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Hedonic regression for digital cameras in Germany

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Hedonic Regression for Digital Cameras in Germany¤

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Hedonic Regression for Digital Cameras in Germany*

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Abstract

Standard measures of consumer price inflation are based on a bundle of representative goods. It is well known that this approach might overstate inflation for new products and products with fast increasing quality. For this reason, hedonic adjustment methods have been proposed and introduced in official statistics for some products like personal computers.

In this contribution, we consider the application of a hedonic regression to digital cameras, which have been introduced in the product bundle of the German consumer price index in 2003 – so far without hedonic quality adjustment. We present first results on hedonic price measurement for digital cameras in Germany for the time period 1999 to 2004. The results are based on data sampled from public interest journals and advertisements.

Keywords: Hedonic regression; hedonic price index; quality adjustment.

1 Introduction

Adequate measures of price inflation are important in different fields of economic policy, including monetary policy, measuring of real GDP growth rates,

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wage setting and for defining minimum income levels in social security systems. They are also of interest in business as an estimate of price trends. In both settings, the difficulties to handle goods with rapidly changing characteristics and new goods are relevant. Neglecting these phenomena might lead to severe measurement errors at least for specific product groups. As a means to deal with quality changes, the use of hedonic methods has been suggested, in particular for high technology goods. For example, the German Statistical Office uses hedonic methods for quality adjustment of producer, import and export price indices of electronic data processing equipment since May 2004 (Linz *et al.*, 2004).[1] It shoud been noted that other approaches to quality adjustment have been used by the German Statistical Office much earlier (Kunz, 1971).

However, computers are far from being the only product with rapid quality changes which might justify the use of hedonic methods. In this contribution, we consider the product category of digital cameras, which also experiences a rapid technological development. Although it does not have a similar weight in the consumer price index,[2] it might serve as an example to study the implementation of hedonic price measurement and also for a critical analysis of this method. In fact, the first digital cameras introduced hardly a decade ago were not targeted at the private consumer, but reserved for professional use. These cameras were expensive and had – at least with regard to their electronic equipment – much less capacitiy than today's general consumer models.

The central idea of hedonic quality adjustment consists in exploiting an empirical relationship between product prices and indicators of product quality. This relationship can be found by means of regression analysis. Consequently, the method requires that it is possible to identify and measure a limited number of product properties which mirror product quality and show a relevant impact on product prices. Furthermore, for a successful application of regression analysis, the number of observations per period should not be too small.

[1] This application includes desktop computers, laptops, servers, laser printers, ink jet printers, combined printers, central processor units, memory chips and hard disks. In particular, for the import price index, the weight of these products of about 8.8% is important, while it amounts to only 1.3% for the producer price index.

[2] Of course, the application of hedonic methods is not constraint to the consumer price index. However, our application will focus on the final consumer market.

In this paper, we will present a first hedonic price index for digital cameras sold to the final consumer in Germany for the time period 1999 till 2005. The paper is organized as follows. In section 2 we discuss different hedonic methods, their applications and advantages as well as possible disadvantages of this approach. Section 3 is devoted to our application, introducing the product category, our database, the econometric framework and estimation results, while the hedonic price index itself is reported in section 4. We conclude with some summarizing remarks in section 5.

2 Hedonic Methods

Hedonic regressions became one of the standard tools for quality adjustment when it comes to measure inflation rates (Pakes, 2003). Given the increasing share of high technology products in typical consumption bundles, it becomes increasingly important to take into account price changes resulting from or related to changes in certain characteristics of the goods under analysis. For this purpose, during the last decade, a wide range of quality adjustment methods has been developed (see, e.g., Table 1 in Ahnert and Kenny, 2004, p. 13). Some of these methods are currently used by several European countries for measuring the quality adjusted price developments for the following product categories: Electronic consumer durables, new and/or used cars, garments, men's shirts and best-seller books (Ahnert and Kenny, 2004, p. 17). In particular, for electronic consumer durables, the use of hedonic methods is expected to become more common in the near future. One product category within this commodity class comprises digital cameras, which were first introduced to the German consumer price index in 2003 without using hedonic methods.[3] In this paper, we first discuss and later apply a hedonic method for measuring quality adjusted price changes of digital cameras.

