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Production Efficiency in the Austrian Insurance Industry: A Bayesian Examination

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Abstract

This paper examines the developments in the production efficiency of the Austrian insurance market for the period 1994-1999 using firm-specific data on life/health and non-life insurers obtained from the Austrian insurance regulatory authority. The article uses a Bayesian stochastic frontier to obtain aggregate and firm-specific estimates of production efficiency across insurer types and time. The study provides strong evidence that the process of deregulation had positive effects on the production efficiency of Austrian insurers. The life/health and non-life firms showed similar patterns of development in that they were less efficient during the years 1994-1996 and significantly more efficient in 1997-1999. If the Austrian experience is representative, similar benefits from deregulation may be expected for the Central and Eastern European countries that prepare for the accession to the European Union.

Introduction

On January 1, 1995, Austria became a member of the European Union. However, prior to Austria's entrance into the EU, Austria's insurance industry completed the harmonization of its legal framework with the Insurance Directives of the European single insurance market in 1994.[1]

Until Austria's transition to the single insurance market, Austria's insurance industry followed the German philosophy of insurance regulation in that it applied the material approach of insurance regulation, providing for prior control of insurance products and prices. As in other premember countries, insurers doing business in Austria needed either to be licensed in Austria or had to establish a branch office in

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[1] The European single insurance market was established on July 1, 1994, six months before Austria became a member of the European Union. Austria completed the provisions of the three Generations of Insurance Directives on September 30, 1994.

Austria. However, this offered Austria little protection from international competition. In 1994, this competition included Austrian subsidiaries of insurers domiciled outside Austria, but licensed in Austria. This competition accounted for more than 40 percent of Austria's premium volume. Similar to Germany, the European single insurance market agreements led to a significant deregulation of the Austrian insurance market.

To prepare for the European single insurance market Austrian insurance companies implemented management programs to increase product efficiency. This included numerous mergers and acquisitions that would be viewed as potential threats to competitive and efficient markets in the United States, but appear to be efforts to improve product efficiency and to attract and maintain consumers in the threat of foreign competition. Secondly, Austrian insurers have placed a new importance on distribution systems and have introduced a variety of new products. Lastly, Lauer (1995) finds evidence of enhanced price competition in many insurance lines.

A description of the current environment on the European single insurance market includes several facets. First, the freedom to provide services enables an insurer, licensed in one member state of the European single insurance market, to do business in another member state without an establishment in the local market. Second, the freedom of establishment allows an insurer licensed in one member state of the European single insurance market to obtain an establishment in another member state without being licensed in this particular country.[2] Despite the deregulation of cross-border activities, these activities have not gained significant importance on the European single insurance market.[3] For instance, the contracts written in Austria by insurers licensed in other member states accounted for only 0.6 percent of Austria's 1998 total premium volume. With this in mind, we contemplate the consequences of the single insurance market for Austria's insurance industry. We test the hypothesis that Austrian insurers' efficiency has not been affected by the efficiency building programs.

With this background, the current article examines the developments in the production efficiency of the Austrian insurance market for the period between 1994 and 1999. For the purpose of analysis the data published by the Austrian insurance regulatory authority and a Bayesian stochastic frontier methodology is used. This unique approach allows one to ascertain aggregate and firm-specific estimates of production efficiency, in addition to obtaining information about the precision of all of the production frontiers' parameter estimates to estimate the relative efficiency between the early years of membership, 1994-1996, and in the more recent years, 1997-1999. The objective of the article is to determine whether changes in market structure and

[2] Other pillars of the single European insurance market are the single license principle, the principle of home-country control, harmonization in the requirements of equity capital, and other provisions laid down in the three Generations of Insurance Directives. For an overview on the foundations of the European single insurance market and for an overview on the process of transition to the European single insurance market see Ennsfellner (1998).

[3] A study by Ennsfellner and Dorfman (1998) revealed the following reasons for this fact. First, national differences in the contract and company law and in the taxation of insurance contracts deter interunion activity. It is also the case that differences in the insurance culture and in the language discourage interunion activities, while presently the multiple currencies is still a temporary problem.

regulatory environment have had an influence on the production performance of Austrian insurance companies.

In the section "The Austrian Insurance Market and Prior Research" the authors provide an overview of the Austrian insurance market, a review of the prior efficiency studies of Austrian insurers and provide a brief summary of other efficiency estimation methodologies. "Data and Methodology" provides readers with the construction and summaries of the sample data and makes available the stochastic frontier estimation methodology with reference to Appendix A illustrating the Bayesian estimation originally used in Van den Broek, Koop, Osiewalski, and Steel (1994), Koop, Osiewalski, and Steel (1994), and Lewis and Anderson (1999). "Results" present the empirical results and "Conclusions and Future Research" draws conclusions and implications for other single insurance market members as well as prospective members.

AUSTRIAN INSURANCE MARKET AND PRIOR RESEARCH

Market Overview

With a premium volume of about 11 billion Euro in 1999, the insurance market of Austria is approximately 1/10 the size of the largest markets in the European Union (France, Germany, and Great Britain). The insurance sector in Austria represents 5.6 percent of the country's total GDP. The respective figure in the EU exceeds 7 percent.

The importance of life insurance increased from 33.5 percent of the total Austrian insurance market in 1994 to 44.0 percent in 1999. The most important reason for this increase can be found in the financial problems of Austria's social insurance system that still plays a dominant role in providing individuals with retirement income. From 1995 to 1996 the relative importance of life insurance increased from 35.8 percent to 41.6 percent. The fall in importance in 1997 to 37.6 percent can be explained by tax law changes, which became effective in 1997. In 1996, the premium payments for annuity contracts were in part tax deductible for the insured for the last time. This motivated many customers to buy annuity contracts in 1996, causing the premium volume to rise 29.5 percent from 1995.

The importance of nonlife insurance, other than health, has decreased from 53.7 percent of the total insurance market in 1994 to 45.6 percent in 1999. The significance of health insurance fell from 12.8 percent in 1994 to 10.4 percent in 1999. Table 1 shows a summary of these developments between 1994 and 1999.

According to the provisions of the Austrian regulatory insurance law, domestic insurers are allowed to conduct business only in the legal form of a stock company, a mutual company, and in the form of a "small mutual."[4] Companies with headquarters in the European single insurance market are entitled to conduct business in Austria under the Freedom to Provide Services Act and under the Freedom of Establishment Act. Companies with headquarters outside the European single insurance market have to establish a branch office in Austria.

Competition improved in the Austrian insurance market after its membership into the European single insurance market. Attributed to heavy price competition, the

[4] This legal form has just local importance, but is of no importance for the whole Austrian insurance industry.

TABLE 1
Relative Importance (in %) of Life Insurance, Nonlife Insurance Other Than Health, and Health Insurance in Austria (1994-1999)

Year	Life Insurance (in %)	Nonlife Insurance Other Than Health (in %)	Health Insurance (in %)
1994	33.5	53.7	12.8
1995	35.8	51.9	12.3
1996	41.6	47.5	10.9
1997	37.6	51.0	11.4
1998	40.2	48.9	10.9
1999	44.0	45.6	10.4

premium volume of auto liability insurance fell by 0.8 percent in 1996 and continued to fall through 1999—the first time since 1979. Auto liability premiums declined 3.2 percent, 6.4 percent, and 5.1 percent, in 1997-1999, respectively. From 1994 until 1999 the premiums for auto liability insurance fell a total of 24.3 percent, despite increases in the loss ratio from 73 percent to 82 percent.

