OECD Science, Technology and Industry Working Papers
2016/07

Hedonic Prices for Fixed Broadband Services: Estimation across OECD Countries

Carol Corrado,

Olga Ukhaneva

https://dx.doi.org/10.1787/5jlpl4sgc9hj-en

OECD

FOREWORD

The objective of this report is to set out a framework to estimate quality-adjusted price levels and price changes for fixed broadband services in OECD countries and suggest how price comparisons based on random coefficient hedonic models might be useful in telecommunication policy analysis in OECD countries.

The paper was first presented at a joint session of the Working Party on Communication Infrastructures and Services Policy (WPCISP) and the Working Party on Measurement and Analysis of the Digital Economy (WPMADE) and then presented to Committee on Digital Economy Policy (CDEP) for declassification. CDEP declassified this report on December 2015. The release of this working paper has been authorised by Andrew Wyckoff, OECD Director for Science, Technology and Innovation and Martine Durand, OECD Chief Statistician and Director for Statistics.

The document was prepared by Carol Corrado and Olga Ukhaneva, Center for Business and Public Policy, McDonough School of Business, Georgetown University with the support of the following staff at the OECD: Agustin Diaz-Pines, Alexia Lee González Fanfalone, Verena Weber, Yuki Yokomori, Vincenzo Spiezia and Sam Paltridge.

Note to Delegations:
This document is also available on OLIS under the reference code:
DSTI/ICCP CISP IIS(2015)1/FINAL

HEDONIC PRICES FOR FIXED BROADBAND SERVICES: ESTIMATION ACROSS OECD COUNTRIES

Abstract

This paper sets out a framework to estimate quality-adjusted price levels and price changes for fixed broadband services in OECD countries. We extend and adapt existing hedonic frameworks for international and interarea comparisons (e.g., Fixler and Zieschang, 1999; Moulton, 1995; Kokoski, Moulton, and Zieschang, 1999; Heravi, Heston, and Silver, 2003; Aten, 2006) and consider the extended country product dummy approach set out in Aizcorbe and Aten (2004). Hedonic pricing studies often are context and data dependent, and this study is no exception. We find that the multilevel structure of international broadband price datasets (country, service provider, plan) suggests modeling hedonic functions at the company, i.e., internet service provider (ISP) level. This not only mitigates efficiency loss due to lack of subscriber information on individual plans but also allows for company costs and markups to influence estimates of hedonic function coefficients following Pakes (2003). Incorporating random variation in hedonic slope coefficients at the ISP level produces results that statistically dominate standard models where slope coefficients are the same across countries, and we suggest how price comparisons based on random coefficient hedonic models might be useful in telecommunications policy analysis.

Carol Corrado and Olga Ukhaneva[1 2]

JEL codes: C23; C43; C82; E01; E31; F40; L16; L96
Keywords: Hedonic Prices; Broadband Prices; International Price Comparisons; Random Coefficient Models

TABLE OF CONTENTS

1 Introduction

Consumption of advanced content and entertainment over the Internet requires bandwidth, and high-capacity broadband networks are widely understood to be fundamental enablers of the digital economy. Understanding how much and why broadband prices differ across geographies helps a country better design policies to foster economic growth via deepening its society's access to broadband networks. Towards this end, this paper estimates quality-adjusted, internationally comparable prices for residential fixed broadband service across OECD countries. Hedonic methods are typically used in international and interarea comparisons to control for product definitions that are imprecise, i.e., differences in products that could be controlled for directly by using more narrowly defined items. Restricting international comparisons to very narrow levels of product definition comes at the cost of reducing observations, whereas a hedonic method allows greater coverage of products and fuller use of available data. Owing to the proliferation of bundled telecom service plans and options, hedonic techniques are natural to consider when modeling and summarising international price differences in residential broadband service.

The estimation of multilateral price estimates of goods and services sold in differentiated markets, possibly under monopolistic or oligopolistic competition, calls for a modeling approach consistent with principles set out in Pakes (2003) concerning the influence of producers and technology on the hedonic function. Although Pakes' considerations largely have been interpreted as a theoretical concern having to do interpretation of estimated coefficients in a hedonic regression (Hulten, 2003, provides a nice discussion), this paper goes a step further and argues that producer influences are an important consideration in *specifying* empirical hedonic functions for differentiated products such as residential broadband service.

The country-level data used in this study consist of price quotes for broadband services plans and their characteristics from a handful of national providers of broadband services and no information on plan-level sampling wts. The multilevel structure of the data (country, company, plans) suggests modeling hedonic functions at the company, i.e., internet service provider (ISP), level to mitigate the lack of subscriber information on individual plans and to account for the possibility that certain producers are "niche" suppliers. Modeling at this level allows for ISP costs and markups to influence estimates of characteristic prices, as well as allowing hedonic functions to vary across countries, e.g., country-level variation in consumer valuations of video services and its characteristics. The approach also handles the situation where telecommunications services may be supplied (and demanded) regionally within a country.

This paper uses random coefficient estimation techniques to incorporate producer heterogeneity in empirical hedonic functions. In terms of standard measures of goodness-of-fit, the preferred approach—random slope coefficients at the producer level—strongly dominates results of standard models where hedonic slope coefficients are fixed across all countries (and all producers). The preferred approach also dominates models that have random slope coefficients at the country level, which underscores the importance of incorporating producer information into the estimation of international price levels for differentiated products such as fixed broadband service.

In addition to statistical horse races that are run to compare the preferred approach to the standard approach, this paper also demonstrates that the multilevel/random coefficients hedonic approach is especially relevant for international price comparisons used in telecom policy analysis. Consider the results of the OECD's matched-model approach to international comparisons of residential fixed broadband prices. Up to eleven "fixed baskets" are compared across as many as 34 OECD countries in the OECD's analysis.[3] The use of many baskets achieves data comparability, but it also produces eleven sets of comparative price results. Hedonic techniques can simplify this cacophony, but note the approach cannot produce a single, valid comparative price result unless it is valid to apply the same empirical hedonic function to each and every country (and if that were valid the OECD's basket analysis would not produce such a wide range of comparative price levels).[4] Assuming a single empirical hedonic function may not be a stretch for commoditised markets, but the OECD's basket results suggest it is rather a stretch for international price comparisons of differentiated products such as bundled broadband service.

Thus, although comparative results by country will depend on the specific product/service base plan used for comparison in the preferred hedonic approach, because comparisons are not dictated by available matches in the data, the model enables the generation of a suite of policy-relevant comparisons, e.g., comparative results for basic service, i.e., how well do countries do in providing basic broadband service to their societies? comparative results for high speed service, i.e., how well do countries do in providing the bandwidth needed for today's digital economy? etc. These can be fine-tuned and all countries compared, even if the specific plan being compared is not available in all countries. This feature of the preferred approach is demonstrated along with the results for median plans that are used in the statistical horse-race analysis against the standard approach.

This paper has four sections that follow. The next section reviews how hedonic regressions can be used to determine spatial parities at the product level and how missing data are handled in hedonic-based comparisons. A third section introduces and reviews properties of the dataset used in this study, and a fourth section presents estimation results. The final section concludes.

2 Hedonic Regressions and Spatial Comparisons

Hedonic regression techniques have been widely used in studies of *price change within a country* following the influential contribution of Griliches (1961), which built upon Court (1939). The theoretical validity of hedonic regression models is grounded in a structural model of consumer behavior due to Rosen (1974), who established the existence and importance of markets in characteristics space. One of the earliest studies to use a hedonic approach to estimate spatial parities was Gillingham (1975), who looked at interarea differences in the cost of shelter in the United States. Many studies of U.S. interarea housing prices followed; Moulton (1995) provides a review and a statistical analysis of estimation approaches that emerged in that context.

2.1 The Hedonic CPD model

The basic idea that information across countries can be pooled via regression analysis to provide improved estimates of spatial parities is due to Summers (1973), who introduced the country product dummy (CPD) model for international price comparisons. The CPD model is a simple fixed effects regression model explaining prices by (a) country effects that provide estimates of purchasing power parities and (b) item effects that provide estimates of international prices in the currency of the numeraire country. The CPD model uses product dummies to represent unique item specifications, whereas the typical hedonic model uses an estimated hedonic function, i.e., an explicit relationship between an item's price and its characteristics.

Consider a dataset of international prices on M varieties of a good or service in N countries in local currency terms, e.g., many observations on M residential fixed broadband service plans in N countries. The CPD model at a point in time is given by

$$lnP_{ij} = \sum_{i=1}^{M} \beta_i Z_i + \sum_{j=2}^{N} \gamma_j C_j + \varepsilon_{ij} \qquad (1)$$

where Z_i is a product dummy, C_j is a country dummy, and ε_{ij} is the error term. The antilog of β_i is the estimated average price for the i th variety in the numeraire currency, and the antilog of the γ_j coefficients are the estimated country parities. Although not a typical hedonic model, as noted in Triplett (2004: 125-126), a dummy variable for each homogeneous variety of a good permits the hedonic function to take on shapes that are not smooth, and the use of a dummy to characterise an item is a substitute for the usual hedonic function specified in terms of quantities of characteristics.[5] Economic theory provides scant guidance for specifying a hedonic function, and the validity of its shape is largely an empirical issue.