2.1 Imputation

The imputation method is one of the commonly employed hedonic approaches. Linz *et al.* (2004, p. 7f) discuss the imputation method for computer equipment (capital goods). An application to the German house price index is

[3] The weight for the whole category equipment for photography and film, which includes digital cameras, amounts to 0.24% in the German consumer price index weighting scheme of 2003.

provided by Linz and Behrmann (2004, pp. 5ff). The imputation method is used to obtain estimates of (virtual) current prices for electronic consumer durables sold in past years and for (virtual) past prices of products sold in the current period. The aim is, on the one hand, to calculate a today's price for a product that does not exist anymore and, on the other hand, to show which price one would have had to pay in the past for a product sold today. Using this imputation method, prices of products can be compared over two or more periods as a result of their quality characteristics even if the products are not available in all periods. This is the typical situation of high technology products undergoing rapid technical change.

For the imputation of prices, we proceed as follows. First, a past time period has to be selected as "base period", while the present time period is labelled "current period". Next, the data of the available cross-sections for both periods are classified into three subsamples. The first sample (A) comprises products which have been sold in the base period and in the current period, i.e. for both periods prices can be observed and price changes can be directly calculated. Obviously, the price changes for these unchanged products are not related to quality changes. The second sample (B) includes products which were sold in the base period, but for which no price data are available for the current period. For these products, we have to estimate (impute) a price, which would apply given the product characteristics in the current period. Finally, for the third sample (C), we are faced with the opposite problem, i.e. with products sold in the current period which were not yet available in the base period. For these products, prices for the base period have to be imputed. The imputations for samples B and C are based on a regression analysis linking prices to product characteristics. Then, the difference between the imputed price for the current period in sample B (base period in sample C) and the observed price of the base period in sample B (current price in sample C) describes the quality adjusted price changes.

2.2 Double Imputation

A potential drawback of the imputation method as described above results from the comparison of imputed prices with real prices. Consequently, the regression residuals will influence the calculated price changes. In order to avoid this problem, the double imputation method compares estimated prices for both periods (Linz *et al.*, 2004, p. 8). Therefore, the actual prices for the base period (sample B) and current period (sample C), respectively, will be

replaced by their estimates. If unobserved characteristics of a product drive its price above (below) the price predicted by the regression model, this effect should be present to a similar extent in both periods, i.e. both residuals will be positive (negative) and of similar size. Thus, comparing the imputed prices, i.e. omitting the residuals for both observations, reduces a potential bias stemming from unobserved product characteristics.

Consequently, the price changes of products in samples B and C result of a comparison of imputed with estimated prices, while for sample A observed prices for both periods can be used. For sample A, the observed price in the current period will be divided by the observed price for the base period. In sample B, the imputed price of the current period will be divided by estimated prices in the base period, and for sample C the estimated price for the current period is divided by the imputed price for the base period. Thus, for each of the three sub samples, we obtain factors describing the price changes from the base period to the current period.

Usually, a hedonic price index is calculated as a weighted geometric mean of these individual factors. Of course, the standard approach for a weighting scheme, i.e. the turnover of the products in the base period and/or current period cannot be used as for the products in sample B and C this information is only available for either the base period or the current period. Therefore, Linz *et al.* (2004, p. 10) propose to use the total turnover of a producer as weights. Unfortunately, we do not have access to such turnover data. Thus, we first present an unweighted geometric mean. Furthermore, we use consumer survey data providing some estimate of market shares of different producers. These estimates allow for the construction of a weighted price index.

3 Application to Digital Cameras

3.1 Digital Cameras and Data

In principle, the data required for our application on the final consumer market for digital cameras could be gathered by different means. First, we could approach individual resellers of digital cameras. However, in contrast to statistical offices, we could not force companies to provide data. Second, we might try to buy data from market research institutions. This option had to be excluded due to missing funds for the project. Furthermore, the

quality of data obtained from private providers is hard to judge. Finally, we decided to use published data from general public computer magazines and offers on the internet.

In order to obtain comparable data over time, we selected data from a single magazine "PC Professionell" for the years 2001 to 2005. This journal appears monthly and includes a so–called "Bestenliste" featuring the most common digital cameras which are considered to offer the best quality in the relevant market segment. The data for the years 1999 till 2001 were collected from an internet supplier of electronic equipment including digital cameras. The internet supplier is a kind of wholesaler, who has contracts with different camera producers. Only these cameras are listed in the data of 1999 till 2001. For this reason, e.g., Sony cameras cannot be found in the data of 1999 till 2001 although Sony was one of the first digital camera producers in the world.

