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AN EQUILIBRIUM MODEL ESTIMATED ON PHARMACEUTICAL DATA

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An equilibrium model estimated on pharmaceutical data[1].

by
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Abstract

The purpose of this paper is to estimate to what extent patients/doctors respond to prices when making a choice between a brand name product and its generics, and also how pharmacies respond to government regulation and to prices set by brand name producers. Data is unique in the sense that we observe prices set by pharmacies as well as by producers. We have estimated the demand side, but also jointly the demand side and the price setting by retailers/wholesalers and producers. Results confirm that estimating only the demand side yields biased estimates. Taking the whole data generating process into account we find much stronger price responses.

JEL-Code: C35, D43, I18, L11.
Keywords: pharmaceuticals, discrete choice model, market equilibrium

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1. Introduction

In this paper we study to what extent patients/ doctors respond to prices when making a choice between a brand name product and its generics, and also how pharmacies respond to government regulation and to prices set by brand name producers. In order to do that we have to account for how the pharmaceutical markets is organised; how prices are set and government regulation of the market. If one simply regresses demand against prices, then it is ignored that prices may depend on demand, which may give rise to biased estimates of price responses. Instead of applying an instrumental variable approach, we estimate jointly the demand side and the prices set by producers of brand-name products and the pharmacies, given the government regulation of brand-name prices. In the modelling of the price setting among brand name producers we assume that they take into account the responses by pharmacies with respect to their sales and price setting of generics versus brand name products. We thus try to take into account the whole data generating process in order to get unbiased estimates, as advocated in Haavelmo (1943, 1944).

It should be noted that since 2001 the pharmacies in Norway are almost entirely owned by international firms that also are wholesalers. In the period analysed here there were three pharmacy chains in Norway. The regulatory authority related to the pharmaceutical sector in Norway is the Norwegian Ministry of Health and Social Affairs. The Ministry, and its agency (Norwegian Medicines Agency), control the entry of new drugs, the wholesale prices, and the retail margins. The manufacturer price is unregulated, see Brekke et al (2012) for details of the markets structure and regulation in Nordic countries, and Vogler (2012) for an overview of pharmaceutical pricing and market regulation in 29 European countries, including Norway.

During the last decades there have been several policy initiatives by the Norwegian government to foster competition after patent expiration. From 1987 doctors were encouraged to prescribe the cheapest of the available versions of the drug. In 1991 this light-handed regulation was replaced by a law that instructed doctors to prescribe the cheapest available generic drug. Doctors could still prescribe a more expensive brand-name version, as long as a medical reason for this could be provided. In this period, generic competition was entirely based on the prescription-choice of the doctor. The pharmacy was required to dispense the exact product name written on the prescription. This changed in March 2001 when pharmacies were allowed to substitute a branded drug for a generic, independent of the product name prescribed by the doctor. Being permitted to intervene between the physician and the patient, the pharmacies now got an active role in the market for generics. The doctor can still guard against substitution, but this requires an explicit reservation to be added to the prescription note ("active substitution method").

In Norway, the physicians objected substitution on 5.2% of the prescriptions in 2005, and on 4.5% in 2006, Brekke et al (2012). Even without such a reservation by the physician, the patient may insist on the branded drug, in which case the pharmacy is obligated to hand out the brand-name drug. In this case, the insurance scheme does not cover the price difference between the branded drug and the reference price. The difference has to be paid by the patient himself. In 2005, the patients refused to substitute on 4.0% of the prescriptions (4.3% in 2006). These come in addition to the reservations made by the physicians, bringing total number refusals to substitute close to an average of 10% of all prescriptions. The two drugs we analyse here are all approved for reimbursement of part of the expenses by the social insurance scheme. For both drugs patents have expired. Thus patients/doctor can freely choose between brand-name drugs and generics.

In the period consider here there was a price cap on brand name products. Under the price cap scheme alone, the regulator sets a maximum price level defined by the lowest observed prices in a selection of European countries. This price cap is first set when the brand-name drug enters the market. After patent expiration, generic drugs are given the exact same price cap, and this cap will only fall if generic competition triggers price reductions in the reference countries. However, competition from generics (made possible by generic substitution) was supposed to lower prices below the price cap.

In most studies of pharmaceuticals, information about prices at the different levels of the market has been lacking. Examples are Coscelli (2000) who was able to reveal the habit behaviour claimed by Hellerstein (1998). Lundin (2000) had access to retail prices (only) and found support for habit persistence among doctors and patients, but the results indicated that these are affected by the price differences – especially the share of price differences covered by the patient. If the price differences between generic and brand-name increases, the doctor becomes more inclined to prescribe a generic version.

The data we use here are register data for the period 2004-2006. We have access to unique price data that give the prices set by the brand-name producers as well as by the retailers/wholesalers. Our results indeed clearly indicate that if only the demand side is estimated, the estimates of price responses are biased. It should be noted that what we analyse here are products which from a medical point of view are perfect substitutes. The chemical substance in the brand-name products and the generics are identical. We should thus expect the demand elasticities to be numerically high.

The paper is organised as follows. In Section 2 we present the theoretical models and the econometric models that take the model to data. We let patients and doctors choose between brand-name drug and generics across the three pharmacy chains[5]. We specify how the brand-name producers and the generics producers set their prices. Section 3 reports estimates and price elasticities. Section 4 concludes.