A comparable situation can be observed in fire insurance: declining premium volumes, especially in 1996 and 1997, with loss ratios on the rise. Overall, the premium volume of nonlife insurance declined 1997 and in 1998. Hoyos (2000) attributes this trend to higher competition between insurers licensed in Austria, rather than cross-border activities.

As evidence of the changing environment in Austria during this transition, Tables 2-4, provide some information about the number and size of insurers and their

TABLE 2
Concentration in the Austrian Insurance Markets (Market Share Measured by Premium Volume), 1994 and 1999

	Companies	Market Share 1994 (in %)	Market Share 1999 (in %)
Nonlife insurance other than health			
	Top 1	11.79	12.52
	Top 3	31.28	32.28
	Top 5	50.00	49.29
	Top 10	72.49	72.72
Life insurance			
	Top 1	12.78	12.01
	Top 3	34.32	34.29
	Top 5	48.94	49.75
	Top 10	70.62	73.29
Health insurance			
	Top 1	31.88	49.99
	Top 3	72.09	84.72
	Top 5	95.14	97.49

TABLE 3
Number of Firms in the Life, Nonlife (Other Than Health), and Health Insurance Markets (1994 and 1999)

	Number of Firms in 1994	Number of Firms in 1999
Life insurance	39	37
Nonlife insurance (other than health)	57	52
Health insurance	9	8

concentration in the market. In 1999, there were 54 insurance companies with headquarters in Austria. Most of the companies on the Austrian insurance market received their licenses before Austria joined he European single insurance market. In Austria, companies founded before 1994 are entitled to offer life and nonlife insurance from one legal entity even now.[5] Therefore, most firms are "mixed insurers," active in more than one balance sheet division. However, according to the Austrian insurance regulatory law these "mixed insurers" are obliged to publish an annual statement for each of the three "balance sheet divisions" separately. In this respect, the reporting duties of the "mixed insurers" are comparable to the reporting duties of an insurance company founded after 1994.

Although the number of companies in the nonlife insurance other than health business declined from 57 to 52, the concentration ratios remain stable in the period between 1994 and 1999. Likewise, despite the number of life insurance companies declining from 39 to 37, the life insurance sector's concentration does not change significantly. In the health insurance market, the market share of the largest insurer rose from 31.88 percent in 1994 to 49.99 percent in 1999. The reason for this development is a merger of two health insurers that were among the largest three health insurance companies in Austria. This merger reduced the number of health insurance companies from nine to eight and increased the concentration of the industry markedly.

Prior Studies

There are three studies that comprehensively review efficiency methodologies and results in the financial service sector: Firstly, Cummins and Weiss (2000) focus their comprehensive survey on productivity and efficiency in the insurance industry. They concentrate their review on studies that utilize modern frontier efficiency methodologies. In addition, Cummins and Weiss analyze the methodological problems as well as the measurement of inputs and outputs of insurance firms. Secondly, Berger, Hunter, and Timme (1993) look at the efficiency literature of financial institutions. Finally, Berger and Humphrey (1997) summarize most of the remaining efficiency studies on financial institutions in their follow-up review.

Numerous efficiency studies examine the U.S. insurance market. However, very few studies have focused on the insurance industry efficiency outside the United States.

[5] The Austrian insurance regulatory law divides the insurance lines into three "balance sheet divisions": life insurance, nonlife insurance, nonlife insurance other than health insurance, and health insurance.

TABLE 4
Size Characteristics of the Austrian Insurance Market (Measured by Premium Volume (in 1,000 ATS), 1994 and 1999

	Life in 1994	Life in 1999	Nonlife (Other Than Health) in 1994	Nonlife (Other Than Health) in 1999	Health in 1994	Health in 1999
Premium volume	40,760,947	65,987,743	81,485,923	89,160,093	15,505,496	15,584,963
Quartile 0	0	31,068	191	1,622	952	1,531
Quartile 1	195,125	366,112	69,445	177,710	295,787	249,373
Quartile 2	540,756	832,401	419,230	534,568	1,466,057	994,830
Quartile 3	1,264,767	2,100,829	1,596,705	1,744,055	3,062,814	2,429,893
Quartile 4	5,210,075	7,923,073	9,615,288	11,159,165	4,942,724	7,791,292
Mean	1,045,152	1,783,453	1,429,578	1,714,617	1,722,833	1,948,120
SD	1,306,559	2,190,905	2,364,833	2,669,214	1,632,765	2,459,691

Note: ATS is the abbreviation for Austrian Schilling. 1 Euro (€) exchanges 13.7603 Austrian Schillings.

This is especially true for efficiency of insurance markets that are members of the European single insurance market. Literature review identified insurance industry efficiency studies on companies operating in the following member markets: United Kingdom, Spain, France, Italy, and Austria.

Hardwick (1997) analyzes the cost inefficiency of the United Kingdom's life insurance industry. Using a Stochastic Frontier Approach (SFA) for data between 1989 and 1993, the study identifies high levels of inefficiency, with companies' costs being on average about 30 percent above the estimated cost frontier. However, the findings of the study suggest that larger life insurance companies are less inefficient than smaller life insurers, implying that economies of scale are present.

Cummins and Rubio-Misas (1998) present a study of the efficiency of the Spanish life insurance market and of the Spanish nonlife insurance market. The authors use Data Envelopment Analysis (DEA) for data for the years 1989-1996. The findings also show a cost efficiency of merely 25.6 percent for life and nonlife insurance companies. The study identifies significant differences in the factor productivity of stock insurance companies *versus* mutual insurers in Spain. While stock insurance companies improved factor productivity by 3 percent per year between 1989 and 1996, mutual insurers suffered from a 3.5 percent decline in factor productivity per year in this period.

Fecher et al. (1993) use DEA and SFA to analyze the cost and technical efficiency of life and nonlife insurance companies in France. The authors use data for the period between 1984 and 1989. The authors compare the results of DEA and SFA and conclude that the findings of both methods do not lead to significant differences. The study suggests a wide dispersion of efficiency in the French insurance market with an average efficiency in the life insurance industry of 30 percent and 50 percent for the nonlife insurance industry.

Cummins, Turchetti, and Weiss (1996) use data for the period 1985-1993 to analyze technical efficiency and productivity growth in the Italian insurance industry. Their results indicate that technical efficiency in the Italian insurance industry ranged from 70 percent to 78 percent during the sample period. The study found almost no technical efficiency changes over the sample period.

Holding scale efficiency constant, Mahlberg and Url (1998) find an average efficiency score of 75 percent for the Austrian insurance industry that is generally comparable to the Italian results. The authors use DEA and data for the period 1992-1996. When allowing for scale inefficiencies in addition to *X*-inefficiencies, the authors find even greater the potential for efficiency gains with potential cost reduction between 44 percent and 60 percent.

There are several obvious deficiencies in the literature. Most importantly, the literature lacks a critical analysis of changes in productive efficiency during and after the formation of the single insurance market.[6] Second, the methodologies used—DEA and the traditional SFA—have several shortcomings.