The hedonic CPD regression model at a point in time is given by

$$lnP_{ij} = \beta_1 + \sum_{k=2}^{K} \beta_k X_{ik} + \sum_{j=2}^{N} \gamma_j C_j + \varepsilon_{ij} \qquad (2)$$

where X_{ik} 's are quantities or indicators of the K characteristics of the item (e.g., download speed, data limit, number of TV channels, etc.). As in (1) the antilogs of the γ_j coefficients are the estimated country parities. But in (2) the estimated price in the currency of the numeraire country in the hedonic CPD model is the antilog of the estimated hedonic function, i.e., the terms in characteristics and the regression constant. The constant β_1 is the logarithm of the price of the base plan in the currency of the base country. Whether one uses model (1) or (2) for actual international price comparisons is substantially an empirical matter. For example, when a dataset contains a large number of unique item specifications relative to the total number of observations, the simple (dummy) CPD model could “overfit" the data whereas a hedonic approach likely would remain feasible. On the other hand, when hedonic surfaces are complex and/or inconsistent over countries (or time), the simple CPD model (or its time-extended variant, discussed below) may yield better fitting equations than simple hedonic regressions.[6] That said, both models have their limitations.

First, as written, equations (1) and (2) are unweighted. A feature of the CPD model, hedonic or dummy, is that, in its unweighted or elementary form, country parities are geometric means of the ratios of country prices to estimated prices for the numeraire country. A geometric mean index number formula has very desirable properties at levels of aggregation where quantity information is not available. The formula is used for temporal aggregation of entry level item prices in the consumer price indexes of many countries.[7] Exact and superlative indexes due to Diewert (1976) have an important role in the economic approach to index number theory, however, and expenditure-weighted versions of (1) and (2) approximate the theoretical desiratum (Feenstra, 1995; Silver and Heravi, 2001, 2003; Diewert, 2005; Rao, 2005). Note, however, that even when information for developing appropriate weights is unavailable, OLS estimation of equations (1) and (2) yields unbiased coefficient estimates. Though these estimates are inefficient in the absence of expenditure information for weighting, from an econometric point of view, equations (1) and (2) remain appropriate regression models for determining point estimates of international parities.

Second, as is readily apparent, equation (2) assumes that the slopes of the characteristic regression lines are constant across geographic areas and that all price level differences are captured by shifts of the country parity intercept. Equation (1) makes a similar assumption, namely, that apart from a parity adjustment the hedonic surface for a given configuration of characteristics is the same across all countries. Finally, both equations are silent on whether coefficients—slope or intercept—are constant over time. We will return to these and other modeling issues in due course, following a discussion of the role of missing data.

2.2 Role of Missing Data

The geometric mean property of parities estimated using the CPD model was originally pointed out by Summers (1973), and its importance is most evident when assessing the impact of missing data in regression models based on (1) or (2). Consider the case of comparing country a with country b where v out of a total of M varieties being compared are missing in country b. Both the CPD and hedonic CPD models' comparison of prices in the two countries is given by:

$$\hat{\gamma}_a - \hat{\gamma}_b = \left[\sum_{i \notin v} (lnP_{i,a} - lnP_{i,b}) + \sum_{i \in v} (lnP_{i,a} - ln\hat{P}_{i,b}) \right] \frac{1}{M}. \tag{3}$$

Equation (3) illustrates that estimated parities are a function of both the available matches (the first term) and predictions of the estimated hedonic function for missing matches (the second term). The equation suggests that when v is small relative to M, the estimated parities approximate a geometric mean of price relatives of the available data, but when v is not small, estimated parities depend importantly upon the model's predictions for the missing prices.

In the simple CPD model the prediction for $ln\hat{P}_{i,b}$ is $\beta_i + \gamma_b$ and in the hedonic CPD model it is $\beta_1 + \sum_2^K \beta_k Z_{i,k} + \gamma_b$. Apart from a parity correction, *the prediction for one country's missing price for a given item specification is the same as the prediction for all other countries* in both models. Because item effects are constant and given that the actual price $lnP_{i,a}$ includes the error term $\varepsilon_{i,a}$, it can be shown that (3) simplifies to the following:

$$\hat{\gamma}_a - \hat{\gamma}_b = \left[\sum_{i \notin v} (lnP_{i,a} - lnP_{i,b}) + \sum_{i \in v} \hat{\varepsilon}_{i,a} \right] \frac{1}{M - v}. \tag{4}$$

Equation (4) also shows the estimated parity for country a relative to country b as the sum of two terms. As before one term is based on observed matched prices. But in equation (4) the other term reflects the residuals associated with the fit of the unmatched price specifications, i.e., the residuals of predictions of country a's unique varieties. In the general case where both countries have missing varieties, equation (4) will also contain a term reflecting the residuals of predictions of country b's unique varieties, but ignoring this term does not affect the equation's interpretation.[8]

A technical matter pointed out by Aizcorbe and Aten (2004) is that the noise/error introduced in estimated parities due to missing data may be either larger or smaller than the model's overall error, suggesting the need for a more formal variance test when evaluating parity estimates from CPD type models estimated using datasets with significant fractions of missing observations. Nevertheless, given that the expected value of a regression model's residuals for any grouping of observations (specifications), i.e., matched or unmatched, is of course zero, equation (4) suggests that the expected value of estimated parities is the geomean of the $M - v$ actual matches that can be made.

The average fit of unmatched specifications may have systematic tendencies relative to matched ones, however. In such situations, hedonic estimation of missing prices may lower (raise) a country's relative price level when its unique varieties have negative (positive) residuals in the regression, i.e., when the regression model's predicted prices for a country's unique varieties are systematically higher (lower) than actual prices. Equation (4) thus says that if unmatched varieties are predictably different from matched ones (i.e., the second term in (4) approaches zero), then relative prices are not fundamentally different from what the matched model approach revealed in the first place. This is most likely the case in competitive markets, where cost determines price and no economies of scale and scope are present (Hausman, 2003).

All told, there are two major takeaways from equation (4). First, empirical strategies that improve the fit of CPD-type models, e.g., pooling over time to increase the number observations relative to number of unique item specifications, are desirable, and perhaps necessary, to avoid introducing noise in regression-based parity estimates. Second, equation (4) lays bare the crucial assumption of constant item effects. When goods and services are sold in differentiated product markets, producer markups and technological capacity will in all likelihood differentially impact country-level supply and demand. Under these circumstances, it does not seem reasonable to posit that a single, empirical hedonic function holds across all countries.

2.3 Pooling Strategies

Many international price datasets have a richer structure than exploited in the models set out thus far. Consider first the time-extended CPD model due to Aizcorbe and Aten (2004) and then consider approaches that allow for country-specific hedonic functions.

The time-extended CPD model uses a panel dataset where, after allowance for entry and exit of product varieties, the cross-country data are repeated for Q quarterly time periods.[9] The time-extended model has two variants. The first adds a time dummy to capture time effects (price change) averaged across countries; country effects (parities) also are specified as averages over time.[10] The second uses an interacted time and country dummy to capture both country price change and parities on a period-by-period basis. These models, called TCPD and TiCPD, respectively, are written as follows:

$$lnP_{ijt} = \sum_{i=1}^{M} \beta_i' Z_i + \sum_{j=2}^{N} \gamma_j' C_j + \sum_{t=2}^{Q} \lambda_t T_t + \varepsilon_{ijt} \quad (5a)$$

$$lnP_{ijt} = \sum_{i=1}^{M} \beta_i' Z_i + \sum_{j=2}^{N} \sum_{t=1}^{Q} \delta_{jt} C_j T_t + \varepsilon_{ijt} \quad (5b)$$

The hedonic versions of these models are:

$$lnP_{ijt} = \beta_{1'} + \sum_{i=2}^{K}\beta'_k X_{ik} + \sum_{j=2}^{N}\gamma'_j C_j + \sum_{t=2}^{Q}\lambda_t T_t + \varepsilon_{ijt} \quad (6a)$$

$$lnP_{ijt} = \beta_{1'} + \sum_{i=2}^{K}\beta'_k X_{ik} + \sum_{j=2}^{N}\sum_{t=1}^{Q}\delta_{jt} C_j T_t + \varepsilon_{ijt} \quad (6b)$$

Aizcorbe and Aten (2004) show that if regressions for (1) are estimated for each time period, yielding parities for each period denoted $\gamma_j(t)$, then when data are complete, γ'_j from (5a) equals $\sum_t \gamma_j(t)/Q$. Similarly, $\delta_{a,t} - \delta_{b,t}$ from (5b) equals $\gamma'_a(t) - \gamma'_b(t)$ when data are complete. The same properties can be shown to hold for parities estimated using (2) for each time period, relative to parities estimated using (6a) and (6b).