2. Demand and pricesetting

The pharmaceuticals can be specified according to chemical substance. One specific substance, identified by atc code[6], is one market. In each market the patient/doctors can choose between the brand-name product and generics and between three pharmacy chains. The model deals therefore with generic substitution.

2.1 The demand side

2.1.1 Demand, given the chain

Let U_{ncd} be the utility for patient/doctor n of using drug d bought in retailer chain c, where d=B,G and c=1,2,3. B stands for brand-name product and G for generics, of which there can be many different drugs but with the same chemical substance. Let P_{cd} be the price of the drug d in retailer chain c. We will assume that

$$U_{ncd} = a_{cd} + bP_{cd} + \varepsilon_{ncd} \quad (1)$$

Here a_{cd} and b (<0) are constants. ε_{ncd} is assumed to be extreme value distributed with zero expectation and unit variance. The latter means that the coefficients a_{cd} and b are scaled with the

[5] Chains: 1 Holtung, 2 NMD, 3 Apokjeden

[6] Anatomical Therapeutic Chemical Classification System

standard deviation of the extreme value distributed taste shifter. For each chain we get the following choice probabilities, denoted Y_{cd}.

(2)
$$Y_{cd} = \frac{exp(v_{cd})}{\sum_{s=B,G} exp(v_{cs})}; c = 1,2,3; d = B,G$$

where

(3)
$$v_{cd} = a_{cd} + bP_{cd}$$

To this end we divide trough the probabilities by v_{1B}. The brand-name drug sold by chain 1 is therefore the reference case.

2.1.2 The choice of chain

Let Z_c denote the probability of choosing chain *c, c*=1,2,3, and it is given by

(4)
$$Z_c = \frac{exp(S_c)}{\sum_{r=1}^{3} exp(S_r)} = \frac{\sum_{j=B,G} exp(v_{cj})}{\sum_{r=1}^{3} \sum_{j=B,G} exp(v_{rj})}; \quad c = 1,2,3$$

(5)
$$S_c = ln \sum_{j=B,G} (exp(v_{cj}))$$

S_c is the expected value of the maximum of utility, see Train (2003), and Z_c is thus the ratio of the expected value of the maximum utility of choosing chain *c* to the sum of the expected value of maximum utility across the three chains.

2.1.3 The choice of drug

The unconditional probability of choosing a generic drug is then given by the product of Y_{cd} and Z_c, which here will be denoted X_{cd}:

(6)
$$X_{cd} = Y_{cd} Z_c = \frac{exp(v_{cd})}{\sum_{r=1}^{3} \sum_{j=B,G} exp(v_{rj})}; c = 1,2,3, d = B,G$$

Note that when the agents choose between generics/brand **and** chains, $X_{cG} + X_{cB}$ is not equal to one, but $\sum_{r=1}^{3} \sum_{j=B,G} X_{rj} = 1$

The empirical parallel to the aggregate demand probabilities are market shares. In the empirical part we will come back to how we deal with the heterogeneity in the market share equations.

2.2 The supply side: A non-cooperative game

There are three stages in this game. In the first stage the brand-name producer sets the price. In doing so he takes into account the demand structure and the price setting of the generic producers and the retailers. In the second stage the generic producers set their prices and in third stage the retailer set his prices, given the prices set by the generic producers and brand-name producer (see Figure 1).

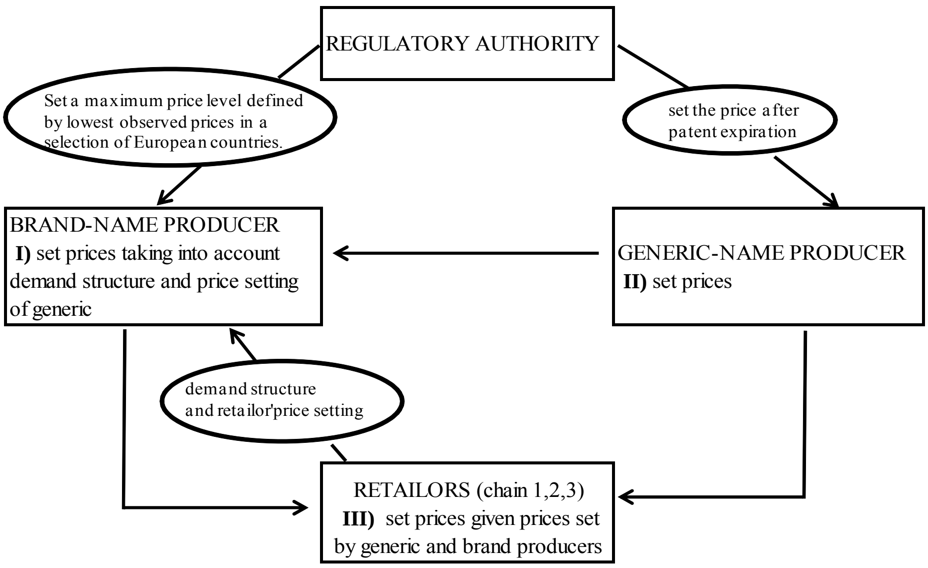

Figure 1. Stage representation of the game

As common in these games we start backwards. The type of model we employ, which combine a demand model derived from logit probabilities and monopolistic price setting, is discussed at length in Anderson et al (1992).