In particular, DEA considers any deviation from the efficient frontier as inefficiency without allowing for the possibility that some of the deviation may be a function of random measurement error. DEA is also exceptionally sensitive to the exact input/output specification of the model and to outliers. Additionally, when numerous firms are classified as fully efficient, DEA allows these firms to be repeatedly used to construct additional hypothetical sample firms, biasing the results. Although, this problem can be eliminated with the use of the Free–Hull Disposal technique, the aforementioned authors did not attempt to use it. In short, when efficiency is estimated using DEA, potential problems exist that reduce the robustness of the results.

Although the drawbacks of the traditional, frequentist form of the SFA are less severe, two important points should be mentioned. Traditional SFA is unable to assess the precision of individual firms' efficiency estimates without drastic assumptions or bootstrapping. The aforementioned authors that use SFA do not attempt to measure their individual firm efficiency estimates' precision. Finally, under the traditional SFA, authors are unable to measure relative inefficiency between different subsamples in the data. Some authors may estimate multiple independent frontiers, but because frontiers may cross, comparing results from multiple frontiers makes deciphering the relative inefficiencies difficult or even impossible.

Other statistical techniques currently employed in other industries include the distribution-free approach (DFA) and the thick frontier method (Berger and Humphrey, 1991). DFA assumes that individual firms exhibit constant inefficiency across time that can be revealed by estimating a panel cost or production function and averaging together the annual residuals for individual firms over time.

Berger and Humphrey's (1991) thick frontier method does not estimate a precise function for the data, but estimates a broad frontier. Average cost is divided into quartiles where the lowest average cost quartile is assumed to be relatively more

[6] To our knowledge there is just one paper by Cummins and Rubio-Misas (2002) that deals with the effects of deregulation and consolidation on the efficiency of the Spanish insurance industry.

efficient than the highest average cost quartile. They estimate two frontiers—one for the lowest quartile and one for the highest quartile. The difference between the two frontiers is separated on the basis of market factors that are not easily attributable to inefficiency and a residual representing inefficiency. Inefficiency is approximately the difference between the average cost of the highest quartile and the average cost of the lowest quartile. This method also assumes that the error terms within the highest and lowest quartile frontiers only reflect random error, while the difference between the high average cost quartile and the low average cost quartile measures inefficiency and market factor effects.

The obvious advantage of the thick frontier method is that it requires less specificity in the statistical assumptions. Unfortunately, the major drawback of this method is that an arbitrary assumption about where inefficiencies stop and random error begins must be made. This method is not a good fit for all data sets because it requires data to be highly dispersed. In particular, the Austrian insurance industry may be too small to adapt to this method. With the aforementioned problems associated with DEA, SFA, DFA, and the thick frontier, and the need to accurately assess performance, efficiency should be estimated with other techniques with fewer drawbacks.

To overcome the limitations of other statistical methods, and to provide evidence of how membership in the EU and the single insurance market has affected Austrian insurers' efficiency, production efficiency is estimated with the help of a Bayesian stochastic frontier technique. This technique overcomes many of the noted problems associated with DEA, DFA, and a thick frontier, and alleviates some of the problems associated with SFA.

Although, as with the traditional stochastic frontier, the Bayesian version is a parametric approach that requires assumptions about the frontier's functional form. However, we improve on the prior study of Mahlberg and Url (1998) by noting differences in the type of insurance firms in the market. Instead of combining all the firms into a single category, we divide the industry into life/health and nonlife (other than health) firms. This is appropriate as the three types of companies employ different inputs and outputs in the production process and therefore have a different technology set.

DATA AND METHODOLOGY

The Data

To estimate efficiency, financial data were obtained from the Austrian Insurance Statistics for the years 1994-1999. The Austrian Ministry of Finance publishes these data annually.[7] The data set includes all insurance companies licensed in Austria and marketing their products on the Austrian insurance market. Branch offices operating in Austria were not included. Furthermore, the data of the legal form of the so-called "small mutual" were not accounted for. These insurers have only very little influence on the Austrian insurance industry and operate under different technology, which would hinder the frontier estimation.

[7] In Austria the Minister of Finance serves as the insurance regulatory authority.

To estimate production efficiency, defining a production function with firm inputs and outputs is the first step. As a review of the literature shows there is no clear consensus on the "best" input/output specification. The inputs and outputs of insurance companies were defined in accordance with Cummins, Weiss, and Zi (1999), Cummins, Turchetti, and Weiss (1997), and Cummins and Weiss (1993). Tables A6 and A7 summarize the life/health and nonlife insurers' input and output levels for 1994-1999. For nonlife insurance companies, the output was divided into the risk-bearing function, the services related to insured losses, and into the intermediation function. Following Cummins and Zi (1999), the output of a life or health insurance company was divided into the risk-bearing function and the intermediation services.

Since the types of services related to insured losses and the nature of the intermediation function differs between the principal types of insurance, we use separate output measures for the principal types of insurance.[8] In the nonlife industry, the risk-bearing function was proxied, and the services related to insured losses with the losses incurred net of reinsurance in a given year, while the intermediation function was proxied for nonlife insurance companies with the total invested assets. In the life insurance industry and in the health insurance industry, the risk-bearing function was proxied with the incurred benefits net of reinsurance in a given year. Total invested assets and the changes in reserves net of reinsurance proxy the intermediation function for life and health insurers. Incurred losses net of reinsurance and incurred benefits net of reinsurance represent the insurers' payments net of reinsurance in the current year.[9]

To model the inputs of both life/health and nonlife insurance companies in this study, we use net operating expenses to proxy the distribution of insurance products, the inputs of their labor force, business services, and materials used in the production of the insurance products.[10] Equity capital and technical provisions proxy the inputs for the risk-bearing and risk-pooling function of the insurer.

In Austria, the required level of equity capital for nonlife insurance firms is a function of the insurance pool risk. The Austrian regulatory law provides a "premium index" and "claims index" to calculate the required equity capital for nonlife insurers. An insurer's required equity capital is the higher result of the premium index and of the claims index. However, Austrian regulatory law requires a minimum amount of equity capital. This minimum amount is independent of the development of the insurance pool.

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8 *See also* Cummins and Rubio-Misas (2002, pp. 10-11).

9 For the life insurance industry see Cummins, Tennyson, and Weiss (1998, p. 16).

10 Although it is customary to divide net operating expenses into categories, the translog functional form used in this analysis generates many parameters to estimate. The more the number of parameters estimated the less precise are the estimates. Therefore, to reduce the number of estimated parameters, the operating expenses are treated as a single input. The sensitivity of the results using categorized expenses was tested and little difference was found in the results.

For *nonlife insurance* companies[11] the *premium index*[12] is calculated as follows:

$$\text{Premium index } (A)\text{: } 0.18 \cdot P \cdot \frac{C_{\text{net}}}{C} = Er \tag{1}$$

$$\text{Premium index } (B)\text{: } (0.18 \cdot 10,000,000€ + 0.16(Pt - 10,000,000€)) \cdot \frac{C_{\text{net}}}{C} = Er \tag{2}$$

where P is the premium volume (if $\leq$€ 10,000,000); Pt is the premium volume (if $>$€ 10,000,000); C_{net} are the claims net of reinsurance; C are claims; Er is the required equity capital; and € is euro.