Of course, the limited data base we use does not allow to assume that the data are representative for the whole market. It is also important to note that the data set does not include high end cameras, e.g., SLR cameras. Nevertheless, it might well reflect the overall trends and the price impact of relevant quality factors.

The number of digital cameras included in the sample increases over time. While our first cross–sections in 1999 and 2000 comprise only 9 and 14 cameras, respectively, our sample for August 2003 includes 38, for August 2004 28 and August 2005 26 digital cameras. To calculate a hedonic price index from year to year, we use data from each August from 1999 till 2005. For the years 1999, 2000 and 2001 the prices are reported in German Mark, but are converted into Euro prior to further analysis. Further information about specifications of the digital cameras and the market shares of digital camera producers are obtained through `www.digitalkamera.de` and the web pages of the companies producing digital cameras.

3.2 Variables

In our model for the price of cameras as a base for hedonic price adjustment, we take into account the following variables: The `price` for final customers measured in Euro. The data from the "Bestenliste" provide means of market prices observed by the editor of the journal, while the price data from the internet supplier are real supply prices. The number of `Megapixel` (mp) of the sensor measures the number of megapixel physically present on the

sensor, i.e. the true hardware resolution. A high resolution allows ceteris paribus for greater details of the pictures. The optical `zoom factor` (zf) is designed as a system of lenses so that its focal length can be varied. In particular, using an optical zoom does not affect the resolution. In contrast, a digital zoom basically works by extracting part of the information obtained from the sensor, i.e. the "effective" resolution will decrease. Consequently, optical zoom factors are more important for high quality results. However, they are also more expensive in production. Thus, the optical zoom factor appears to be a relevant variable for hedonic pricing of digital cameras.

Further variables used in the analysis comprise the following Dummy variables in table 1:

Table 1: Kind of Dummy variables

Capacity of the memory card provided with the camera (megabyte)	Kind of memory card	
D16	SecureDigital-Card	(D^{SD})
D32	CompactFlash I	(D^{CF1})
D64	CompactFlash II	(D^{CF2})
D128	Memorystick	(D^{MS})
D256	Memorystick Duo	(D^{MSD})
	Memorystick Pro	(D^{MSP})
	Memorystick Pro Duo	(D^{MSPD})
	Microdrive	(D^{MD})
	XD-Card	(D^{XD})
	MultiMedia-Card	(D^{MM})
	Smartmedia-Card	(D^{SM})
	Internal memory	(D^{IN})

Thereby, D16 denotes a capacity of the memory card up to 16 megabyte, D32 a capacity between 17 and 32 megabyte etc. Note that it is possible that a camera can be combined with more than one kind of memory card, for example CompactFlash I, CompactFlash II and Microdrive.

3.3 Econometric Model and Results

To model the impact of quality factors on the price of digital cameras, we use a log–linear specification for each cross section. Thereby, the dependent variable is the logarithm of the price of the digital camera, while the factors listed in the previous subsection are the explanatory variables. With the exception of the dummy variables, these explanatory variables enter the estimation equation also as logarithms. The basic econometric specification is given by

$$\begin{aligned} \log p_{it} &= \beta_{0t} + \beta_{1t} \log mp_i + \beta_{2t} \log zf_i \\ &\quad + \delta_{1t} D^{16} + \ldots + \delta_{kt} D^{256} \\ &\quad + \gamma_{1t} D_i^{CT1} + \ldots + \gamma_{lt} D_i^{CTk} + \varepsilon_i \,, \end{aligned} \tag{1}$$

where the index t denotes the time index for a specific cross–section and i is the index for the cameras included in this specific cross–section. The number k of Dummy variables included for different kinds of memory capacity and the number l of memory cards varies across cross–sections depending on the types of memory cards available on the market for the given time period.

As an example, we consider the cross–section for August 2004 comprising 28 observations. Besides the explanatory variables mp_i and zf_i, this specification includes dummy variables for memory capacity D^{16}, D^{32}, D^{64} and the following different card types: CompactFlash(I) (D^{CF1}), CompactFlash(II) (D^{CF2}), Memorystick (D^{MS}), Memorystick-Pro (D^{MSP}), Microdrive (D^{MD}), MultiMedia-Card (D^{MM}), SecureDigital-Card (D^{SD}), XD-Card (D^{XD}) and internal storage (D^{IN}). In August 2004, there exists also a camera with a memory capacity of 256 megabyte. The category D^{256} was chosen as the reference category. The results of a least squares estimation of model (1) using these variables are summarized in table 2.