2.3 Pricing decisions of three retailer/wholesalers chains

For expository reason we only specify one supplier of generics. The expected profit of the chain *c* is given by

(7) $$\pi_c = (P_{cB} - q_{cB})X_{cB} + (P_{cG} - q_{cG})X_{cG};\ c = 1,2,3$$

Here q_{cB} is what retailer *c* has to pay for the brand-name product, while q_{cG} is what he has to pay for the generic product. In the expression above we have set the number of potential users equal to 1, which is a normalisation without any implications for the results. In Norway brand-name prices are regulated with a price-cap (Brekke et al 2012):

(8) $$P_{cB} = \overline{P}_{cB}$$

Maximizing expected profit with respect to the price of generics yields the following first order condition:

(9) $$\frac{\partial \pi_c}{\partial P_{cG}} = (\overline{P}_{cB} - q_{cB})\frac{\partial X_{cB}}{\partial P_{cG}} + X_{cG} + (P_{cG} - q_{cG})\frac{\partial X_{cg}}{\partial P_{cG}} = 0 \quad for\ c = 1,2,3$$

Given the structure of the market shares that we assume that the retailer knows, we then get the following price setting of generics:

(10) $$P_{cG} = q_{cG} + \frac{1}{(-b)(1 - X_{cG})} + \frac{X_{cB}}{1 - X_{cG}}(\overline{P}_{cB} - q_{cB});\ c = 1,2,3$$

The first element on the right hand side, q_{cG}, is the direct cost to the retailer chain *c* of buying generics. The second element is the standard mark-up in these types of models (see Anderson et al (1992), while the third element captures the opportunity cost related to the fact that the retailer can sell brand-name products instead of generics. After some time-consuming but straight-forward calculations, we find that

(11) $$\frac{\partial P_{cG}}{\partial q_{cB}} = -X_{cB} < 0$$

Thus, if the brand-name producer increases his price, the retailer respond by lowering the price of generics in order to shift the sale in pharmacies towards more generics.

2.4 Pricing decisions of the generic producers

To simply matters without introducing too strong assumptions we assume that the prices of generics are set equal to marginal cost, k_G. The marginal cost is not observed but will be estimated together with the other unknown parameters of the model.

(12) $q_{cG} = k_G$

2.5 Pricing decision of the brand producer

The expected profit of the brand producer is given by

(13) $\pi_B = \sum_{c=1,2,3} (q_{cB} - k_B) X_{cB}$

In maximizing expected profit with respect to the price, q_{cB}, the brand-name producer takes into account how the retailers set their price of generics in response to the price of brand-name product, i.e. equation (11). The marginal cost is k_B. The first order condition becomes:

(14) $q_{cB} = k_B + \frac{1}{(-b) X_{cG} X_{cB}}$

2.6 The econometric model

The structural model outlined above will be estimated on *aggregated quarterly data*. The demand probabilities will be specified as market shares; or rather as log odds ratios. These log odds ratio may depend on unobserved heterogeneity in the population of doctors, patients and chains. Both the market shares and the pricing equations will therefore contain unobserved characteristics distributed according to specified (i.e. normal) distribution functions. First we estimate the demand side only. Second we estimate jointly the demand side and the pricing equations (i.e. the equilibrium model). When estimating the model we include a *Jacobian transformation* which gives the transformation from the distribution of the unobserved random variables to the distribution of the observed endogenous random variables. In both cases the unknown coefficients are estimated by maximizing the implied log-likelihood for the observed sample. Appendix 1 gives the specification of the econometric model and the estimation strategy. Results for two different drugs are given in Section 3 where we also report demand elasticites, denoted $E_{cdit,}$ given by

(15) $E_{cdit}=b_i(1-X_{cdit})P_{cdit}$; $c=1,2,3,d=B,G,\ i=1,2,,,I,\ t=1,2,,,T.$

3. Estimates and elasticities

Below we show the result for two important drugs in the Norwegian market: Seroxat/Paroxetin (drug against depression)[7] and Amlodpin/Norvasc[8] (drug against angina pectoris).

3.1. Summary Statistics

In Appendix 2 we have listed the variables used in estimating the model. In Table 1 below we give summary statistics for retail prices and producer prices for brand name drugs. The prices are NOK per DDD (Defined Daily Doses). In Tables 2 and 3 we report the observed market shares for the three chains. The data are quarterly data, from 2004 to 2008. For Seroxat/Paroxetin we have 14 quarters and for Amlodpin/Norvasc 15 quarters.

Table 1. Retail prices and producer prices of the brand name drugs. Prices are NOK per DDD (constant 2008 prices).

atc kode: N06AB05 (Seroxat, Paroxetin) n. obs 14					**atc kode: C08CA01 (Amlodipin, Norvasc) n. obs 15**				
	Mean	Std.Dev.	Min	Max		Mean	Std.Dev.	Min	Max
Retail brand price:					**Retail brand price:**				
Holtung	6.4904	1.6294	3.7613	8.2635	Holtung	3.4308	0.6698	2.8177	4.8262
NMD	5.5363	1.7946	3.3621	8.3736	NMD	3.3446	0.6001	2.7939	4.6527
Apokjeden	6.6516	1.3480	4.1844	8.2706	Apokjeden	3.3037	0.5425	2.8544	4.7287
Retail generic price:					**Retail generic price:**				
Holtung	4.2019	2.1841	2.4222	8.0266	Holtung	1.8870	1.0280	1.1834	4.4075
NMD	4.1310	2.1404	2.3763	7.9805	NMD	1.7835	0.8048	1.1852	3.5540
Apokjeden	4.1010	2.0642	2.3519	7.5591	Apokjeden	1.8955	1.0358	1.1987	4.3877
Producer brand price:					**Producer brand price:**				
Holtung	3.8757	1.2812	1.4927	5.7134	Holtung	2.1636	0.4118	1.8534	3.2379
NMD	3.0472	1.2508	1.9000	5.3101	NMD	1.8973	0.1665	1.8175	2.4769
Apokjeden	3.6785	0.9557	2.5175	4.8691	Apokjeden	1.9889	0.2796	1.8609	2.9036