Premium index (A) is used when the gross premium volume of the insurance company is $\leq$€ 10,000,000. Premium index (B) is used when the gross premium volume of the insurance company $>$€ 10,000,000.

For *nonlife insurance* companies the *claims index*[13] is calculated as follows:

$$\text{Claims index}(A)\text{: } 0.26 \cdot C_{\text{av}} \cdot \frac{C_{\text{net}}}{C} = Er \tag{3}$$

$$\text{Claims index}(B)\text{: } ((0.26 \cdot 7,000,000€ + 0.23(C_{\text{av}}t - 7,000,000€)) \cdot \frac{C_{\text{net}}}{C} = Er \tag{4}$$

where C_{av} is the average claims of the last 3 years (in some lines: average claims in the last seven years) (if $\leq$€ 7,000,000); C_{av} is the average claims of the last 3 years (in some lines: average claims in the last 7 years) (if higher than € 7,000,000); C are the claims in the last year; C_{net} are the claims net of reinsurance of the last year; Er is the required equity capital; and € is euro.

One uses Claims index (A) when the average claims of the last 3 years (in some insurance lines 7 years) of the insurance company are $\leq$€ 7,000,000. One uses Claims index (B) when the average claims of the last 3 years (in some insurance lines 7 years) of the insurance company $>$€ 7,000,000.

For the calculations of the equity capital requirements of *life insurance* companies the Austrian regulatory law provides different methods for the different types of life insurance contracts. These methods reflect the investment risk and the pooling risk of the life insurer. The sum of the single result of these calculation methods represents the equity capital requirement. Again, there are minimum equity capital requirements in place that have to be met independently from the actual investment and pooling risks.

[11] As far as the provisions of the Austrian regulatory law for the equity capital requirements are concerned, nonlife insurance companies and health insurance companies are treated the same in Austria. However, if certain prerequisites are fulfilled by the health insurer, the equity capital requirement is reduced to 1/3 of the result of the premium index or of the claims index.

[12] If C_{net}/C is below 0.5 the company must use 0.5.

[13] If C_{net}/C is below 0.5 the company must use 0.5.

As the amount of equity capital shown in the balance sheet and reported to the regulatory authority is a criterion for the security of an insurance company, Austrian insurers usually hold more equity capital than they would be required to.

After removing firms that displayed obviously inaccurate data, the final data sets include 41, 49, 48, 49, 49, and 45 health and life companies in 1994-1999, respectively. A second data set representing nonlife firms includes 57, 55, 53, 50, 51, and 50 observations of nonlife insurers in 1994-1999, respectively. For an alternative model that follows Lewis and Anderson (1999), the samples, by type, are consolidated using a sample of 281 health and life companies and 316 nonlife companies. For estimation purposes, within the statistical model, both inputs and outputs are measured in 100,000s.

Methodology

Appendix A reviews the Bayesian estimation of the stochastic production frontier. Since the stochastic frontier method is a parametric approach, we must define a functional form. We use the familiar and flexible Translog functional form with one aggregate output measure and three production inputs that are used to generate the output. The estimated model follows:

$$\ln Q_i = b_o + \sum_{i=1}^{3} b_i \ln X_i + \sum_{i=1}^{3} b_i \ln^2 X_i + \sum_{i=1}^{3}\sum_{j=1}^{3} b_{ij} \ln X_i \ln X_j + z_i - v_i, \tag{9}$$

where Q denotes the total aggregate output of insurance firm i, $\ln X_i$ represents the natural log of each of the inputs employed ($I = 1, 2,$ and 3), z is a stochastic error term reflecting firm inefficiency, and v_i is a symmetric error term that captures other effects such as measurement error.

The bias in the results will depend upon the number of sample data points and the spread in those data points. The fewer observations and the greater the variance in the data, the more emphasis the prior distribution has on the posterior. Likewise, the larger the spread in the data or the fewer observed data, the greater the weight placed on the prior. The Bayesian estimation is particularly suitable for small finite samples, as it will produce parameter estimates that are exact small sample estimates that are not based on asymptotic theory as are traditional frequentists' estimates. Although due to the limited number of insurance company observations, results will tend to be biased toward the prior mean efficiency. In models with more observations of insurance firms, estimates will tend to be less biased. In fact, we test for the presence of this bias and find that although results are somewhat sensitive to the choice of the prior due to the small sample, that the relative trends in efficiency over time remain surprisingly consistent.

Given the differing production technologies, the frontier was estimated once for each year of data (1994-1999) on life and health insurance firms and once for each year of data on nonlife insurance firms. By estimating the frontiers in this fashion we are allowing the affects of technology, environment, and regulations to vary throughout the time period studied.

Finally, a single frontier for both health/life and for nonlife companies using all sample data points between 1994 and 1999 was estimated and the industries inefficiency was calculated, conditional on time periods—1994-1996 and 1997-1999. Table A1 provides the production frontiers' parameter estimates for the life/health and nonlife industries. Based on the relative inefficiency results it is possible to ascertain the probability that firms have become more efficient since Austria's entrance into the European Insurance Union. Using the conditional marginal density functions for each of the parameters, it is possible to calculate the probability and corresponding odds ratio that the period 1997-1999 is more efficient than the period 1994-1996.

RESULTS

The posterior mean firm efficiency results for the health/life insurance companies and the nonlife companies appear in Tables A2 and A3, respectively. We report the posterior mean firm efficiency for several firms that was followed throughout the 6-year period, industry inefficiency, industry efficiency, and the variance of the model for each year with the corresponding 98 percent highest density region to reflect the estimates' precision. As an example, in Table A4, Basler is 96.62 percent efficient in 1994 meaning that Basler could increase output by only approximately 3.38 percent without increasing input usage. For life and health companies in 1994 the industry was 6.79 percent inefficient corresponding to 93.44 percent efficient.[14]

Table A2 reports the results for nonlife companies during the sample period and should be interpreted in the same fashion as Table A4. Nonlife companies consistently become more production efficient over the 1994-1999 period. In 1994, the nonlife industry was over 48 percent inefficient. By 1999, the nonlife sector gained efficiencies, reaching an inefficiency low in 1999 with 16.49 percent. One should note that the 98 percent highest density regions reported are relatively tight given the rather small number of observations in both sampled groups.

The results for the nonlife group suggest that they are on whole more inefficient than health and life companies across the board. However, because the two types of firms operate under different technologies and have a different input/output mix, the results should not be directly compared. Although, it is useful to note a similar efficiency pattern appearing over time with the health and life companies and the nonlife companies in that each industry appears to be less production efficient during the early years of membership but more recently seem to be making remarkable progress in reclaiming production efficiencies post deregulation.