To account for heterogeneity in hedonic surfaces across countries, the impacts of characteristics on item prices are allowed to vary across levels in the data (countries, producers). Equation (6a), for example, can be written as a multilevel regression with random variation in hedonic slope coefficients across countries as follows:

$$lnP_{ijt} = \overline{\beta}_1 + \sum_{i=2}^{K}(\overline{\beta}_k + \zeta_{kj}) X_{ik} + \sum_{j=2}^{N}\overline{\gamma}_j C_j + \sum_{t=2}^{Q}\overline{\lambda}_t T_t + \varepsilon_{ijt} \quad (7)$$

where the bars over parameters are fixed coefficients to be estimated. The new ζ_{kj} terms are independent, normally distributed random variables (i.e., random coefficients) with expected value 0 and variance τ_k^2. The new parameters to be estimated in the model are not the individual ζ_{kj} values but rather their variances τ_k^2 across the N countries, i.e., there are K new parameters to estimate. The multilevel approach is used in place of dummy interactive terms for several reasons: First, the dummy approach is inefficient, as there would be two additional parameters for each group within a level. Second, the dummy approach will have less predictive power than a multilevel approach as long as the overall sample size is large and the number of groups is not small (assuming that the group size also is not small).[11]

An alternative multilevel specification is to assume that the random coefficient variation is across producers, which exploits information in an additional dimension in the data. This model is as follows

$$lnP_{ijpt} = \overline{\beta}_1 + \sum_{i=2}^{K}(\overline{\beta}_k + \zeta_{kp}) X_{ik} + \sum_{j=2}^{N}\overline{\gamma}_j C_j + \sum_{t=2}^{Q}\overline{\lambda}_t T_t + \varepsilon_{ijpt} \quad (8)$$

where the random variation ζ_{kp} is across the P producers, where $P > N$. Note that there are still K variance parameters to estimate, but estimation is based on a larger number of groups. This specification is of interest for several reasons. One is that it clearly allows for differential impacts of producer markups and technological capacity, as Pakes (2003) and Hausman (2003) suggest is necessary when estimating hedonic price indexes for products sold under imperfect competition. A related point is that the approach may mitigate the OLS inefficiency due to lack of item sales information, i.e., when both national and niche suppliers (or producers with very different markups) are included in a sample and expenditure weights are unavailable.

While multilevel modeling is almost always an improvement in predictive power compared with classical linear methods (Gelman, 2006), the degree of improvement is an empirical matter. Moreover, moving from a model such as (6a) to the one such as (7) or (8) introduces an additional complexity, namely, that parities estimated by aggregating heterogeneous items using multiple hedonic functions will depend on the characteristics of the product used as a base for comparison (e.g., Kokoski et al., 1999). This is, in fact, an attractive feature of (7) or (8) in that it allows for fine tuning of international comparisons, e.g., the capacity to define and choose among key configurations of the data—median broadband plan, high speed plan, basic access plan, and so on—as the base for comparison, thereby providing a range of results for economic analysis.

3 Data

3.1 Sources and Definitions

The data used in this study are collected by Teligen and analysed by the OECD using a "basket" or matched model approach in regular reports of the organisation (e.g., OECD, 2013). The dataset contains information on fixed broadband plans and their prices and covers both standalone plans and broadband bundles offered by ISPs in 34 OECD countries at quarterly intervals from March 2011 to December 2014. Teligen collects sample data from service providers' web sites, i.e., they collect prices for plans that are available online. For most countries, the data are collected from three or four of the largest national carriers. Typically, Teligen collects data in a capital city for small countries and for larger countries if companies and plan offerings are national. For geographically disperse countries, such as the United States or Canada, data are collected from two or three large cities/provinces. Although the data used for the OECD baskets are collected online, operators review these data upon request and some suggest modifications to best fit the profiles for each basket. The number of subscribers to each plan is not available as operators regard this information as commercially confidential. This is a drawback of the dataset for hedonic analysis because, if a company offers 10 plans, out of which only several are popular with its subscribers, this cannot be taken into account. Subscriber information allows for calculation of expenditure weights that could be assigned to each plan in empirical analysis/price index construction. The OECD does not consider this an issue for its basket approach, which is based on usage patterns. Usage patterns are based on surveys of operators in OECD countries producing averages and the offers included in the database are matched to those profiles.

Another drawback for hedonic analysis is that Teligen's data only include plans that are advertised online. If plans with significant subscribers are no longer offered on a website, the appropriate observations would not be included in the dataset. This approach is taken by the OECD basket methodology to ensure transparency and comparability across operators and countries but the approach does not necessarily result in a representative sample of plans.[12]

The Teligen dataset includes a variety of broadband plans. A fixed broadband bundle may include, as additional components, fixed voice (i.e., landline phone service) or video (i.e., TV service). Bundles that include fixed voice are split into two groups: those with free calls on mobile phones and those without free calls on mobile phones. Teligen collects data for both residential and business plans but the business plans data are not used by the OECD and not covered by their methodology. The OECD views the information on prices and characteristics of residential fixed broadband plans as more transparent and more reliable than the information on business plans. Furthermore, Teligen's data do not include data for business plans in two OECD countries (Korea and Israel). Consequently, the analysis in this paper focuses solely on residential plans. Business plans results are available upon request.

The data employed in estimation and statistical analysis reflect four changes to the original dataset supplied by the OECD. A major change is the addition of the number of TV channels to information on characteristics of bundles. Teligen does not systematically collect information on TV quality when the service is part of a broadband plan. Further, unless some feature of the broadband or telephone service differs, Teligen does not report additional bundle offers that differ only in the quantity or character of included television content. However, for about 41% of plans in the dataset that have TV service included in the plan, the number of TV channels was recovered from notes provided for each plan. The number of channels is only an approximation to the quality of TV service. Ideally, controls for availability of HDTV channels, premium channels, movie channels, etc. should be included.[13] Further details and information on other changes made to the original OECD dataset are described in section A of the Annex to this paper.

Table 1. Residential Broadband Plans by Type in Final Dataset

Type of Plan	Number of Plans	Percent of Plans
Standalone	8 516	54%
Bundle		
Broadband+Fixed Voice	3 995	26%
Broadband+Fixed Voice+ Mobile Calls	994	6%
Broadband+TV	521	3%
Broadband+TV+Fixed Voice	1 192	8%
Broadband+TV+Fixed Voice+Mobile Calls	411	3%
Total	**15 629**	**100%**

The revised, final dataset has a total of 15 629 observations on residential fixed broadband plans in OECD countries. Table 1 shows a breakdown of these observations by basic type (standalone, bundle) and bundles by groups of services (broadband plus fixed voice, broadband plus voice and TV, etc.). The most prevalent The revised, final dataset has a total of 15 629 observations on residential fixed broadband plans in OECD countries. Table 1 shows a breakdown of these observations by basic type (standalone, bundle) and bundles by groups of services (broadband plus fixed voice, broadband plus voice and TV, etc.). The most prevalent plan type in the dataset is standalone broadband, followed by broadband bundled with fixed voice. The table also shows that a significant number of residential broadband plans—nearly 14% of the total—include TV service.[14]

Table 2 lists and defines the quality metrics (e.g., download speed, data allowance, contract duration, type of bundle, etc.) that are captured for each broadband plan in the dataset. The definitions of these variables are largely self-explanatory, except for price. The price variable is the monthly price of the broadband plan in local currency, but the dataset also includes factors for conversion to a common currency (US dollars) in either nominal or real terms i.e., via market exchange rates (MER) or aggregate consumption purchasing power parities (PPP).

The natural logarithm of the local currency price is used as the dependent variable in regressions, and estimates of country fixed effects are estimates of parities. The local currency price is the sum of three elements: (1) a recurring fee (monthly price of the service plus monthly rental fee of the modem), (2) a non-recurring fee (installation costs and the price of the modem if purchased, amortised over the life of the contract), and (3) a telecommunications sales tax or VAT, if applicable. An issue with this definition is that the telecommunications taxes do not usually include television licensing fees. Television licensing fees are in effect indirect taxes to fund public TV stations, whose use and importance varies greatly by country.[15] To the extent television license fees are an indirect tax, convention calls for them to be included in price.[16]