[7] An antidepressant drug of the SSRI type. Paroxetine is used to treat major depression, obsessive-compulsive disorder, panic disorder, social anxiety, post-traumatic stress and generalized anxiety disorder in adult outpatients.
[8] An anti-hypertensive used in the treatment of angina pectoris.

We observe that there is some variation in prices across the three chains. This is particular the case for the brand-name drugs. We also note there is a substantial margin in the chains for selling brand- name drugs.

Table 2 Market shares, N06AB05 (Seroxat, Paroxetin). 14 quarters.

Holtung Brand	Holtung Generics	NMD Brand	NMD Generics	Apokjeden Brand	Apokjeden Generics	Sum
0.1468	0.0743	0.3436	0.1291	0.1498	0.1564	1.0000
0.1696	0.0921	0.2156	0.1347	0.1770	0.2110	1.0000
0.0756	0.1912	0.0869	0.2555	0.0862	0.3046	1.0000
0.0334	0.2228	0.0775	0.2583	0.0538	0.3542	1.0000
0.0278	0.2194	0.0782	0.2603	0.0507	0.3637	1.0000
0.0289	0.2186	0.0719	0.2612	0.0500	0.3694	1.0000
0.0336	0.2242	0.0759	0.2613	0.0502	0.3531	1.0000
0.0347	0.2179	0.0794	0.2605	0.0538	0.3537	1.0000
0.0365	0.2081	0.0823	0.2657	0.0598	0.3476	1.0000
0.0389	0.2087	0.1098	0.2364	0.0613	0.3450	1.0000
0.0335	0.2092	0.1005	0.4905	0.1066	0.0569	1.0000
0.1098	0.1017	0.0584	0.3243	0.1658	0.2400	1.0000
0.1951	0.0524	0.0550	0.2962	0.0816	0.3196	1.0000
0.2233	0.0267	0.0562	0.2933	0.0715	0.3289	1.0000

Table 3 Market shares, C08CA01 (Amlodipin, Norvasc).15 quarters

Holtung Brand	Holtung Generics	NMD Brand	NMD Generics	Apokjeden Brand	Apokjeden Generics	Sum
0.1886	0.0995	0.2605	0.0446	0.1854	0.2214	1.0000
0.1610	0.1255	0.1804	0.1280	0.1726	0.2325	1.0000
0.0943	0.1923	0.1100	0.1951	0.1306	0.2776	1.0000
0.0402	0.2324	0.0797	0.2300	0.0775	0.3403	1.0000
0.0356	0.2407	0.0429	0.2612	0.0632	0.3564	1.0000
0.0329	0.2369	0.0421	0.2538	0.0604	0.3739	1.0000
0.0337	0.2357	0.0412	0.2579	0.0579	0.3736	1.0000
0.0339	0.1903	0.0439	0.2783	0.0566	0.3969	1.0000
0.0362	0.2169	0.0410	0.2679	0.0573	0.3806	1.0000
0.0368	0.2263	0.0406	0.2656	0.0574	0.3734	1.0000
0.0379	0.2280	0.0421	0.2665	0.0572	0.3682	1.0000
0.0451	0.1701	0.0517	0.1981	0.0671	0.4679	1.0000
0.0408	0.2232	0.0445	0.2695	0.0532	0.3688	1.0000
0.0384	0.2256	0.0419	0.2709	0.0522	0.3710	1.0000
0.0370	0.2277	0.0419	0.2674	0.0523	0.3737	1.0000

From Tables 2 and 3 we observe that there is a substantial variation in market shares across time and chains. For both drugs, the third chain, Apokjeden, tends to have a higher share on average of generics than the two other chains.

3.2 Estimates

Tables 4 and 5 give the estimates. We first observe that the coefficient in front of price is negative and significant both in the demand model and in the equilibrium model. As alluded to above the numerical value of the price coefficient is significantly higher when the equilibrium process is accounted for relative to the outcome of only using the demand side, i.e. market shares, in estimating price responses. Second, the unobserved heterogeneity as measured by the estimated standard deviations is an important factor in explaining the observed choices. In particular, this is the case for the producer price formation for brand name drugs. The estimates of the marginal cost of producing generics, here assumed to equal the producer price of generics, are considerably lower than the retail prices of generics. This indicates a substantial margin of the generics sold by the retailers.