The high inefficiency values reported for nonlife companies, health, and life companies in the early years of membership could be attributed to several items. First, during

[14] To estimate the sensitivity of our results to our prior distribution choice, we rerun the posterior results for life insurance companies for 1994-1999. We change the mean of the prior distribution from 87.5% to 75% and find that the results do show some sensitivity, but that the efficiency patterns remain consistent. When the prior is altered Basler's efficiency estimates adjust to 95.68, 90.77, 86.13, 85.01, 92.41, and 88.78 percent for the years 1994-1999, respectively. Anker's efficiency results change to 91.60, 92.80, 95.07, 92.17, 91.90, and 95.71 percent for 1994-1999, respectively. The overall efficiency estimates for the health and life group change to 11.04, 9.59, 23.13, 16.76, 11.93, and 12.63 for 1994-1999, respectively.

periods of regulatory change, a learning curve may exist causing productivity to temporarily suffer. Second, the mergers and acquisitions that occurred in preparation for possible outside competition may have added to the learning curve affect. Not only is it possible that government regulations and rules were changing, but also in-house rules and procedures were under revision, causing a temporary state of productivity instability. In addition, an explanation for the dramatic decline in the life and health industry efficiency in 1996 could be the dramatic increase of the premium volume (about 29 percent due to a change in the tax laws in 1997). This influx of additional cash could have caused a "free cash-flow" problem, allowing managers to more easily waste funds and not use them as efficiently as in the past.

We are aware that a whole array of reasons could have been the cause for the marked improvement of production efficiency during the last several years of the study. Carefully analyzing the developments on the Austrian insurance market, it was found that the improvement of production efficiency is most likely due to the positive incentives that are a by-product of the deregulation. The possibility that companies outside Austria could contest the Austrian insurers, enticed insurers to put production efficiency programs in place early in the sample period, in the long run producing positive results. Also, mergers and acquisitions entered into during the early years of membership take time for synergies and economies of scale to realize efficiency gains. It is also possible that an increase in the distribution of life insurance and annuity contracts through banks might also have influenced the development of efficiency in the period 1997-1999.

The reported efficiency results are significantly different from those found by Mahlberg and Url's (1998) DEA estimates for two reasons. First, Mahlberg and Url's results are a combination of all insurance companies in Austria. Thus, from our results, one can see that there are significant differences between the health/life companies and the nonlife companies. This causes the more efficient health/life companies in Mahlberg and Url's (1998) sample to be biased downward and the less efficient nonlife companies to be biased upward in their final results. Second, the DEA results reported by Mahlberg and Url (1998), and results reported by others using any other single-error term model, bias estimates because the model misinterprets random error to be due to inefficiency.

Tables A3 and A5 show results from estimating a single stochastic frontier—all years included—conditional on time period sampled, implicitly assuming technology does not change during the period. The data is broken into two groups, the early years of membership period, 1994-1996, and the more recent period, 1997-1999. In Table A3, the evidence for the health and life insurance companies is compelling. The industry inefficiency during the transition is 10.29 percent while the more recent time period inefficiency estimates are only half as much at 5.59 percent. Using the marginal distributions produced by the Gibbs sampler, we compute that inefficiencies in the early years of membership are more than three times the inefficiencies in more recent years.[15] This corresponds to a probability that the 1994-1996 years are more inefficient than

[15] One should note that since the conditional marginal density functions are not symmetric,

$$\frac{E[\lambda_1]}{E[\lambda_2]} \neq E\left[\frac{\lambda_1}{\lambda_2}\right]$$

the period 1997-1999 of over 95 percent. The resultant odds ratio is 21:1—strong evidence that Austrian health and life insurance companies have become significantly more efficient since initiation into the European insurance markets. This is the approximate equivalent of a frequentist rejecting the null hypothesis in favor of the hypothesis that health and life insurers in the period 1997-1999 are more efficient than the insurers in the period 1994-1996 at the 5 percent level.[16]

In Table A5, nonlife insurance companies illustrate a similar story. Industry inefficiency during the early years of membership is over 48 percent while during more recent years it has fallen dramatically to just more than 35 percent. Although the early years of membership inefficiency is merely 1.4 times that of 1997-1999, the corresponding probability that the inefficiency in 1994-1996 is greater than the inefficiency in 1997-1999 is more than 99 percent. This corresponds to an odds ratio of 166:1—very strong evidence that Austrian nonlife insurance companies have become significantly more efficient in recent years. The Bayesian version of the test statistic demonstrates even more evidence than the traditional frequentist version at the 1 percent level. This is the approximate equivalent of a frequentist rejecting the null hypothesis in favor of the hypothesis that nonlife insurers in the period 1997-1999 are more efficient than the insurers in the period 1994-1996 at the 1 percent level.

It is found that X-efficiencies have changed due to Austria's membership into the EU and the single insurance market. Although X-inefficiencies do exist in these insurance markets, evidence shows that production efficiency has improved substantially implying that market structure and a competitive environment has benefited from Austria's membership in the EU. It appears as if the inefficiencies are greater for nonlife firms than for life firms, but given the differences in production technology, it is impossible to statistically compare the two groups.

CONCLUSIONS AND FUTURE RESEARCH

This article examines the developments in the production efficiency of the Austrian insurance market for the period 1994-1999. Using firm-specific data on life/health and nonlife companies published by the Austrian insurance regulatory authority, we estimate efficiency with a Bayesian stochastic frontier approach. From this method, it is possible to obtain aggregate and firm-specific estimates of production efficiency in addition to information about the precision of our parameter and efficiency estimates. Second, the panel is divided into the years 1994-1996 and 1997-1999. Using Lewis and Anderson's (1999) methodology, one can compare the relative efficiency between these two groups of years and calculate the probability that the firms in the latter years are more efficient than the firms in the single insurance market early years of membership.

[16] To check the sensitivity to the results in Table A3, we change the prior to $r = 75$ percent and reestimate the model. We find that the overall inefficiency for years 1994-1996 remained nearly the same at 10.82 percent while the overall efficiency for years 1997-1999 increased to 9.25 percent. However, with closer examination, the posterior mean ratio of the overall efficiencies $E(\frac{\lambda_{94-97}}{\lambda_{98-99}}) = 1.54$ implying that although there is some mild sensitivity to the estimates the overall efficiency trends remain consistent.

The results of this study provide strong evidence that the process of deregulation has had positive effects on the production efficiency of the Austrian insurance companies. The life and health firms as well as the nonlife firms showed similar patterns of development. During the years 1994-1996 each group appears to be less efficient than during the years 1997-1999. Especially in 1996, a significant decline of efficiency was observed in the life and health insurance group. There are several explanations for this decrease in efficiency during the early years of membership in the single insurance market. The premium volume dramatically increased during 1996 causing a possible free cash-flow problem. Mergers and acquisitions and a new regulatory environment created learning curve affects. And, the strong price competition likely preceded the full effect of company product efficiency programs.

A similar pattern of the developments can be observed in the nonlife group. After deregulation of the Austrian insurance market, these firms increased their production efficiency from 61.7 percent in 1994 to 84.8 percent in 1999. Fierce price competition in major nonlife insurance lines might be the explanation, not only for the positive incentives to increase in efficiency, but also for the higher estimated inefficiency relative to health and life companies.

