, we find scale effects for specialists, where technological input is most relevant. Therefore, smaller practices may not invest in the respective technology. Our data support this hypothesis. Although physicians share a large part of fixed costs in larger practices (i.e., group practices), costs per owner of cost categories that are related to the technical equipment of the practice (e.g., depreciation and rental charges or leasing fees for technical equipment) are significantly higher in group practices for general practitioners and specialists.

To determine whether our results would change if we considered the intensity of technological services used in practices, we estimated further regressions for specialists and general practitioners. In Germany, the outpatient reimbursement system is a mixture of flat fee and fee-for-service components for technical services. All services provided are associated with a certain number of points depending on the costs related to the respective service. The total number of all points generated by each practice was used as an alternative output variable, as this variable should control for differences in costs per case treated that are caused by differences in technologies. However, this change had no effect on our result. All relevant coefficients remained robust.

Second, higher costs of larger practices may be explained by lower incentives of the practice owners to (a) treat a high number of cases, i.e., by free-rider problems in larger practices with several physicians, as proposed by DeFelice and Bradford (1997), and (b) control costs, as proposed by Newhouse (1973). For general practitioners, the number of cases treated per owner is significantly lower in larger practices, whereas there is no significant difference for specialists. Regarding the incentive to control costs, our data do not confirm this hypothesis. Input factors that are unrelated to the type and complexity of cases treated (e.g., the square metre of the practice or the full-time equivalents per owner) are not higher or even lower in larger practices.

Third, the incentive to treat more patients and to control costs may be lower for employed physicians than for owners. To control for this effect, we perform further regressions and include the share of employed physicians (i.e., the ratio of FTEs of employed physicians to the total number of physicians, including owners) as a variable in our cost function. This variable is negative and insignificant for general practitioners and positive (0.2159) and highly significant ($p \leq 0.01$) for specialists, but the remaining results are unaffected by these changes.

The coefficient of the degree of specialisation is negative and highly significant ($p \leq 0.01$) for general practitioners (-1.4827) and specialists (-0.3800), which indicates that an increase of specialisation by 1% reduces practice costs of general practitioners by 1.48% and costs of specialists by 0.38%. Physicians who focus on specific services or procedures may be more efficient in providing these services and therefore may treat the same number of patients with lower resource input, thus leading to lower costs. The results of two hospital efficiency studies point in a similar direction. Both studies found specialisation (although measured by different indices) to be positively associated with efficiency (Daidone and D'Amico, 2009; Lee *et al.*, 2008).

The coefficient for participation in gatekeeper models is negative and highly significant ($p \leq 0.01$) for general practitioners (-0.0772), which indicates that costs decrease by 7.72% if practices participate in gatekeeper models, whereas the coefficient for disease management programs is insignificant. For specialists, the coefficient for participation in disease management programs is negative (-0.0442) and highly significant ($p \leq 0.01$), which indicates that participation in disease management programs leads to a decrease of 4.42% for costs of specialists. This finding may be the result of the impact of participation in these programs on internal processes in the physician practice and/or the result of changes in the patient population visiting the respective practice. First, practices participating in disease management programs have to implement evidence-based guidelines, which is not obligatory in traditional care in Germany. Implementation of these guidelines is usually associated with a standardisation of processes (Busse, 2004), which may lead to a lower resource input for a given output. Second, practices participating in disease management programs or gatekeeper models should be visited relatively more often by established (rather than new) patients. This may be another reason for our results, as prior studies (Escarce and Pauly, 1998; Gunning and Sickles, 2011) found the treatment of new patients to be much more expensive than the treatment of established patients.

The coefficients for quality certification and for the number of days of professional development are both positive. Thus, quality certification increases costs of general practitioners by 9.12% and costs of specialists by 10.96%, whereas one further day of professional development increases costs by 0.62% for general practitioners and by 0.37% for specialists. Both variables may be indicators of a focus on structural quality of the practice. Prior studies investigating the association between quality and costs in the healthcare sector reported conflicting results (Carey and Burgess Jr, 1999; Hvenegaard *et al.*, 2011; Jha *et al.*, 2009; Schreyögg and Stargardt, 2010). However, all of these studies are based on the hospital sector. To date, there is no other study examining the association between quality indicators and costs for physician practices.