Table 4. Estimates. ATC code NO6AB05: Seroxat, Paroxetin

	Demand model		Equilibrium model	
Parameters	Estimates	t-values	Estimates	t-values
a_{2B}	-0.1441	-0.9449	-0.3341	-1.4790
a_{3B}	0.3148	4.6985	0.3469	5.6224
a_{1G}	-0.4669	-1.5228	-0.9227	-3.1109
a_{2G}	0.1061	0.5954	-0.3638	-2.1176
a_{3G}	0.1498	0.5916	-0.3261	-1.2292
b	**-0.5503**	**-9.3748**	**-0.7495**	**-13.7271**
k_G			2.0257	5.9830
σ_{B2}	0.5309	4.3445	0.8227	4.5833
σ_{B3}	0.2482	4.8955	0.2284	5.2027
σ_{G1}	1.0311	5.2715	1.0062	5.2902
σ_{G2}	0.4191	5.0985	0.4251	5.0789
σ_{G3}	0.7883	5.2729	0.8645	5.2047
σ_{P1}			2.0861	5.2481
σ_{P2}			2.0485	5.2837
σ_{P3}			1.9399	5.2715
σ_{Q1}			164.0017	4.9224
σ_{Q2}			59.5189	4.9068
σ_{Q3}			78.0807	4.9118
Log-likelihood	8.4541		53.8313	

* For the meaning of the parameter' symbols see Appendix 1

Table 5. Estimates. ATC code C08CA01:Amlodpin,Norvasc

	Demand model		Equilibrium model	
Parameters	Estimates	t-values	Estimates	t-values
a_{2B}	0.1341	7.2097	0.1036	3.6608
a_{3B}	0.3028	6.977	0.2579	4.7148
a_{1G}	0.3066	1.8787	-0.2391	-1.2363
a_{2G}	0.3029	1.2399	-0.2794	-1.0418
a_{3G}	0.8633	5.7248	0.3205	1.7231
b	**-0.7148**	**-10.4503**	**-1.0683**	**-11.082**
k_G			0.4332	2.4868
σ_{B2}			0.1046	4.3583
σ_{B3}	0.0683	5.4206	0.2063	5.1191
σ_{G1}	0.1648	5.3856	0.4779	5.3757
σ_{G2}	0.482	5.4157	0.8367	5.4722
σ_{G3}	0.8398	5.4746	0.4367	5.2299
σ_{P1}	0.4195	5.4129	0.9603	5.4254
σ_{P2}			0.7226	5.466
σ_{P3}			1.0276	5.4313
σ_{Q1}			103.3854	4.8912
σ_{Q2}			75.9816	4.8869
σ_{Q3}			37.7333	4.8618
Log-likelihood	56.3915		181.7330	

* For the meaning of the parameter' symbols see Appendix 1

3.3. Own price elasticities

Table 6 and 7 give the elasticities for the two drugs. In both cases the brand elasticites tend to be higher than the generic elasticities, which follows from the fact that the price of bran- named drugs exceeds the price of generics. Moreover, the brand name market shares are lower than the market shares for generics in almost all periods and for all three chains. According to the formula (15) higher prices and lower market shares will contribute to higher elasticities. Most important here, however, is the result that the elasticities are numerically higher when the equilibrium process is accounted for compared to when only a demand model is used in estimating the elasticities.

Table 6. Own price elasticities. N06AB05: Seroxat and Paroxetin.

	Demand model						Equilibrium model					
	Brand			Generic			Brand			Generic		
Chain*	1	2	3	1	2	3	1	2	3	1	2	3
Mean, all periods	-3.29	-2.68	-3.34	-1.95	-1.73	-1.61	-4.48	-3.65	-4.55	-2.65	-2.36	-2.2
Last period	-1.63	-3.18	-3.05	-1.3	-0.93	-0.89	-2.22	-4.34	-4.16	-1.78	-1.26	-1.21

Chains: 1 Holtung, 2 NMD, 3 Apokjeden

Table 7. Own price elasticities.C08CA01: Amlodpin,Norvasc.

	Demand model						Equilibrium model					
	Brand			Generic			Brand			Generic		
Chain*	1	2	3	1	2	3	1	2	3	1	2	3
Mean, all periods	-2.29	-2.2	-2.16	-1.1	-1.01	-0.92	-3.43	-3.28	-3.23	-1.64	-1.51	-1.37
Last period	-1.95	-1.96	-1.97	-0.67	-0.64	-0.54	-2.92	-2.94	-2.94	-1.01	-0.95	-0.81

Chains: 1 Holtung, 2 NMD, 3 Apokjeden

5. Conclusions

When estimating price response based on demand modelling only, the risk is that the estimates of price elasticites can be biased. Price responses could be underestimated, as demonstrated above. This will be the case if there are unobserved elements in the demand model that correlates with price. There are two ways of dealing with this problem: One could either employ an instrument variable approach or as done here, modelling the assumed whole data generating approach of demand and prices. The advantage of an instrument variable approach is that it is rather straightforward to estimate the model. The disadvantage is that it is hard to find good instruments. The advantage of estimating jointly the demand and the price formation is that one avoids the search for proper instruments. The disadvantage is that it could be hard to estimate the model. But as shown here, with the software and computers available to day this joint estimation of demand and price setting is manageable.

References

Anderson, S.P., Palma, A.D. and Thisse J.F. (1992): *Discrete choice theory of product differentiation*, MIT Press.

Brekke. K.R., Dalen, D.M. and Strøm, S. (2012): Should Pharmaceuticals Costs be Curbed? *Nordic Economic Policy Review*, 2, 1-28.

Coscelli A. (2000): “The Importance of Doctors’ and Patients’ Preferences in the Prescription Decision”, *Journal of Industrial Economics* Vol. **3**, pp. 349-369.