Table 2. Definition of Variables in Broadband Dataset

Variable	Definition
Price	Price of the broadband plan (in local currency, USD MER, or USD PPP)
BB+Fixed Voice	Indicator that bundle includes fixed broadband and fixed voice
BB+Fixed Voice+Mobile Calls	Indicator that bundle includes fixed broadband and fixed voice with calls to mobile phones
BB+TV	Indicator that bundle includes fixed broadband and TV
BB+Fixed Voice+TV	Indicator that bundle includes fixed broadband, fixed voice, and TV
BB+TV+Fixed Voice+Mobile Calls	Indicator that bundle includes fixed broadband, fixed voice with calls to mobile phones, and TV
Mb/s Download Speed $<$ 5 Mb/s	Indicator that download speed is less than 5 Mb/s
Download Speed $\geq$ 5 and $<$ 10 Mb/s	Indicator that download speed is between 5–10 Mb/s
Download Speed $\geq$ 10 and $<$ 25 Mb/s	Indicator that download speed is between 10–25 Mb/s
Download Speed $\geq$ 25 and $<$ 50 Mb/s	Indicator that download speed is between 25–50 Mb/s
Download Speed $\geq$ 50 and $<$ 90 Mb/s	Indicator that download speed is between 50–90 Mb/s
Download Speed $\geq$ 90 and $<$ 120 Mb/s	Indicator that download speed is between 90–120 Mb/s
Download Speed $\geq$ 120 Mb/s	Indicator that download speed is more than 120 Mb/s
Cable	Indicator that broadband is provided via cable
Fibre	Indicator that broadband is provided via file
ADSL	Indicator that broadband is provided via ADSL
Data Cap $\leq$ 10 GB	Data volume allowance limit is less or equal 10 GB, including 10 GB
Data Cap $>$ 10 and $\leq$ 100 GB	Data volume allowance limit is between 10 and 100 GB, including 100 BG
Data Cap $>$ 100 and $\leq$ 500 GB	Data volume allowance limit is between 100 and 500 BG, including 500 GB
Data Cap $>$ 500 and $\leq$ 3000 GB	Data volume allowance limit is between 100 and 3000 BG, including 3000 BG
Data Cap $>$ 100 and $\leq$ 3000 GB	Data volume allowance limit is between 500 and 3000 BG, including 3000 BG
Data Cap $>$ 3000 GB	Data volume allowance limit above 3000 GB, or unlimited data
Speed Slow Down after Data Cap	Indicator that speed slows down after data cap
No Contract	Indicator that plan does not have a contract
Contract Length $>$ 0 and $\leq$ 1 Years	Indicator that contract length less than or equal to a year
Contract Length $>$ 1 and $\leq$ 2 Years	Indicator that contract length is between 1 and 3 years, including 3 years
Contract Length $>$ 2 Years	Indicator that contract length is more than 3 years
Promo price	Indicator that fixed voice has discounts on weekend, peak or off-peak calling
International	Indicator that fixed voice includes international calls
1-69 TV Channels	Indicator that Number of Channels in the Plan is between 1 and 69
70-149 TV Channels	Indicator that Number of Channels in the Plan is between 70 and 149
>150 TV Channels	Indicator that Number of Channels in the Plan is more than 150

3.2 Descriptive Statistics

Table 3 shows country-level descriptive statistics from the dataset. On balance, there is considerable variation in key plan characteristics across countries, which underscores the advantages of using hedonic analysis in international price comparisons of residential fixed broadband service. Note first that the number of plans available in each country, reported in column (1), is not at all uniform or proportional to the number of broadband subscribers in a country, but that is not the variation in question. Recall that the number of plans is not intended to correspond to number of subscribers. The object of the dataset is to include what is needed to obtain a representative sample for each country, and for some countries that entails collecting many more observations than for others.

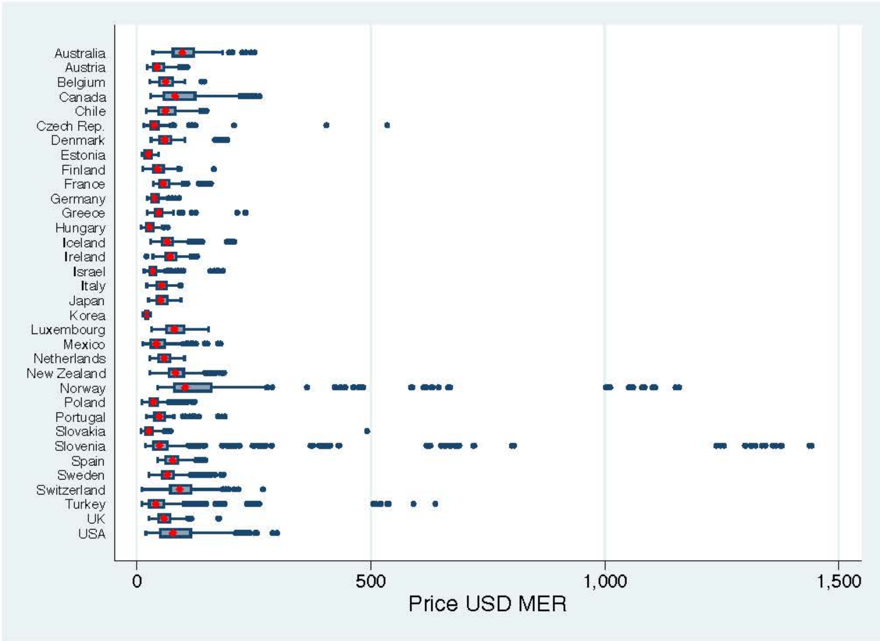
Median prices of residential fixed broadband plans, reported in column (2) in U.S. nominal dollars, USD, vary widely across OECD countries. The median price in a few countries, such as Australia, Norway and Switzerland, is more than USD 90 whereas the median price in other countries, such as Estonia, Hungary, Slovakia, and South Korea, is under USD 30. As displayed via the "box and whisker" plot in figure 1 (a), there also are differences across countries in the degree of within-country price variation.[17] As may be seen, while prices for residential plans have a fairly tight distribution in most countries, the distributions in a few countries show considerable skewness and many outliers (Czech Republic, Norway, Slovenia, and Turkey).

Table 3. Distribution of Plans by Country in Broadband Dataset

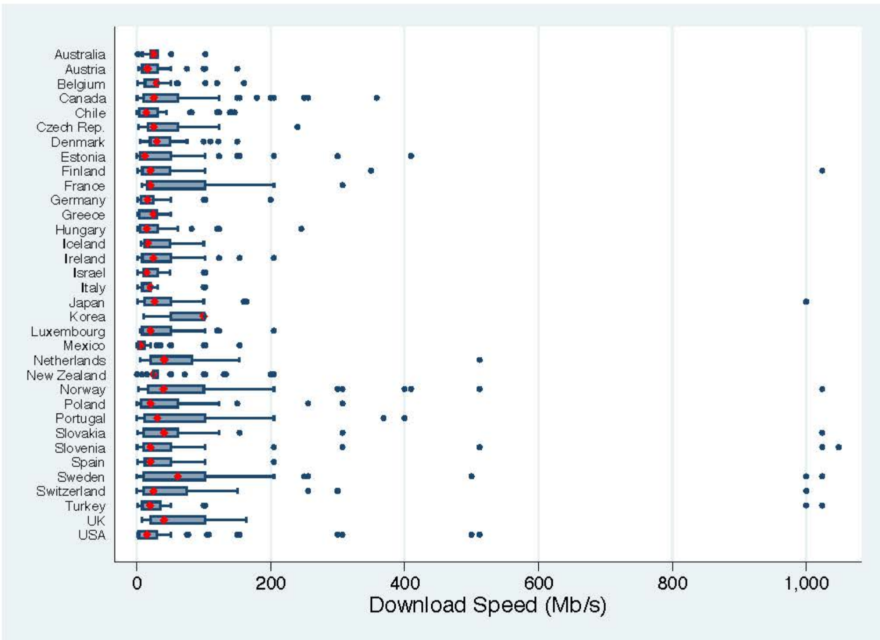
Country	Number of Residential Plans	Median Price (USD MER)	Median Download Speed (kb/s)	Percent Bundled	Percent Plans With TV	Percent Plans with Data Limit	Number of ISPs
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Australia	1,415	97	24.6	44	2	99	3
Austria	333	43	16.4	41	2	3	4
Belgium	241	62	30.0	45	13	47	5
Canada	537	82	25.6	15	10	91	4
Chile	506	61	14.4	56	34	2	3
Czech Rep.	166	37	25.6	42	26	0	4
Denmark	221	60	30.0	18	7	3	4
Estonia	299	25	12.3	7	7	0	3
Finland	220	44	20.5	0	0	0	4
France	303	56	20.5	83	69	0	4
Germany	197	37	16.0	77	4	0	4
Greece	341	47	24.6	69	0	0	4
Hungary	746	26	15.0	26	10	2	3
Iceland	692	65	16.4	37	0	96	3
Ireland	684	71	24.6	72	9	58	4
Israel	212	34	15.0	13	0	0	6
Italy	291	54	20.5	66	9	0	3
Japan	185	51	26.6	13	0	0	5
Luxembourg	275	81	20.5	48	26	40	4
Mexico	356	42	5.1	74	34	12	4
Netherlands	197	59	41.0	51	8	0	3
New Zealand	871	83	24.6	68	0	94	5
Norway	289	104	40.0	0	0	0	3
Poland	676	35	20.5	30	11	0	5
Portugal	250	48	30.7	74	17	11	5
Slovakia	338	26	41.0	38	33	1	3
Slovenia	1,343	48	20.5	48	30	0	3
South Korea	209	22	100.0	29	0	0	3
Spain	222	77	20.5	88	41	5	4
Sweden	498	65	61.4	28	0	0	3
Switzerland	385	92	25.0	68	56	0	4
Turkey	998	41	20.0	23	0	51	3
UK	446	58	41.0	86	4	17	3
USA	687	77	15.4	60	32	4	3
OECD Countries	460*	58.27	20,480	46	14	30	116 **

Notes. * denotes mean for all OECD countries, ** denotes count of unique ISPs in our sample.