Due to the log–linear specification (1), the coefficients β_1 and β_2 can be interpreted as the elasticities of the price with regard to the number of megapixel and the zoom factor supplied with the camera, respectively. According to the estimates for August 2004, a doubling of the number of megapixel of the sensor increases the price by 51%, while a doubling of the optical zoom factor has only an effect of 26% on the price of the camera. Finally, the memory supplied with the camera has an increasing, though not significant effect on the price, if the memory card includes less than 32 megabyte. The type of memory card which can be used with a digital

Table 2: Estimation results August 2004

Independent Variables	Dependent Variable log Price	Standard Errors
Constant	4.86**	(0.40)
log Megapixel	0.51**	(0.17)
log Zoom factor	0.26**	(0.07)
D^{16}	0.61	(0.29)
D^{32}	0.40	(0.22)
D^{64}	-0.01	(0.17)
D^{CF1}	-0.29	(0.23)
D^{CF2}	0.29	(0.18)
D^{MS}	-0.43*	(0.18)
D^{MSP}	-0.05	(0.27)
D^{MD}	0.38	(0.23)
D^{MM}	0.05	(0.08)
D^{SD}	-0.34	(0.23)
D^{XD}	-0.35	(0.21)
D^{IN}	-0.16	(0.09)
Adjusted R–squared	0.863	

**, * denotes significance of the coefficients at the 1 and 5%–level, respectively.

camera does not seem to have a significant impact on the price of the camera. Although the effect of different memory cards does not seem to be very important and is not stable comparing different cross–sections, using the F–test, the hypothesis of joint non significance of all card type dummies has to be rejected at the 1% level for the years 1999 till 2003. For August 2004, the null hypothesis can be rejected at the 5% but not at the 1% level.

Nevertheless, the value of the adjusted R^2 amounts to 86,3%, i.e. a large share of the variation of prices of digital cameras in the cross–section can be explained through the variables included in our model. In particular, megapixel and zoom factor have a highly important impact. The unexplained share of prices might be attributed to missing variables. Missing variables might cover further technical features of the camera like red–eye reduction, movie modes, or size of the camera, as well as other aspects such as producer's reputation, design, and the availability of camera specific accessories.

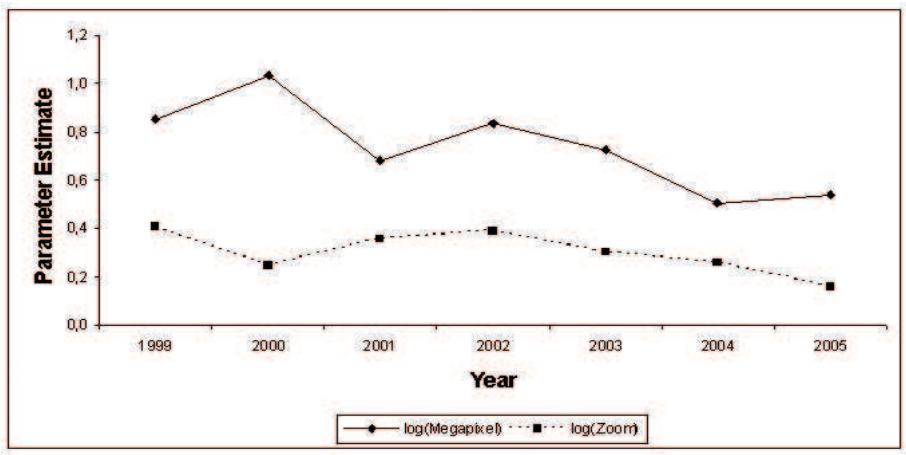
When considering all available cross–sections, it turns out that the coefficients β_{1t} and β_{2t} are always highly significant. In table 3 the values for β_{0t}, β_{1t} and β_{2t} are reported for all cross–sections included in our analysis. The table also provides information on sample size and the R^2 for each cross–section.

Table 3: Coefficients for different cross–sections

Cross–Section	Constant	Megapixel	Zoom factor	Observations	R^2
August 1999	5.75	0.85	0.41	9	0.88
August 2000	5.59	1.03	0.25	14	0.86
August 2001	4.79	0.68	0.36	30	0.92
August 2002	5.24	0.83	0.39	36	0.83
August 2003	6.27	0.73	0.30	38	0.89
August 2004	4.86	0.51	0.26	28	0.93
August 2005	5,35	0,54	0,16	26	0,81

Figure 1 presents the findings for the two most influential variables (megapixel and zoom factor).