Haavelmo, T. (1943): “The Statistical Implications of a System of Simultaneous Equations”, *Econometrica* 11(1), 1-12.

Haavelmo, T. (1944): “The Probability Approach in Econometrics”, *Econometrica*, 12 (supplement), iii-vi and 1-115.

Hellerstein J. (1998): “The Importance of Physician in the Generic versus Trad-Name Prescription Decision”, *RAND Journal of Economics,* Vol. **29**, pp 109-136.

Lundin, D. (2000): Moral Hazard in Physician Prescription Behaviour. *Journal of Health Economics*, Vol. **19** (5), pp 639-662.

Train, K.E. (2009): *Discrete Choice Methods with Simulation* (2nd ed.). Cambridge: Cambridge University Press.http://dx.doi.org/10.1017/CBO9780511753930

Vogler S. (2012: “The Impact of Pharmaceutical Pricing and Reimbursement Policies on Generics Uptake: Implementation of Policy Options on Generics in 29 European Countries–An Overview. Available from: http://gabi-journal.net/the-impact-of-pharmaceutical-pricing-and-reimbursement-policies-on-generics-uptake-implementation-of-policy-options-on-generics-in-29-european-countries%E2%94%80an-overview.html

Appendix 1. Econometric specification and estimation strategy

The structural model outlined above will be estimated on aggregated quarterly data. The demand probabilities will hence be specified as market shares; or rather as log odds ratios. These log odds ratio may depend on unobserved heterogeneity in the population of doctors, patients and chains. Both the market shares and the pricing equations will therefore contain unobserved characteristics distributed according to specified distribution functions.

Demand

$$(1)\quad ln\left[\frac{X_{cBit}}{1-\sum_{r=2,3} X_{rBit} - \sum_{r=1,2,3} X_{rGit}}\right] = a_{cBi} + b_i(\overline{P}_{cBit} - \overline{P}_{1Bit}) + \varepsilon_{cBit}; c = 2,3, i = 1,2,,,I, t = 1,2,,,T$$

$$(2)\quad ln\left[\frac{X_{cGit}}{1-\sum_{r=2,3} X_{rBit} - \sum_{r=1,2,3} X_{rGit}}\right] = a_{cGi} + b_i(P_{cGit} - \overline{P}_{1Bit}) + \varepsilon_{cGit}; c = 1,2,3, i = 1,2,,,I, t = 1,2,,,T$$

The subscript *i* denotes the drug type *i* and *t* denotes the month.
Given the drug type *i*, the *ε*-s are iid normal. For the moment we ignore possible correlations.

Retail prices

$$(3)\quad P_{1Git} = k_{Gi} + \frac{1}{(-b_i)(1-X_{cGit})} + \frac{1-\sum_{r=2,3} X_{rBit} - \sum_{r=1,2,3} X_{rGit}}{1-X_{cGit}}(\overline{P}_{1Bit} - q_{1Bit}) + \eta_{cG1t}; \ for\ c = 1$$

$$(4)\quad P_{cGit} = k_{Gi} + \frac{1}{(-b_i)(1-X_{cGit})} + \frac{X_{cBit}}{1-X_{cGit}}(\overline{P}_{cBit} - q_{cBit}) + \eta_{cGit}; c = 2,3, i = 1,2,,,I, t = 1,2,,,T$$

The η_{cGit}-s are iid log-normal and capture unobserved characteristic of pricing and/or marginal costs of producing generics other than unobserved characteristic in the population of doctors, patients and chains.

Brand – name prices

$$(5)\quad q_{cB1t} = k_{Bi} + \frac{1}{(-b_i)X_{1Git}\left[1-\sum_{r=2,3} X_{rBit} - \sum_{r=1,2,3} X_{rGit}\right]} + \mu_{1Bit}; \ for\ c = 1$$

$$(6)\quad q_{cBit} = k_{Bi} + \frac{1}{(-b_i)X_{cGit}X_{cBit}} + \mu_{cBit}; c = 2,3, i = 1,2,,,I, t = 1,2,,,T$$

The μ_{cGit}-s iid log-normal and capture unobserved characteristic of pricing and/or marginal costs of producing generics other than unobserved characteristic in the population of doctors, patients and chains.

Demand (reference case)

$$(7)\ B_2(X_{2Bit}, X_{3Bit}, X_{1Git}, X_{2Git}, X_{3Git}) = ln\left[\frac{X_{2Bit}}{1-\sum_{r=2,3} X_{rBit} - \sum_{r=1,2,3} X_{rGit}}\right] - a_{2Bi} - b_i(\overline{P}_{2Bit} - \overline{P}_{1Bit})$$

$$(8)\ B_3(X_{2Bit}, X_{3Bit}, X_{1Git}, X_{2Git}, X_{3Git}) = ln\left[\frac{X_{3Bit}}{1-\sum_{r=2,3} X_{rBit} - \sum_{r=1,2,3} X_{rGit}}\right] - a_{3Bi} - b_i(\overline{P}_{3Bit} - \overline{P}_{1Bit})$$

$$(9)\ G_1(X_{2Bit}, X_{3Bit}, X_{1Git}, X_{2Git}, X_{3Git}, P_{1Git}) = ln\left[\frac{X_{1Git}}{1-\sum_{r=2,3} X_{rBit} - \sum_{r=1,2,3} X_{rGit}}\right] - a_{1Gi} - b_i(P_{1Git} - \overline{P}_{1Bit})$$