Figure 1. Distribution of Residential Broadband Prices and Download Speeds within and across OECD Countries



(a) Price of Residential Plans



(b) Download Speed of Residential Plans

Note. Figure 1(a) compares with Figure 1 in Wallsten and Riso (2010a).

Column (3) shows that median download speeds are also distributed differently across OECD countries. Some countries have median download speeds at or greater than 40 MB/s, for example, Netherlands, Norway, Slovakia, South Korea, Sweden, and the UK, with South Korea having a remarkably high median download speed of 100 MB/s. Other countries, such as Chile, Germany, Hungary, and Mexico, have median speeds that are at or lower than 15 Mb/s. it should be noted that during the four years covered by the dataset, the median speed per quarter rose substantially for certain countries, e.g., Spain, while in other countries, such as Australia and France, median download speeds remained approximately the same. The within-country variation in median download speed for residential plans is displayed via “box and whisker" plot in Figure 1 (b), which shows considerable dispersion in the download speed of offerings within most countries. For example service providers in Finland, Japan, Norway, Slovakia, Slovenia, Sweden, Switzerland, and Turkey offer plans with lower download speeds, and also plans with download speeds over 1 GB/s.

The percent of standalone vs. bundled plans, shown in column (4), is very different across countries. Finland and Norway have no bundled offers,[18] whereas in France, Spain, and the UK, more than 80% of offerings consist of broadband bundled with other services. With regard to video services, the prevalence of plans offering TV service shows significant variation across OECD countries (column 5).

Carriers in some countries, e.g., Finland, Greece, Iceland, Israel, Japan, New Zealand, Norway, South Korea, Sweden, and Turkey either do not have bundles with TV as an option, or have only few plans that include TV. By contrast, in Chile, France, Mexico, Slovakia, Spain, and Switzerland more than a third of offered bundles include a TV option. Column (6) shows variation across countries in the number of plans that have data limits, or a bitcap. In some countries data limits are common: More than 90% of broadband plans in Australia, Canada, Iceland, and New Zealand have bitcaps. In the majority of OECD countries, however, only small share (or none) of broadband offerings have bitcaps.

Finally, column (7) shows number of ISPs, providers or residential fixed broadband, by country. In the majority of OECD countries Teligen collected data from three-four carriers. Note, that some carriers provide broadband in more than one country, that is why total number of unique ISPs in the whole dataset is lower than the sum of number of ISPs across all countries. There are 116 unique carriers in the dataset. In terms of sample size sufficiency for multilevel random coefficient estimation at the ISP level, this is a very large number of groups, and sample size criteria set out by Maas and Hox (2005) are more than satisfied.

3.3 Match Rates and Plan Durations

Statistics on plan match rates across countries and plan duration within countries provide additional insights into the advantages of using hedonic analysis for international comparisons of item-level prices.

The dataset contains 1084 residential plans (observations) in 2014:Q4, of which 449 are unique, i.e., there are 449 different configurations of the characteristics shown in table 2 in the dataset in that quarter. The remaining 635 plans match one of the 449 unique configurations. Figure 2 graphs the match rate of plans by country in 2014:Q4. The match rate of unique plans varies substantially by country, ranging from as low as 4% of plans in a country having at least one match in another country in the same period to a 100%, with an average match rate of 60%.[19] Taking into account all sixteen quarters of residential plan prices (15 629 observations), a total of 999 unique residential plans are found.[20] Despite significant variation in match rates across countries in a given quarter, the large sample size relative to the number of unique plans suggests there is much matching *within countries* *over time*. All told, pooling has produced a dataset with a very large number of observations relative to the number of unique plans.

Table 4 provides an overview of the product dynamics in the dataset. As may be seen, of the 449 unique plans present in the dataset in 2014:Q4 (the sum of columns 1 and 2), 402 plans (column 2), or 90% (column 4), also are present in 2014:Q3. Although this is the highest match rate for adjacent quarters in the dataset, the temporal match rate averaged over all quarters is still high at 82 %. Because the dataset covers only four years, it is difficult to calculate a definitive number for the average survival rate of plans, i.e., some plans that entered in 2011:Q2 were still in the sample in 2014:Q4. Ignoring this truncation, the average lifetime of plans that entered in 2011:Q2 is 4 quarters. Even though these results suggest the pooled dataset will generate robust spatial empirics, adding the time dimension introduces additional complexities, namely, the possibility that the hedonic function is temporally unstable. While temporal instability of hedonic coefficients is common for ICT products (e.g., Berndt, Griliches, and Rapporport, 1995; Pakes, 2003), the high within-country match rate suggests that the pace of quarterly change in fixed broadband markets, while rapid by many standards, is not so fast as to offset the advantages of pooling.

Figure 2. Match Rate of Plans by Country in 2014:Q4

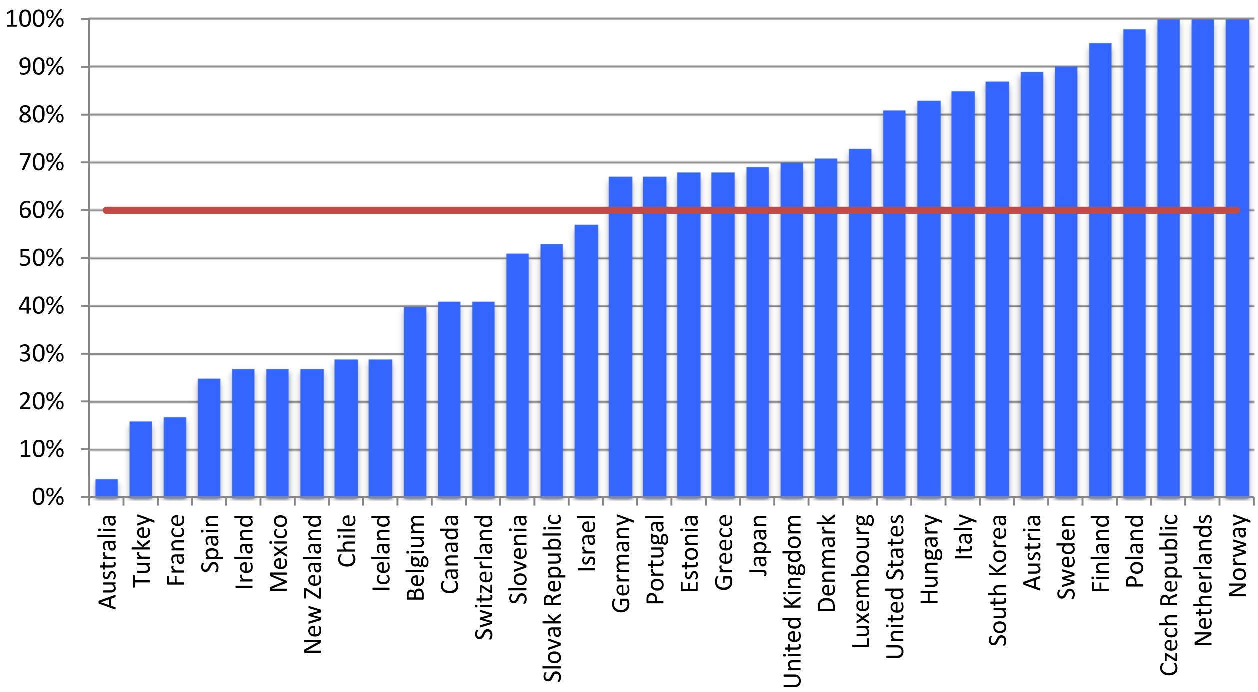


Table 4. Number of Entering/Continuing/Exiting Plans

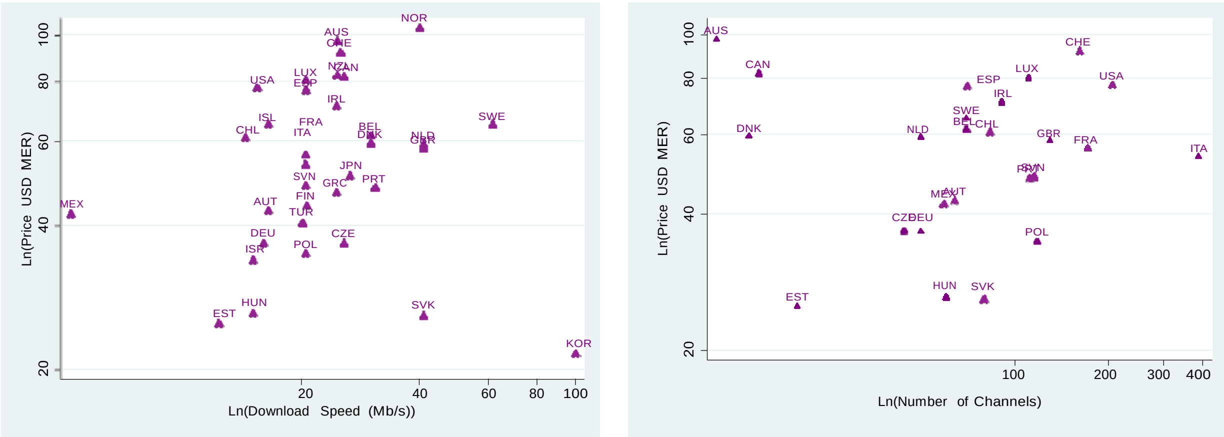
Quarter	Entering Plans (1)	Continuing Plans (2)	Exiting Plans (3)	Memo: Percent Continuing (4)
Q2	100	173	54	63%
Q3	75	218	55	74%
Q4	56	249	44	82%
Q1	65	262	43	80%
Q2	65	263	64	80%
Q3	49	282	46	85%
Q4	60	283	48	83%
Q1	73	281	62	79%
Q2	61	290	64	83%
Q3	89	298	53	77%
Q4	83	348	39	81%
Q1	56	385	46	87%
Q2	63	357	84	85%
Q3	76	361	59	83%
Q4	47	402	35	90%
Average	68	274	47	82%

Notes. Residential plans only. Percentage of continuing plans is calculated as a ratio of continuing plans over the sum of entering and continuing plans.