We investigate the robustness of our findings in several ways. First, as recommended by Blough *et al.* (2009), we account for missing values by different types of missing value imputation; we perform different versions of multiple imputations (with five and 20 imputations) and also perform a single imputation for all variables with missing values to produce an even larger sample. We run regressions based on the different imputations performed as well as based on the data set without imputation. The coefficients have the same direction throughout the different versions and the standard deviation changes only slightly. Second, we divide the sample of specialists into further subsamples and estimate separate cost functions for these subsamples to investigate whether our findings deviate among different specialties (e.g., for anaesthesiologists, dermatologists, gynaecologists and surgeons). For the majority of specialties, coefficients have the same direction and significance, but the calculated economies of scale of some specialties differ from the economies of scale of the total sample of specialists. Due to the smaller sample size of the single specialties, these results are less robust than the results for the total sample. Third, we estimate the cost function with and without restrictions to determine whether our main findings depend on the restrictions imposed. Without restrictions, coefficients for the number of cases treated (i.e., the output variable) and for input prices differ slightly, whereas the coefficients of other covariates are not affected by these changes. Fourth, as a proxy for capital, we include depreciations divided by the area of the practice in the square metres in the cost function as a further input price. This additional variable has only marginal effects on our results. Fifth, we also estimate regressions with the number of owners or the total number of physicians (not FTEs) as independent variables. These changes have no effect on our results. Sixth, we add further control variables that were excluded from our initial cost function because of a large number of missing values (the number of practice visits per case and the number of years since practice foundation). Both variables are insignificant, and their inclusion does not change the results. Finally, we also investigate several interaction effects among different variables in our regressions (e.g., the degree of specialisation, the practice's size and quality certification), but the coefficients are insignificant for general practitioners and specialists.

Our study also has several important limitations. First, data from a large number of practices were incomplete. However, even without missing value imputation, our dataset is still quite extensive relative to previous datasets in this field. Moreover, we performed a multiple missing value imputation to take this problem into account. Second, only cases of patients with statutory health insurance are included in our output variable. We would have preferred to include cases of patients with all types of insurance policies, but the respective data are not available. Therefore, we only control for the share of patients treated with different types of insurance policies. Third, we estimate a single-output cost function. Subdivision of cases into new and established patients would have most likely increased the accuracy of the estimation, but the relevant information is missing. Fourth, individual prices could only be calculated for office space and labour. However, prices for other inputs are not expected to vary largely among practices. The inclusion of further individual prices is impossible because of missing data. Finally, we have only limited information on the private situation of the physicians. Additional information would have provided us with other variables as proxies for physician preferences in the labour input equation, which could have increased the precision of our results.

6. Conclusion

The main problem in the estimation of physician practice cost functions is the lack of a price for the time of self-employed practice owners, i.e., of the owners' opportunity costs. The inclusion of the owners' time, which is the most appropriate proxy variable to measure opportunity costs, leads to endogeneity problems and to biased estimates. In this study, we estimated a physician practice cost function based on panel-data and took the endogeneity of the owners' time input into account. The results of this analysis can provide useful information for the development of a more appropriate physician payment system.

In particular, we find that costs per case increase with a rising number of physicians, whereas we detect economies of scale for specialists, which indicates that specialists could reduce their costs per case if they increased the number of cases treated. It is likely that this finding results from the existence of indivisibilities of certain expensive technical equipment, which leads to step costs. We found that larger practices invest more in technological equipment and thus produce higher costs per case relative to smaller practices. However, several further approaches may be used to explain our finding, especially varying incentives with practice size. The impact of practice size on costs and potential explanations for the respective findings should be addressed by future research papers. This is the first paper to deal with this issue in the context of outpatient care. More studies in different countries with different and possibly improved data sets are necessary to generate robust evidence. Moreover, implications of size and other variables on the quality of care, which were not focused on in this study, should be investigated in future studies.

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