Figure 1: Parameter estimates for log(Megapixel) and log(Zoom) over time



Obviously, the impact of the factors varies over time. However, the impact of the number of megapixel is consistently higher than the impact of the optical zoom factor. Furthermore, in particular the first cross–sections are based on a rather limited sample. Consequently, we test the hypotheses that the coefficients β_{1t} and β_{2t} are in fact constant over time. For this purpose, we calculate the mean values $\bar{\beta_{1t}}$ and $\bar{\beta_{2t}}$ and test each individual β_{1t} and β_{2t}, respectively, against these mean values. The hypotheses of constant β_1 and β_2 could never be rejected for any cross–section. Nevertheless, given the rather imprecise estimates for the first two cross–sections and the observed decreasing trend in the parameter estimates afterwards, we do not impose the restriction of constant parameter values for the further analysis. Consequently, the hedonic price index presented in the following section is based on the individual sets of parameter estimates for each time period under consideration.

4 Hedonic Price Index

Our hedonic price index for digital cameras is based on the double imputation method (see subsection 2.2). For this method, both prices used for the index are obtained as forecasts from estimated models. Thus, products with specific features not covered by our variables might exhibit similar residuals in both periods, which cancel in the calculation of the price index. Therefore,

the double imputation method appears more appropriate when the residual variance cannot be neglected. In order to obtain a yearly price index in a first step of the analysis, we choose data for every August for the years 1999 till 2004.

4.1 How to Calculate a Price Index

We describe the actual proceeding for obtaining the yearly price index using the index for the year 2003 as an example. In this case, August 2002 defines the "base period" and August 2003 becomes the "current period". For August 2002, we have 36 observations and for August 2003, we find 39 observations in our data base.

As described in subsection 2.2, we split the data into three subsamples. Sample (A) consists of cameras, which were sold in the base and the current period. Due to the rapid development of technology, only 6 digital cameras of our sample were offered in both periods. For the products in sample (A), the relation of individual base year and current year prices can be calculated directly and is used as price factor $\nabla p_i = p_{i,2002}/p_{i,2003}$ for camera i. Obviously, for this subsample, no quality adjustment is required. Sample (B) consists of the 30 cameras sold in the base period, but not in the current period. It can be assumed that these products have been replaced by more advanced models in the current period. Using the regression results for the base period, a model forecast of the logarithmic base year price ($\log(\hat{p}_{i,2002})$) is calculated. Similarly, the regression model for the current period is used to impute a logarithmic price for the current period ($\log(p^{imp}_{i,2003})$), which is solely based on the quality characteristics of the digital cameras. This estimate can be interpreted as the expected market price if the camera was still on offer in the current period. Using both price forecasts, the individual imputed price change factor ∇p_i can be calculated for all cameras in sample B:

$$\nabla p_i \quad = \quad e^{log(p^{imp}_{i,2003}) - log(\hat{p}_{i,2002})} \, . \tag{2}$$

Finally, sample (C) consists of the 33 cameras, which were sold in the current period, but not in the base period. Therefore, for this cameras, current period prices were forecasted from the regression model for the current period ($\log(\hat{p}_{i,2003})$), while imputed prices are based on the base year regression ($\log(p^{imp}_{i,2002})$). Similar to sample B, the individual price change factors are calculated according to

$$\nabla p_i \quad = \quad e^{log(\hat{p}_{i,2003}) - log(p^{imp}_{i,2002})} \,. \tag{3}$$

Using the individual price change factors obtained for all cameras in the three subsample, an unweighted hedonic price index for 2003 (I^u_{2003}) is obtained by calculating the geometric mean of the price change factors:

$$I^u_{2003} \quad = \quad (\nabla p_1 \cdot \nabla p_2 \cdot \ldots \cdot \nabla p_{69})^{1/69} \,. \tag{4}$$

For the year 2003, e.g., this calculation results in an unweighted hedonic price index of 0.49, i.e. a digital camera of comparable quality has been sold in August 2003 at roughly half of the August 2002 price. However, this calculation does not take into account that the market shares of different cameras differ and might change over time. In order to take this composition effect into account as well, a weighted hedonic price index has to be calculated.