4 Estimation Results

The models set out in the first section of the paper are estimated using the dataset described in the previous section. Figure 3 gives a flavor of the relationship that is being modeled. The figure plots logarithms of price versus median download speed on the one hand (panel a), and price versus median number of TV channels on the other (panel b).

Figure 3. Broadband Prices and Selected Characteristics, OECD countries, 2011-2014 average values



(a) Median Price and Download Speed

(b) Median Price and Number of Channels (residential)

Note. Panel (a) may be compared with Figure 2 in Wal lsten and Riso (2010a).

Both panels show a basic relationship between the natural logarithm of price and natural logarithm of quantities of the characteristic, either download speed or number of TV channels, as in the double-log hedonic function. Panel (a) reveals that there are a few outliers: Korea and Slovakia with high median download speeds and relatively low prices, and Mexico with much lower median download speed than average and relatively high price. Panel (b) shows significant dispersion of median number of TV channels included in the bundle and suggests the possibility of different country-level preferences for consumption of video services.

4.1 Model specification

The characteristics shown in table 2 are in indicator function form although data on download speed and number of TV channels are also available in quantities. When information on characteristics is in indicator form, the standard way to approach specifying the hedonic function is to include each indicator in a linear regression such as TCPD or TiCPD, and then possibly follow up with an exploration of interactions among the variables to see if the fit of the model can be improved. When characteristics are in quantity form, the standard approach is to explore linear, semi-log, and double-log functional forms for the hedonic function (Triplett, 2004). As previously noted, economic theory provides no guidance for the functional form of the relationship between the price of an item and quantities of its characteristics, but statistical index number theory *does* provide guidance as to the form of the dependent variable (Diewert, 2002). The dependent variable is therefore specified as the natural logarithm of price (or a simple transformation of price) in this study.

Table 5 presents goodness-of-fits statistics for a range of models. The columns of the table represent alternative modeling and estimation approaches. The first row of the table presents a specification, where the dependent variable is logarithm of price in local currency and independent variables are all of the indicator-only characteristics listed in table 2. The rows 2-4 of the table report alternative specifications to specification 1 to determine whether an indicator function or double log function (as in figure 3) should be used to model the relationship between price and download speed and number of TV channels. Finally, row 5 of the table reports results for the models specifications where the dependent variable is the ratio of price to download speed and all independent variables are in the indicator-only form as in specification 1.

There are three key takeaways from this table. First, using a double-log function to estimate a hedonic TCPD model with logarithm of price as the dependent variable and download speed and number of TV channels in quantity terms does not perform as well as using an indicator function for these characteristics. This conclusion follows from a comparison of statistics in column 2 (the hedonic TCPD model) for specification 2 versus specification 1. Specifications 3 and 4 use a blend of forms. Scanning down column 2 (i.e., sticking with the hedonic TCPD model), the double-indicator form remains dominant.

Specification 5 considers the widely used characteristic price measure of price per unit of download capacity as a dependent variable. Although the goodness-of-fit statistics for this specification cannot be compared directly with specification 1 (one needs to multiply the estimated residual errors by the logarithm of the average download speed, which equals to 20 480 MB/s), the unadjusted standard deviation of this regression's residuals is larger than comparable results for specification 1. All told, specification 1 is our preferred specification. Although note, when all columns are considered, there is little difference between specification 1 and specification 4, i.e., the use of TV channels variables in indicator form does not yield much improvement of the model fit compared with the double-log form.

Categories of download speed may be the most appropriate way to express download speed because internet access pricing may take on a shape that is not smooth. For example, lower or higher speed plans may be disproportionally cheaper/more expensive compared to plans with average speeds. As shall be shortly shown, regression results in fact indicate that plans in the highest speed category are disproportionately more expensive than plans with lower speeds. An indicator function may also fit better to the extent carriers do not offer plans along the whole range of download speed, but instead offer plans that fall only within a few categories.

A second takeaway from table 5 is that the product dummy TCPD model outperforms the hedonic TCPD model. Consider specification 1. The log-likelihood of the dummy TCPD model is -2 371, which is significantly greater than the log-likelihood of the hedonic TCPD model, which is -4 845. As the discussion in the previous section made clear, the indicator data used in the hedonic model are the very same data used to construct the product dummies that represent each unique broadband plan in product dummy TCPD model. This comparison suggests that if a hedonic characteristic model used *some* set of interactions among the 30+ variables shown in table 2, it would perform as well as, or better than, the product dummy model.

Another possibility is that the product dummies are picking up country-specific time effects, which is always a possibility when currencies of different countries change differentially due to shocks that are exogenous to item-level pricing that is being modeled. This possibility does not appear to be the primary reason for the dominance of the product dummy model, as the fit of the simple linear hedonic TiCPD model does not greatly improve upon the simple linear (i.e., without interaction effects) hedonic TCPD model. A third possibility is that the generality of the product dummy approach is picking up certain differences in country-level hedonic functions; recall the very low cross-country match rates for some countries.

There are, then, two basic ways to proceed. The first approach is to fish for the best form of dummy interactions among the characteristic indicators, where the search is still within the confines of estimating a single hedonic function for residential broadband across OECD countries. The discussion in the introduction to this paper, hedonic practice as it pertains to differentiated products (i.e., concerns of Hau03,Pak03), and figure 3b, all raise questions about the validity of this assumption. The second approach is to employ random coefficient estimation/modeling (or RCM). RCM implicitly allows for all possible interactions, enables country-specific hedonic surfaces, and is more efficient in terms of parameters to be estimated than are dummy interactions (or estimating separate hedonic models for each country, and various variants of this approach). Furthermore, although the RCM approach is demanding in terms of sample size, the size of the pooled OECD dataset is sufficient.[21]

The last four columns of table 5 demonstrate the final key takeaway from the table, namely, that when RCM is used at both the country and ISP levels, its results strongly dominate the TCPD and TiCPD models with no interaction effects among characteristics. RCM also dominates the product dummy TCPD model, suggesting that it finds even richer interactive effects and/or country differences in hedonic functions. This is the approach that is used in this paper to estimate comparative price levels for residential broadband plans across OECD countries.

4.2 Regression results

The detailed regression results for the product dummy and hedonic TCPD and TiCPD models are reported in the first three columns of table 6, and the RCM results are shown in the last four columns. The estimated coefficients on characteristics for models in columns (2) and (3) are very similar. Both regressions show that residential plans with higher speeds are on average more expensive than plans with slower speeds. According to both regressions, ADSL is the most expensive technology for fixed broadband, a result that can possibly be explained by the fact that the majority of the plans through ADSL are provided by legacy carriers that tend to charge higher prices for services. Also, a higher data allowance is found to increase the price of fixed broadband. If the download speed slows down after a data cap is reached, the price of the plan is, on average, cheaper. According to the estimation results presented in columns (2) and (3), the price of broadband is not significantly impacted by the length of contract. Dummies for various types of bundles also have mostly insignificant coefficients according to the results of both models, presumably because the regression is successful at parsing characteristic prices for elements of the bundles. A greater number of TV channels significantly increases the price of a bundled broadband service plan in these models, consistent with this interpretation.[22]