If the Austrian experience is representative, similar benefits from deregulation may be expected for the Central and Eastern European countries that prepare for the accession to the European Union.[17] However, the differences in the insurance markets' recent history has to be taken into account. While Austria's economy has been a social market economy, after World War II the Central and Eastern European accession candidates' economies were run as centrally planned economies until the late 1980s and early 1990s. The foundation of the transition to the single insurance market in these countries is, in every case, a state-owned insurance monopoly run by a branch of the Ministry of Finance. Although more competition has gradually been allowed to contest the markets, insurance legislation has created market distortions to protect the original monopolist insurer. This has led to key market structure differences in the transitional countries and Austria.[18]

On account of these foundational differences, a complete transfer of this article's results to the insurance markets of the Czech Republic, Estonia, Hungary, Poland, and Slovenia is not possible. However, this study shows that deregulation of the market has created a discernable increase in production efficiency for Austria. If it is assumed that deregulation broadens the managers' decision alternatives and creates an environment for contestable markets, efficiency in a deregulated market can be assumed to be a function of managerial incentives, quality and experience.

Deregulation can encourage foreign investments and the development of adequately educated managers (and regulators). Through education and foreign investment,

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[17] The Central and Eastern European countries that prepare for the accession in the next wave of enlargement of the European Union are the Czech Republic, Estonia, Hungary, Poland, and Slovenia.

[18] For example, in the Czech Republic, the former monopolist insurer Ceská Pojist'ovna has been allowed to maintain its monopoly in auto liability insurance until January 1, 2000, to allow the company more time to adapt to market conditions.

insurance companies can become more efficiently managed and be able to compete in an ever-increasing competitive environment. However, education and training in management skills takes time. To allow foreign companies to invest in the domestic insurance industry would be a quick substitute to internally training managers trained in the market economy.

The countries in transition should be aware of a tradeoff. On the one hand, there is the political and economic desire to integrate the respective economies as quickly as possible into the European single markets. Yet, on the other hand, the characteristics of competitive insurance markets argue for a slower transition, given that the domestic dominance of the respective insurance markets is desired (Dorfman and Ennsfellner, 2001).

Starting from a centrally planned economy, accession candidates to the European Union have chosen different paths of preparing their insurance markets for accession to the European single insurance market. Hungary opened markets early while other markets, like Poland or the Czech Republic, have protected their markets. Poland and the Czech Republic have imposed market distortion in order to allow their former monopolist insurers more time to adapt to competition.

Several research problems need to be addressed. First, it is interesting to know which of these approaches helps to avoid inefficiencies during the various stages of the transition process.[19] Second, future research can show which approach to transition leads to the highest efficiency in the insurance markets. And, do the efficiencies between approaches equalize over time? This is especially important for accession candidates to the European Union, because the principle of the freedom to provide services and the principle of freedom of establishment allow all insurance companies of existing member states to market their products without restrictions in the new member states.

Studies on efficiency, comparing different insurance markets in Europe form another fruitful area for future research. First, efficiency studies on member states are necessary for comparison sake to the insurance firms of accession candidates. Given that the country data are comparable, this research allows policymakers to evaluate the relative progress in the insurance markets' preparation for membership in the European single insurance market. Second, efficiency studies that compare the efficiency of the accession candidates' insurance markets to the member markets could provide information on benchmarks that accession candidates should have achieved before entering the European single insurance markets. Third, comparisons of the efficiency of the member states of the European single insurance market could identify the local market with the highest efficiency score. This "best practice" insurance market could be the object for further research on methods to achieve higher efficiency in the insurance business. In addition, due to the implementation of the European single currency, the Euro, in eleven member states of the European Union, the importance of cross-border activities on insurance markets is expected to increase, making efficiency comparison of insurance markets even more important.

[19] For an overview on the typical stages in the transition process of an insurance market from a centrally planned economy to a market economy see Dorfman and Ennsfellner (2001).

APPENDIX A

TABLE A1
Posterior Mean Parameter Estimates for the Single Production Frontier in the Health/Life Industry and for the Nonlife Industry

Parameter	Health/Life Posterior Mean	Nonlife Posterior Mean
β_1	1.97	1.74
	[1.86, 2.10]	[1.46, 2.05]
β_2	0.73	0.26
	[0.65, 0.82]	[0.07, 0.43]
β_3	54	
	[0.65, 0.83]	
β_4	0.17	0.26
	[0.12, 0.21]	[[0.10, 0.45]
β_5	0.15	0.07
	[0.12, 0.18]	[0.01, 0.11]
β_6	0.038	0.04
	[−0.01, 0.09]	[0.02, 0.07]
β_7	0.110	0.14
	[0.09, 0.11]	[−0.01, 0.04]
β_8	0.10	−0.11
	[0.09, 0.11]	[−0.15, −0.06]
β_9	−0.15	0.00
	[−0.19, −0.13]	[−0.05, 0.05]
β_{10}	−0.17	−0.07
	[−0.20, −0.13]	[−0.12, −0.03]

Note: Parameter estimates are calculated using a single stochastic frontier. The numbers in parentheses beneath each mean are the 98% highest density regions.

TABLE A2
Mean Posterior Parameter Results for Nonlife Insurance Companies for Years 1994-1999

Parameter	1994 $N=57$ (in %)	1995 $N=55$ (in %)	1996 $N=53$ (in %)	1997 $N=50$ (in %)	1998 $N=51$ (in %)	1999 $N=50$ (in %)
Nonlife						
BV-Arag	77.43%	80.14	79.03	83.11	84.36	89.46
	[43.07 99.47]	[47.91, 99.60]	[46.22, 99.55]	[48.89, 99.79]	[52.57, 99.81]	[58.41, 99.91]
Basler	84.95	78.06	76.14	74.93	81.21	88.62
	[50.84, 99.80]	[42.74, 99.58]	[37.79, 99.57]	[30.17, 99.71]	[43.28, 99.78]	[51.97, 99.88]
Anker	79.26	72.95	82.08	82.08	75.76	85.80
	[44.15, 99.59]	[39.19, 99.18]	[45.20, 99.80]	[45.21, 99.80]	[42.63, 99.70]	[48.30, 99.88]
D.A.S.	81.83	72.82	77.34	77.34	72.10	81.86
	[46.96, 99.70]	[40.15, 99.25]	[40.44, 99.71]	[40.44, 99.71]	[39.90, 99.56]	[42.47, 99.83]
Industry Inefficiency (λ)	48.23	37.07	37.44	28.29	32.97	16.49
	[27.29, 76.45]	[20.22, 60.33]	[20.75, 61.09]	[3.86, 54.79]	[3.58, 60.97]	[2.90, 42.68]
Industry Efficiency ($\exp(-\lambda)$)	61.74	69.03	68.77	75.36	71.91	84.80
	[46.56, 76.12]	[54.70, 81.69]	[54.29, 81.26]	[57.82, 96.21]	[54.35, 96.48]	[65.26, 97.14]
σ^{λ}	8.77	6.92	7.02	10.95	8.08	10.35
	[1.60, 23.18]	[1.95, 17.09]	[1.91, 17.59]	[2.66, 29.14]	[0.95, 28.27]	[2.79, 21.15]

Note: The numbers in parentheses beneath each mean are the 98% highest density regions.