$$(10)\ G_2(X_{2Bit}, X_{3Bit}, X_{1Git}, X_{2Git}, X_{3Git}, P_{2Git}) = ln\left[\frac{X_{2Git}}{1-\sum_{r=2,3} X_{rBit} - \sum_{r=1,2,3} X_{rGit}}\right] - a_{2Gi} - b_i(P_{2Git} - \overline{P}_{1Bit})$$

$$(11)\ G_3(X_{2Bit}, X_{3Bit}, X_{1Git}, X_{2Git}, X_{3Git}, P_{1Git}) = ln\left[\frac{X_{3Git}}{1-\sum_{r=2,3} X_{rBit} - \sum_{r=1,2,3} X_{rGit}}\right] - a_{3Gi} - b_i(P_{3Git} - \overline{P}_{1Bit})$$

Retailers/wholesalers

$$(12)\ P_1(X_{2Bit}, X_{3Bit}, X_{1Git}, X_{2Git}, X_{3Git}, P_{1Git}, q_{1Bit}) = P_{1Git} - k_{Gi} - \frac{1}{(-b_i)(1 - X_{1Git})} - \frac{1 - \sum_{r=2,3} X_{rBit} - \sum_{r=1,2,3} X_{rGit}}{1 - X_{1G1t}} (\overline{P}_{1Bit} - q_{1Bit})$$

$$(13)\ P_2(X_{2Bit}, X_{2Git}, P_{2Git}, q_{2Bit}) = P_{2Git} - k_{Gi} - \frac{1}{(-b_i)(1 - X_{2Git})} - \frac{X_{2Bit}}{1 - X_{2Git}} (\overline{P}_{2Bit} - q_{2Bit})$$

$$(14)\ P_3(X_{3Bit}, X_{3Git}, P_{3Git}, q_{3Bit}) = P_{3Git} - k_{Gi} - \frac{1}{(-b_i)(1 - X_{3Git})} - \frac{X_{3Bit}}{1 - X_{2Git}} (\overline{P}_{3Bit} - q_{3Bit})$$

Producers

$$(15)\ Q_1(X_{2Bit}, X_{3Bit}, X_{1Git}, X_{2Git}, X_{3Git}, q_{1Bit}) = q_{1Bit} - k_{Bi} - \frac{1}{(-b_i) X_{1Git} \left[1 - \sum_{r=2,3} X_{rBit} - \sum_{r=1,2,3} X_{rGit} \right]}$$

$$(16)\ Q_2(X_{2Bit}, X_{2Git}, q_{2Bit}) = q_{2Bit} - k_{Bi} - \frac{1}{(-b_i) X_{2Git} X_{2Bit}}$$

$$(17)\ Q_3(X_{3Bit}, X_{3Git}, q_{3Bit}) = q_{2Bit} - k_{Bi} - \frac{1}{(-b_i) X_{3Git} X_{3Bit}}$$

To sum up, the estimation strategy is the following:

1) We estimate the model(s) for each i separately. One i is one chemical substance; that is one market.
2) For each market i we have time-series observations (quarterly observations)
3) We estimate first the demand model; that is based only the iid normal with the likelihood (f(.) is the standard normal density):

$$L_i = \prod_t \frac{1}{\sigma_{B2}} f\left(\frac{B_{2it}}{\sigma_{B2}}\right) \frac{1}{\sigma_{B3}} f\left(\frac{B_{3it}}{\sigma_{B3}}\right) \frac{1}{\sigma_{G1}} f\left(\frac{G_{1it}}{\sigma_{G1}}\right) \frac{1}{\sigma_{G2}} f\left(\frac{G_{2it}}{\sigma_{G2}}\right) \frac{1}{\sigma_{G3}} f\left(\frac{G_{3it}}{\sigma_{G3}}\right).$$

   We obtain estimates of the α–s, the *b*-s and the σ-s.

4) Then we estimate the whole model, separately for each market, in a simultaneous approach. The likelihood is then given by L_i:

$$L_i = \prod_t \frac{1}{\sigma_{B2}} f\left(\frac{B_{2it}}{\sigma_{B2}}\right) \frac{1}{\sigma_{B3}} f\left(\frac{B_{3it}}{\sigma_{B3}}\right) \frac{1}{\sigma_{G1}} f\left(\frac{G_{1it}}{\sigma_{G1}}\right) \frac{1}{\sigma_{G2}} f\left(\frac{G_{2it}}{\sigma_{G2}}\right) \frac{1}{\sigma_{G3}} f\left(\frac{G_{3it}}{\sigma_{G3}}\right) \frac{1}{\sigma_{P1}} f\left(\frac{P_{1it}}{\sigma_{P1}}\right) \frac{1}{\sigma_{P2}} f\left(\frac{P_{2it}}{\sigma_{P2}}\right) \frac{1}{\sigma_{P3}} f\left(\frac{P_{3it}}{\sigma_{P3}}\right) \frac{1}{\sigma_{Q1}} f\left(\frac{Q_{1it}}{\sigma_{Q1}}\right) \frac{1}{\sigma_{Q2}} f\left(\frac{Q_{2it}}{\sigma_{Q2}}\right) \frac{1}{\sigma_{Q3}} f\left(\frac{Q_{3it}}{\sigma_{Q3}}\right) |J_{it}|$$

Here $\left|J_{it}\right|$ is the numerical value of the Jacobian determinant, which is the determinant of the 11x11 matrix below. The reason for including the Jacobian is that it is needed when going from the distribution of the unobserved random variables to the observed random variables (market shares and prices).