Table 5. Comparison on Model Specifications

	Product Dummy TCPD	Hedonic Characteristic					
		Hedonic TCPD	Hedonic TiCPD	RCM Cntry Basic	RCM ISP Basic	RCM ISP Median	RCM ISP High
Specification	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1. DV: ln(Price) Download speed (categories) TV channels (categories)							
Log pseudolikelihood	**-2,371**	**-4,845**	**-4,154**	**-676**	**1,380**	**1,325**	**1,001**
sd(Residual)	**0.282**	**0.330**	**0.315**	**0.243**	**0.203**	**0.205**	**0.203**
st. err. sd(Residual)	**(0.019)**	**(0.024)**	**(0.023)**	**(0.001)**	**(0.001)**	**(0.001)**	**(0.001)**
2. DV: ln(Price) ln(Download speed) ln(TV channels)							
Log pseudolikelihood	–	-4,990	-4,329	-2,060	-245	-245	-656
sd(Residual)	–	0.333	0.319	0.268	0.228	0.228	0.237
st. err. sd(Residual)	–	(0.025)	(0.024)	(0.002)	(0.001)	(0.001)	(0.001)
3. DV: ln(Price) ln(Download speed) TV channels (categories)							
Log pseudolikelihood	–	-4,961	-4,295	-2,061	-257	-257	-667
sd(Residual)	–	0.332	0.319	0.268	0.228	0.228	0.237
st. err. sd(Residual)	–	(0.025)	(0.024)	(0.002)	(0.001)	(0.001)	(0.001)
4. DV: ln(Price) Download speed (categories) ln(TV channels)							
Log pseudolikelihood	–	-4,872	-4,184	-680	1,403	1,336	1,014
sd(Residual)	–	0.330	0.316	0.243	0.203	0.205	0.204
st. err. sd(Residual)	–	(0.024)	(0.023)	(0.001)	(0.001)	(0.001)	(0.001)
5. DV: ln(Price/Download Speed) Download speed (categories) TV channels (categories)							
Log pseudolikelihood	-5,577	-8,376	-7,780	-4,757	-3,478	-2,914	-3,076
sd(Residual)	0.346	0.414	0.398	0.312	0.274	0.268	0.268
st. err. sd(Residual)	(0.016)	(0.014)	(0.014)	(0.002)	(0.002)	(0.002)	(0.002)

Note. DV indicates the form of the dependent variable. Categories refers to expressing the characteristic using the indicator variables set out in table 2.

Table 6. Regression Results for Logarithm of residential plan prices

	(1) Product Dummy TCPD β / SE	(2) Hedonic TCPD β / SE	(3) Hedonic TiCPD β / SE	(4) Hedonic Country RCM Basic β / SE	(5) Hedonic ISP RCM Basic β / SE	(6) Hedonic ISP RCM Median β / SE	(7) Hedonic ISP RCM High-Speed β / SE
Hedonic Characteristics							
Download Speed < 5 Mb/s						−0.265***	−1.087***
						(0.029)	(0.061)
Download Speed ≥ 5 and < 10 Mb/s		0.176***	0.177***	0.136***	0.147***	−0.116***	−0.903***
		(0.031)	(0.031)	(0.024)	(0.025)	(0.023)	(0.056)
Download Speed ≥ 10 and < 25 Mb/s		0.264***	0.263***	0.243***	0.243***		−0.781***
		(0.036)	(0.036)	(0.028)	(0.020)		(0.046)
Download Speed ≥ 25 and < 50 Mb/s		0.456***	0.451***	0.374***	0.385***	0.142***	−0.636***
		(0.043)	(0.041)	(0.030)	(0.023)	(0.016)	(0.048)
Download Speed ≥ 50 and < 90 Mb/s		0.557***	0.573***	0.507***	0.499***	0.272***	−0.562***
		(0.047)	(0.045)	(0.035)	(0.025)	(0.019)	(0.053)
Download Speed ≥ 90 and < 120 Mb/s		0.693***	0.709***	0.690***	0.681***	0.443***	−0.361***
		(0.046)	(0.045)	(0.047)	(0.041)	(0.036)	(0.059)
Download Speed ≥ 120 Mb/s		1.085***	1.107***	1.017***	1.061***	0.826***	
		(0.170)	(0.167)	(0.108)	(0.092)	(0.091)	
ADSL							0.130***
							(0.030)
Cable		−0.181***	−0.203***	−0.158***	−0.179***	−0.170***	−0.042
		(0.036)	(0.036)	(0.039)	(0.041)	(0.040)	(0.028)
Fibre		−0.223***	−0.223***	−0.144***	−0.131***	−0.146***	
		(0.039)	(0.042)	(0.031)	(0.026)	(0.026)	
Data cap ≤ 10 GB		−0.461***	−0.467***	−0.366***	−0.445***	−0.461***	−0.406***
		(0.105)	(0.101)	(0.083)	(0.066)	(0.069)	(0.067)
Data Cap > 10 and ≤ 100 GB		−0.282***	−0.298***	−0.317***	−0.341***	−0.357***	−0.304***
		(0.070)	(0.071)	(0.077)	(0.045)	(0.049)	(0.050)
Data Cap > 100 and ≤ 500 GB		−0.084	−0.104	−0.209***	−0.146***	−0.164***	−0.119**
		(0.070)	(0.070)	(0.078)	(0.049)	(0.054)	(0.053)
Data cap > 500 and ≤ 3000 GB		0.160	0.130	−0.126	−0.028	−0.033	−0.056
		(0.123)	(0.126)	(0.157)	(0.132)	(0.121)	(0.126)
Speed Slow Down		−0.023	−0.123**	0.002	0.016	0.011	0.006
		(0.041)	(0.060)	(0.010)	(0.011)	(0.011)	(0.011)
No Contract		0.094	0.001	0.078***	0.129***	0.141***	0.163***
		(0.102)	(0.051)	(0.010)	(0.011)	(0.011)	(0.011)
Contract Length > 1 and ≤ 2 Years		−0.054	−0.091**	−0.064***	−0.047***	−0.058***	−0.031***
		(0.038)	(0.039)	(0.006)	(0.007)	(0.007)	(0.007)
Contract Length > 2 Years		0.088	0.122	−0.078***	−0.017	−0.034	0.008
		(0.160)	(0.123)	(0.024)	(0.028)	(0.028)	(0.027)
BB+Fixed Voice		0.003	0.010	0.036	0.065**	0.068**	0.067**
		(0.030)	(0.029)	(0.036)	(0.028)	(0.030)	(0.030)
BB+Fixed Voice+Mobile Calls		0.015	0.048	0.026	0.076*	0.075	0.075*
		(0.049)	(0.045)	(0.045)	(0.046)	(0.047)	(0.044)
BB+TV		−0.141	−0.234**	0.051	0.039	−0.009	0.004
		(0.092)	(0.098)	(0.259)	(0.223)	(0.219)	(0.223)
BB+Fixed Voice+TV		−0.120	−0.232**	0.061	0.070	0.039	0.042
		(0.099)	(0.100)	(0.258)	(0.224)	(0.219)	(0.223)
BB+TV+Fixed Voice+Mobile Calls		−0.002	−0.101	0.088	0.078	0.061	0.056
		(0.107)	(0.104)	(0.262)	(0.224)	(0.219)	(0.222)
International Calls		−0.067	−0.085	0.054***	0.148***	0.149***	0.160***
		(0.076)	(0.075)	(0.016)	(0.017)	(0.017)	(0.017)
Promotional Price		0.048	0.056*	0.082***	0.013	0.016	0.013
		(0.042)	(0.033)	(0.013)	(0.013)	(0.013)	(0.013)
1-69 TV Channels		0.261***	0.369***	0.083	0.177	0.203	0.220
		(0.100)	(0.107)	(0.259)	(0.227)	(0.224)	(0.227)
70-149 TV Channels		0.322***	0.421***	0.247	0.322	0.345	0.347
		(0.088)	(0.094)	(0.256)	(0.225)	(0.221)	(0.224)
> 150 TV Channels		0.505***	0.612***	0.369	0.363	0.358	0.383*
		(0.094)	(0.107)	(0.258)	(0.232)	(0.230)	(0.231)
2011 Q2	0.009	0.001		−0.005	0.000	−0.001	−0.004
	(0.020)	(0.020)		(0.013)	(0.011)	(0.011)	(0.011)
2011 Q3	0.013	0.025		0.020	0.021**	0.020*	0.014
	(0.026)	(0.025)		(0.012)	(0.011)	(0.011)	(0.011)
2011 Q4	−0.005	0.020		0.011	0.010	0.009	0.002
	(0.026)	(0.025)		(0.012)	(0.011)	(0.011)	(0.011)
2012 Q1	−0.013	0.013		0.002	−0.003	−0.001	−0.006
	(0.029)	(0.028)		(0.012)	(0.011)	(0.011)	(0.011)
2012 Q2	−0.031	−0.008		−0.027**	−0.021*	−0.021**	−0.025**
	(0.026)	(0.027)		(0.012)	(0.011)	(0.011)	(0.011)
2012 Q3	−0.034	−0.009		−0.026**	−0.018*	−0.019*	−0.023**
	(0.024)	(0.027)		(0.012)	(0.011)	(0.011)	(0.011)
2012 Q4	−0.045*	−0.022		−0.038***	−0.027**	−0.029***	−0.032***
	(0.025)	(0.027)		(0.012)	(0.011)	(0.011)	(0.011)
2013 Q1	−0.043	−0.032		−0.045***	−0.034***	−0.039***	−0.040***
	(0.029)	(0.029)		(0.012)	(0.011)	(0.011)	(0.011)
2013 Q2	−0.069**	−0.053*		−0.043***	−0.032***	−0.036***	−0.035***
	(0.030)	(0.031)		(0.013)	(0.011)	(0.011)	(0.011)
2013 Q3	−0.089***	−0.071**		−0.060***	−0.051***	−0.055***	−0.057***
	(0.032)	(0.032)		(0.012)	(0.011)	(0.011)	(0.011)