TABLE A3
The Relative Health and Life Insurance Industry Efficiency Between the European Union Early Years of Membership (1994-1996) and Recent Years (1997-1999)

Parameter	Posterior Mean [98% Highest Density Region]
Industry inefficiency 1994-1996 (λ_1)	10.29%
	[5.93%, 15.96%]
Industry inefficiency 1997-1999 (λ_2)	5.59%
	[0.3%, 13.29%]
Relative industry inefficiency (λ_1/λ_2)	3.64
	[.85, 25.68%]
Probability that ($\lambda_1 > \lambda_2$)	95.36%
Odds ratio that ($\lambda_1 > \lambda_2$)	21:1

Note: *X*-efficiency estimates are calculated using a single stochastic frontier. λ_1 is the inefficiency associated with years 1994-1996 and, λ_2 the inefficiency associated with years 1997-1999. Posterior means are given with the associated 98% highest density region.

TABLE A4
Posterior Efficiency Means for Health and Life Insurance Companies for Years 1994-1999

Parameters	1994 $N = 41$ (in %)	1995 $N = 49$ (in %)	1996 $N = 48$ (in %)	1997 $N = 49$ (in %)	1998 $N = 49$(in%) (in %)	1999 $N = 45$ (in %)
Life						
Basler	96.62	97.53	95.16	94.95	97.03	96.53
	[84.30, 99.97]	[88.63, 99.98]	[79.15, 99.95]	[76.73, 99.95]	[86.49, 99.97]	[83.92, 99.97]
Anker	94.12	95.20	89.78	91.05	93.45	93.23
	[75.25, 99.94]	[77.84, 99.95]	[70.23, 99.80]	[61.74, 99.91]	[72.98, 99.93]	[72.02, 99.93]
Drei Banken	94.31	94.84	92.88	90.18	94.34	93.24
	[75.68, 99.94]	[77.84, 99.95]	[75.47, 99.92]	[58.96, 99.91]	[75.36, 99.94]	[70.16, 99.93]
Health						
Wiener Städtische	92.49	94.92	90.58	92.72	94.72	94.57
	[64.62, 99.93]	[77.46, 99.95]	[67.94, 99.87]	[66.18, 99.93]	[76.85, 99.94]	[74.28, 99.95]
Volksfür-sorge Jupiter	95.56	94.44	87.17	94.91	90.81	94.98
	[79.54, 99.95]	[73.88, 99.95]	[59.00, 99.81]	[76.11, 99.96]	[59.33, 99.92]	[76.65, 99.95]
Industry Inefficiency (λ)	6.79	6.11	20.16	10.45	7.42	8.05
	[2.07, 16.99]	[2.05, 14.81]	[11.37, 32.42]	[2.54, 29.74]	[2.18, 18.51]	[2.26, 20.15]
Industry Efficiency (exp $(-\lambda)$)	93.44	94.07	81.74	90.08	92.85	92.27
	[84.37, 97.95]	[86.23, 97.97]	[37.54, 42.22]	[74.27, 97.49]	[83.10, 97.84]	[81.75, 97.77]
σ^{λ}	2.49	2.10	1.34	7.41	2.98	3.64
	[1.15, 4.99]	[1.04, 3.84]	[.27, 3.86]	[2.70, 13.92]	[1.39, 5.48]	[1.67, 6.96]

Note: The numbers in parenthesis beneath each mean are the 98% highest density regions.

TABLE A5
The Relative Nonlife Insurance Industry Efficiency Between the European Union Early Years of Membership (1994-1996) and Recent Years (1997-1999)

Parameter	Posterior Mean [98% Highest Density Region]
Industry inefficiency 1994-1996 (λ_1)	48.44%
	[37.82%, 61.04%]
Industry Inefficiency 1997-1999 (λ_2)	35.05%
	[26.33%, 45.43%]
Relative industry inefficiency (λ_1/λ_2)	1.41
	[1.02, 1.71]
Probability that ($\lambda_1 > \lambda_2$)	99.40%
Odds ratio that ($\lambda_1 > \lambda_2$)	166:1

Note: X-efficiency estimates are calculated using a single stochastic frontier. λ_1 is the inefficiency associated with years 1994-1996 and λ_2 the inefficiency associated with years 1997-1999.

TABLE A6
Summary Statistics for Health, Life, and Nonlife Insurance Company Outputs

	1994	1995	1996	1997	1998	1999
Health						
Incurred benefits net of reinsurance	1,395,768	1,756,203	1,696,990	1,879,913	1,694,469	1,949,512
	(1,485,659)	(1,848,902)	(1,750,331)	(1,728,832)	(1,742,548)	(2,744,500)
Changes in reserves net of reinsurance	131,149	201,525	212,064	248,060	211,491	236,177
	(137,776)	(213,416)	(220,624)	(226,107)	(207,667)	(309,062.5)
Total invested assets	1,693,531	3,052,509	3,303,713	4,077,765	3,697,867	3,975,923
	(1,910,926)	(3,999,774)	(4,287,011)	(4,864,329)	(4,664,202)	(5,570,681)
Life						
Incurred benefits net of reinsurance	747,886	982,182	1,010,997	1,289,639	1,301,272	1,484,605
	(1,096,057)	(1,404,469)	(1,472,733)	(1,865,497)	(1,785,960)	(2025942)
Changes in reserves net of reinsurance	382,530	404,498	641,954	327,264	439,000	713,223
	(488,050)	(608,869)	(869,729)	(480,005)	(824,773)	(1247003)
Total invested assets	6,326,481	7,663,801	8,303,602	9,183,098	10,265,938	12,177,068
	(9,136,922)	(10,808,275)	(11,676,902)	(12,736,603)	(13,849,559)	(16,046,894.6)
Nonlife						
Claims incurred net of reinsurance	1,693,120	1,799,395	1,983,334	2,156,812	2,195,293	2,300,948
	(2,963,744.2)	(3,041,248.2)	(3,279,753.3)	(3,757,986.3)	(3,952,211.7)	(3,784,849)
Total invested assets	2,162,073	2,345,635	2,595,924	3,000,396	2,839,599	2,943,677
	(3,395,182.5)	(3,634,906.8)	(3,857,046.5)	(4,618,480.9)	(4,584,732.2)	(4,580,335)

TABLE A7
Summary Statistics for Health, Life and Nonlife Insurance Company Inputs

	1994	1995	1996	1997	1998	1999
Health						
Net operating expenses	190,826	248,064	251,049	290,230	262,624	306,298
	(186,886)	(237,716)	(236,949)	(237,801)	(242,128)	(400,018.7)
Equity capital	249,298	345,138	375,390	448,842	424,049	284,737
	(359,185)	(447,925)	(494,864)	(597,436)	(699,088)	(334,749.4)
Technical provisions net of reinsurance	1,265,185	2,107,752	2,334,353	2,506,487	2,759,390	3,323,098
	(1,365,940)	(2,637,664)	(2,867,016)	(2,870,557)	(3,281,703)	(4,836,973)
Life						
Net operating expenses	200,872	179,618	196,439	200,386	229,372	271,527
	(228,635)	(224,933)	(245,811)	(258,244)	(285,438)	(336,710.6)
Equity capital	220,969	267,253	285,330	323,285	366,261	414,053
	(362,851)	(406,364)	(431,484)	(474,545)	(543,944)	(567,667.9)
Technical provisions net of reinsurance	5,775,101	6,889,713	7,520,035	8,322,298	9,413,279	11,017,975
	(8,673,363)	(9,702,090)	(10,521,149)	(11,502,427)	(12,629,946)	(14,533,593)
Nonlife						
Net operating expenses	575,174	333,405	361,907	393,197	404,788	423,620
	(931,694.744)	(556,208.852)	(586,364.413)	(673,922.568)	(699,610.515)	(674,421.85)
Equity capital	489,258	518,489	564,253	780,775	803,244	632,198
	(1,322,551.1)	(1,344,141.9)	(1,382,552.4)	(2,106,800.6)	(1,373,395.1)	(1,280,260)
Technical provisions net of reinsurance	304,404	315,381	330,423	342,056	362,678	373,748
	(546,948.82)	(583,259.55)	(593,411.86)	(647,617.1)	(781,976.14)	(822,357.7)