5) We then compare the estimates obtained in point 1) with the ones obtained in point 5). Our hypothesis is that demand is more responsive when we have accounted for equilibrium effects.

$$J_{it} = \begin{pmatrix} X_{1Bit}^{-1} + X_{2Bit}^{-1}, X_{1Bit}^{-1}, X_{1Bit}^{-1}, X_{1Bit}^{-1}, X_{1Bit}^{-1}, 0, 0, 0, 0, 0, 0 \\ X_{1Bit}^{-1}, X_{1Bit}^{-1} + X_{3Bit}^{-1}, X_{1Bit}^{-1}, X_{1Bit}^{-1}, X_{1Bit}^{-1}, 0, 0, 0, 0, 0, 0 \\ X_{1Bit}^{-1}, X_{1Bit}^{-1}, X_{1Bit}^{-1} + X_{1Git}^{-1}, X_{1Bit}^{-1}, X_{1Bit}^{-1}, -b_i, 0, 0, 0, 0, 0 \\ X_{1Bit}^{-1}, X_{1Bit}^{-1}, X_{1Bit}^{-1}, X_{1Bit}^{-1} + X_{2Git}^{-1}, X_{1Bit}^{-1}, 0, -b_i, 0, 0, 0, 0 \\ X_{1Bit}^{-1}, X_{1Bit}^{-1}, X_{1Bit}^{-1}, X_{1Bit}^{-1}, X_{1Bit}^{-1} + X_{3Git}^{-1}, 0, 0, -b_i, 0, 0, 0 \\ 0, 0, -b_i^{-1}(1 - X_{1Git})^{-2}(\overline{P}_{1Bit} - q_{1Bit}), 0, 0, 1, 0, 0, -b_i^{-1}(1 - X_{G1it})^{-1}, 0, 0 \\ 0, 0, 0, -b_i^{-1}(1 - X_{2Git})^{-2}(\overline{P}_{2Bit} - q_{2Bit}), 0, 0, 1, 0, 0, -b_i^{-1}(1 - X_{G2it})^{-1}, 0 \\ 0, 0, 0, 0, -b_i^{-1}(1 - X_{3Git})^{-2}(\overline{P}_{3Bit} - q_{3Bit}), 0, 0, 1, 0, 0, -b_i^{-1}(1 - X_{G3it})^{-1} \\ b_i^{-1}X_{1Git}^{-1}X_{1Bit}^{-2}, b_i^{-1}X_{1Git}^{-1}X_{1Bit}^{-2}, b_i^{-1}X_{1Git}^{-1}X_{1Bit}^{-1}(X_{1Bit}^{-2} - X_{1Git}^{-1}), b_i^{-1}X_{1Git}^{-1}X_{1Bit}^{-2}, b_i^{-1}X_{1Git}^{-1}X_{1Bit}^{-2}, 0, 0, 0, 1, 0, 0 \\ -b_i^{-1}X_{2Git}^{-1}X_{2Bit}^{-2}, 0, 0, -b_i^{-1}X_{2Git}^{-2}X_{2Bit}^{-1}, 0, 0, 0, 0, 0, 1, 0 \\ 0, -b_i^{-1}X_{3Git}^{-1}X_{3Bit}^{-2}, 0, 0, -b_i^{-1}X_{3Git}^{-2}X_{3Bit}^{-1}, 0, 0, 0, 0, 0, 1 \end{pmatrix}$$

Appendix 2. Variables

Table 2.1. Description of the variables

variable name	Description
atckode	drug identifier
per	quarterly data from 2004 to 2008
trinnpris1, trinnpric2, trinnpris3	dummy =1 if under step price regulation, 0 otherwise, respectively for chain 1, 2 and 3. Internal reference pricing after 1.1.2005
indeks1, indeks2, indeks3	dummy= 1 if under index price regulation, 0 otherwise, respectively for chain 1, 2 and 3. Internal reference pricing before 2005
ref_price1, ref_price2, ref_price3	Not all substances (atc kode) are subject to internal reference pricing. ref_price*i* is a dummy that indicates if a substance has reference price in chain *i*. Dummy equals to 1 if trinnpris = 1 or indekspris = 1
chain_id1, chain_id2, chain_id3	chain identifier: 1 (holtung), 2 (nmd), 3 (apokjeden)
aup_bn1, aup_bn2, aup_bn3	mean brand retail price per period, respectively for chain 1, 2, and 3.
aup_gen1, aup_gen2, aup_gen3	mean generic retail price per period, respectively for chain 1, 2, and 3.
gip_bn1, gip_bn2, gip_bn3	mean brand manufacture price per period, respectively for chain 1, 2, and 3.
gip_gen1, gip_gen2, gip_gen3	mean generic manufacture price per period, respectively for chain 1, 2, and 3.
vol_bn1, vol_bn2, vol_bn3	volume brand drug in ddd (defined daily dose) respectively for chain 1, 2, and 3.
vol_gen1, vol_gen2, vol_gen3	volume generic drug in ddd respectively for chain 1, 2, and 3.