4.2 The Weighted Hedonic Price Index

A weighted hedonic price index results if the individual price factors are weighted with the market share of the product. Unfortunately, we could not obtain any volume information for individual digital cameras nor reliable estimates of market shares of different producers. However, the internet resource used to measure camera characteristics (`www.digitalkamera.de`) also offers the results of a consumer behavior survey once a year. In this survey, consumers are asked from which producer they are going to buy a digital camera if they decide to acquire one. The answers to this question are summarized as expected market shares of different producers. Obviously, this measure is far from being perfect. First, it is a measure related to the cameras' sales figures not to their value. Second, it is doubtful whether the survey participants are representative for the market.

Nevertheless, we calculate a weighted hedonic price index based on this market survey data in order to assess the robustness of our unweighted index. To this end, we grouped our data according to producer groups. For the 2003 example, the 69 cameras are split up into 13 producer groups, e.g. Canon with 7, Casio with 5, Fuji with 8 cameras etc. Within each group, a simple geometric mean of price factors was calculated to obtain a producer specific hedonic price index. Let I_j, $j = 1, \ldots, 13$ denote these producer specific

price indices and ms_j the corresponding market shares. Then, the aggregate weighted price index is obtained as follows:

$$I_{2003} = \prod_{j=1}^{13} I_j^{ms_j} . \tag{5}$$

For 2003, the value of this weighted hedonic price index amounts to 0.48. Thus, the impact of weighting appears to be small for this year. Table 4 summarizes the estimates of unweighted and weighted hedonic year to year price indices for the years 2000 to 2005.[4]

Table 4: Hedonic price indices 2000 – 2004

Year	unweighted index	weighted index
2000	0.80	0.89
2001	0.76	0.77
2002	0.46	0.55
2003	0.49	0.48
2004	0.37	n.a.
2005	0,60	n.a.

Obviously, the decrease in prices as measured by the weighted hedonic year to year price index became more pronounced over time.

5 Conclusions

5.1 Adequacy of Results

Our results on quality adjusted prices of digital cameras indicate a strong and fastening decrease. However, when interpreting these findings, we have to check the relevance of quality adjusted prices for different purposes. In fact, if we assume that consumers have a strong preference for cameras with

[4]There is no data for market shares available since August 2004. So it is not possible to calculate a weighted hedonic price index in 2004 and 2005.

the latest quality characteristics, our approach using hedonic methods might be adequate to demonstrate that the consumer obtains the same quality at falling prices or an increase in quality for given expenditures.

Nevertheless, one could also argue that most consumers do not care about technical characteristics explicitly and do not acquire digital cameras repeatedly. Instead, they rather buy a digital camera for certain applications like holidays, family celebrations etc. Then, a further increase in the number of megapixels might not make a relevant difference once a certain level has been reached. In fact, for this group of consumers an increase in the number of megapixel might result in additional cost for additional disk space on the computer to store larger picture files. Thus, it might be adequate to take this additional cost also into account when measuring price changes. However, such an approach is beyond the scope of our present application.

5.2 Final Remarks

This paper describes the calculation of a hedonic price index for digital cameras based on public available data. It turns out that the resolution of the sensor and the optical zoom factor are the most important quality characteristics which explain about three quarters of the price variation within a given cross–section. Using linear regression models of prices based on these and some additional characteristics provide reasonable parameter estimates and price forecasts starting with 2001. Unfortunately, the number of observations included in our sample is still too small to obtain reliable parameter estimates for the first two years. Therefore, the imputation of a hedonic price index fails for these periods.

The estimated price indices do not change drastically if a weighting based on estimated market shares is introduced. Overall, the quality adjusted prices of digital cameras shrank by roughly 50% per year during the last three years.

Further analysis will concentrate on extending our data base and to incorporate further product characteristics, e.g. power supply, software features, and the availability of camera specific accessories. Furthermore, the adequacy of the hedonic method of quality adjustment will be discussed. Although, the quality adjusted prices of digital cameras fall rapidly, the final consumers' cost of producing photographies might not decrease at the same rate. In particular, more powerful digital cameras require also a more powerful computer equipment to handle the data. Furthermore, consumers might still wish to obtain paper prints. Although the price of paper prints from digital input

decreased over the past few years, it probably did not decrease at the same rate as our hedonic price index of digital cameras. Consequently, the consumers' quality adjusted overall cost of digital photography did not decrease at a rate of 50% per year.

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