APPENDIX B

The Bayesian Stochastic Frontier Model

Van den Broek et al. (1994) and Koop, Osiewalski, and Steel (1994) provide a basis for the stochastic frontier model to be applied with Bayesian statistics. To generally explain the methodology without detracting with technical details, we initially define a set of unknown parameters that includes the production frontier's coefficients, the measurement error's variance, the overall industry performance measure, and an individual efficiency parameter for each insurance firm in the sample. Next, we collect information about the parameters that may be known before the data has been observed, calling this the "prior" density function. We then collect the aforementioned data. The data depends upon the parameters in a known way and can be described by a probability density function known as the likelihood function. Using Bayes rule, the "prior" knowledge and the "likelihood" function combine to form the "posterior" density function.

More specifically, following van den Broek, Koop, Osiewalski, and Steel (1994) and Koop, Osiewalski, and Steel (1994) and in this study a flat (constant) prior is chosen for the vector of frontier parameters, $\tilde{\beta}$. That is, we assume no prior knowledge about these parameters.

Gamma priors for σ^2 and $\lambda_{j^{-1}}, \pi(\sigma^{-1}) = f_G(\sigma^{-2} \,|\, \frac{\tau}{2}, \frac{s_p^2}{2})$ and $p(\lambda_j^{-1}) = f_G(\lambda^{-1} \,|\, 1, -\ln(r_j^*))$, respectively (Fernandez, Osiewalski, and Steel, 1997).

Here $f_G(\cdot \,|\upsilon_1, \upsilon_2)$denotes a gamma density distribution with mean υ_1/υ_2 and variance υ_1/υ_2^2. λ_j is the shape parameter that defines the mean of the exponential density function, where j is the firm type (for Tables A2 and A4 only one firm type is assumed; thus, j ceases to exist. In Tables A3 and A5, multiple sources of efficiency are allowed, $j = 1$ if the observation occurs between 1994 and 1996, while $j = 2$ if the observation occurs between 1997 and 1999). Choosing an informative prior for λ_j^{-1} and σ^2 ensures that the posterior is proper, and defines the complete prior as:[20]

$$\pi\left(\beta, \sigma^2, \lambda_j^{-1}\right) \propto \sigma^{-2} f_G\left(\sigma^{-2} \,\middle|\, \frac{\tau}{2}, \frac{s_p^2}{2}\right). \tag{5}$$

Note that, $r_{ji} = \exp(-z_i)$ measures the efficiency of the ith firm, type j (if applicable), relative to an efficient firm facing the same input prices, and r_j^* is the prior mean for the industry's efficiency (for Tables A3 and A5, there are two grouping characteristics, therefore $j = 1$ for the years 1994-1996 and $j = 2$ for the years 1997-1999). As in prior studies, we set $r_1^* = r_2^* = 0.875$, $s_p^2 = 0.03$ and $\tau = 1.0$. We are implying that we have no prior about whether insurance companies are more or less efficient in the 1994-1996 than in the 1997-1999 period and a very weak prior on σ^2.

Koop, Steel, and Osiewalski (1993) derive the joint conditional density of β and σ^2 for the model with a single firm type. Tables A2 and A4 report these results.[21] Lewis

[20] A proper posterior integrates to one.

[21] Koop, Steel, and Osiewalski (1993) show the conditional density of β, σ^{-2} to be the following:

$$\begin{aligned} p(\beta, \sigma^{-2} \,|\, data, z, \lambda^{-1}) &= p(\beta, \sigma^{-2} \,|\, data, z) \\ &= f_G\left(\sigma^{-2} \,\middle|\, \frac{N-2}{2}, \frac{1}{2}(y - X\hat{\beta} - z)'(y - X\hat{\beta} - z)\right) f_N(\beta \,|\, \hat{\beta}, \sigma^2(X'X)^{-1}) \end{aligned}$$

and Anderson (1999) derive the conditional density functions for $\lambda_1^{-1}\lambda_2^{-1}$ and z_{ij} to construct a single stochastic frontier conditional on firm characteristic, such as time period. Table A3 and A5 report the results from this method. The conditional densities follow:

$$p\left(\lambda_1^{-1}\,\middle|\,data, z, \beta, \sigma^{-2}\right) = p\left(\lambda_1^{-1}\,\middle|\,z\right) = f_G\left(\lambda_1^{-1}\,\middle|\,k_1 + 1, z'i_{k1} - \ln\left(r_1^*\right)\right) \tag{6}$$

$$p\left(\lambda_2^{-1}\,\middle|\,data, z, \beta, \sigma^{-2}\right) = p\left(\lambda_2^{-1}\,\middle|\,z\right) = f_G\left(\lambda_2^{-1}|n - k_1 + 1, z'i_{n-k1} - \ln\left(r_2^*\right)\right)$$

$$p\left(z_{ij}\,\middle|\,data, \beta, \lambda_1^{-1}, \lambda_2^{-1}\sigma^{-2}\right) \propto f_N\left(z\,\middle|\,y - X\beta - \frac{\sigma^2}{\lambda_j}, I_n\sigma^2\right)\prod_{i=1}^{n} I(z_i \geq 0) \tag{8}$$

where $\hat{\beta} = (X'X)^{-1}X'Y - z$, and $f_N(\cdot\,|\,\mu,\ \Sigma)$ is a normal density with mean μ and covariance matrix Σ, i represents an $n \times 1$ vector of ones, f_G a gamma density, I_n denotes the $n \times n$ identity matrix, and $I(\cdot)$ the indicator function. Also, n represents the number of firm observations in the sample, k_1 the number of observations between 1994 and 1996, and $n - k_1$ is the number of firm observations between 1997 and 1999.

Using these conditional densities, the Gibbs sampler follows. Under regularity conditions satisfied in this application, Tierney (1991) shows that the Gibbs sampler converges to the actual joint posterior density function as the iterations approach infinity. In this article, we generate 26,000 parameter vectors and drop the first 1,000 to avoid sensitivity to starting values. The final posterior density functions include 25,000 randomly sampled points. Koop, Steel, and Osiewalski (1994) find that numerical standard errors for the Gibbs sampler are approximately equal to numerical standard errors that would be generated sampling directly from the joint posterior density.

Next, because analytic solutions to the marginal posterior density functions are impossible, we use Monte Carlo integration.[22] The Gibbs sampler draws observations from the conditional probability distribution functions to form marginal posterior density functions. We calculate the expected value and 98 percent highest density regions for each estimated parameter from each of the parameters' marginal probability distribution functions.

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