Table 7. Regression Results for Logarithm of residential plan prices (Cont)

	(1) TCPD	(2) Hedonic TCPD	(3) Hedonic TiCPD	(4) Hedonic Country RCM Basic	(5) Hedonic ISP RCM Basic	(6) Hedonic ISP RCM Median	(7) Hedonic ISP RCM High-Speed
	β / SE	β / SE	β / SE	β / SE	β / SE	β / SE	β / SE
2013 Q4	−0.092***	−0.072**		−0.057***	−0.049***	−0.053***	−0.057***
	(0.031)	(0.032)		(0.012)	(0.011)	(0.011)	(0.011)
2014 Q1	−0.087***	−0.073**		−0.056***	−0.049***	−0.052***	−0.056***
	(0.033)	(0.034)		(0.012)	(0.011)	(0.011)	(0.011)
2014 Q2	−0.107***	−0.094**		−0.071***	−0.070***	−0.074***	−0.077***
	(0.036)	(0.037)		(0.012)	(0.011)	(0.011)	(0.011)
2014 Q3	−0.079**	−0.065*		−0.044***	−0.040***	−0.043***	−0.046***
	(0.036)	(0.037)		(0.012)	(0.011)	(0.011)	(0.011)
2014Q 4	−0.098***	−0.077**		−0.064***	−0.047***	−0.051***	−0.054***
	(0.035)	(0.039)		(0.012)	(0.011)	(0.011)	(0.011)
Constant		4.080***	4.070***	3.793***	3.740***	4.020***	5.210***
		(0.063)	(0.041)	(0.025)	(0.023)	(0.024)	(0.035)
Random-Effects Parameters							
				Country Level:	ISP Level:	ISP Level:	ISP Level:
sd(Download Speed < 5 Mb/s)						0.219***	0.474***
						(0.022)	(0.042)
sd(Download Speed ≥ 5 and < 10 Mb/s)				0.109***	0.192***	0.187***	0.461***
				(0.025)	(0.020)	(0.018)	(0.040)
sd(Download Speed ≥ 10 and < 25 Mb/s)				0.144***	0.176***		0.451***
				(0.022)	(0.015)		(0.032)
sd(Download Speed ≥ 25 and < 50 Mb/s)				0.150***	0.179***	0.130***	0.437***
				(0.023)	(0.017)	(0.014)	(0.034)
sd(Download Speed ≥ 50 and < 90 Mb/s)				0.180***	0.186***	0.142***	0.451***
				(0.025)	(0.018)	(0.015)	(0.036)
sd(Download Speed ≥ 90 and < 120 Mb/s)				0.241***	0.327***	0.299***	0.491***
				(0.036)	(0.030)	(0.027)	(0.041)
sd(Download Speed ≥ 120 Mb/s)				0.561***	0.672***	0.674***	
				(0.076)	(0.067)	(0.066)	
sd(Data cap ≤ 10 GB)				0.325***	0.359***	0.378***	0.350***
				(0.060)	(0.048)	(0.051)	(0.048)
sd(Data cap > 10 and ≤ 100 GB)				0.252***	0.228***	0.259***	0.249***
				(0.057)	(0.033)	(0.037)	(0.036)
sd(Data cap > 100 and ≤ 500 GB)				0.239***	0.223***	0.258***	0.242***
				(0.059)	(0.034)	(0.040)	(0.038)
sd(Data cap > 500 and ≤ 3000 GB)				0.262**	0.283***	0.258***	0.266***
				(0.112)	(0.095)	(0.087)	(0.092)
sd(ADSL)							0.214***
							(0.026)
sd(Cable)				0.194***	0.261***	0.259***	0.151***
				(0.030)	(0.033)	(0.032)	(0.026)
sd(Fibre)				0.162***	0.198***	0.210***	
				(0.022)	(0.020)	(0.019)	
sd(BB+Fixed Voice)				0.189***	0.236***	0.253***	0.252***
				(0.026)	(0.021)	(0.022)	(0.023)
sd(BB+Fixed Voice+Mobile Calls)				0.177***	0.248***	0.258***	0.232***
				(0.035)	(0.035)	(0.035)	(0.033)
sd(BB+TV)				0.150***	0.061	0.104***	0.083**
				(0.046)	(0.054)	(0.039)	(0.045)
sd(BB+Fixed Voice+TV)				0.164***	0.161***	0.105**	0.149***
				(0.040)	(0.049)	(0.045)	(0.057)
sd(BB+TV+Fixed Voice+Mobile Calls)				0.235***	0.127***	0.091**	0.110**
				(0.055)	(0.042)	(0.048)	(0.048)
sd(1-69 TV Channels)				0.176***	0.232***	0.285***	0.258***
				(0.040)	(0.046)	(0.045)	(0.052)
sd(70-149 TV Channels)				0.060	0.182***	0.198***	0.182***
				(0.049)	(0.035)	(0.036)	(0.039)
sd(> 150 TV Channels)				0.089**	0.287***	0.330***	0.277***
				(0.046)	(0.059)	(0.062)	(0.061)
sd(Residual)	0.282***	0.330***	0.315***	0.243***	0.203***	0.205***	0.203***
	(0.019)	(0.024)	(0.023)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	15,629	15,629	15,629	15,629	15,629	15,629	15,629
Log Pseudolikelihood	-2,371	-4,845	-4,154	-676	1,380	1,315	1001
P-value of LR Test OLS vs RCM (χ^2)				0.000	0.000	0.000	0.000

Note. All regressions are estimated using the Stata 14 *xtmixed* routine with robust clustered standard errors. Significance of time coefficients is not reported, because no test was undertaken as there is no natural zero, or other number, to act as the null hypothesis for the parameter on time.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses.

Next consider the results for the RCM models that were set out in equations (7) and (8). The first model allows the slope coefficients of the hedonic characteristics to vary across countries, whereas the second model allows coefficients of hedonic characteristics to vary across ISPs. The second model arguably better accounts for the way Teligen collected its data, at least in some countries.[23] More generally, both models must estimate 20 random coefficient parameters, and the second one uses 116 groups/ISPs (see again column (7) of table 3), whereas the first model only has 34 groups, i.e., 34 countries, with which to estimate 20 distributions.

The results indicate, first, that the models where coefficients are distributed across ISPs are a better fit than when they are distributed across countries for the reasons just discussed. Second, the estimated standard deviations of the slope parameters for different categories of download speed, data allowances, types of technologies, types of bundles, and categories of number of TV channels are all statistically significantly different from zero, suggesting considerable variation in hedonic surfaces for fixed broadband across OECD countries.

Unlike the linear (i.e., no interaction) models, in random coefficient models, the choice of base plan matters. If one wants to compare prices of basic plans across countries, then the characteristics specific to the basic plan shall be made the reference categories. For example, if one is interested in comparing average (median) plans across countries, then the reference plan should be a plan with median characteristics. Columns (5), (6), and (7) show estimations that compare price levels across countries for basic, median, and high-speed broadband plans, respectively.[24]

The results of RCM models in columns (4)-(7) are largely consistent with the patterns in the linear models in columns (1)-(3) although, as mentioned above, there is some heterogeneity in the RCM results themselves. Focusing on the comparison of the linear models with the ISP RCM model with the median plan as the base for comparison (column 5), the results show that the price of fixed broadband increases with the download speed and data allowance in both sets of results. The results also show that plans provided through ADSL are more expensive than plans provided through cable or fibre, and plans with the contract term between 1 and 2 years, including 2 years, are less expensive than plans with shorter or longer contract or no contract. The RCM model results indicate that bundles including broadband and fixed voice are more expensive than bundles of other types, a result not found in the results from linear models. Surprisingly, in the RCM regressions, prices do not increase with number of TV channels; note that this is because the mean of the distribution for these coefficients is imprecisely estimated, as suggested by figure 3 (b). This results may arise from an issue discussed previously, namely, that the number of TV channels is an imperfect measure of the quality video services. The number of HDTV channels, premium channels, and/or sports channels in a TV package are in all likelihood systematically related to a plan's price, but these characteristics are not in the OECD dataset.

4.3 Price Levels

When comparing the price of an individual good or service across countries, it is necessary to use a common metric. This section reports results in two metrics, U.S. dollars based on market exchange rates (MER) and U.S. dollars based on purchasing power exchange rates (PPP). Besides converting to U.S. dollars, PPP rates take into account how expensive a country is relative to the United States. As a technical matter, this paper's annex explains how price level comparisons in USD terms (MER or PPP) are calculated from the original regression coefficient estimates.

USD price levels using MER exchange rates. Figure 4 shows the estimated country price levels expressed relative to the OECD average and converted to USD using market exchange rates. In all cases the price levels are from the time-averaged model and thus price levels are for the entire 2011 to

2014 period. The figure's five panels display results based on the following models: (1) dummy TCPD, (2) hedonic TCPD, (3) hedonic ISP RCM for median plans, (4) hedonic ISP RCM for basic plans, and (5) hedonic ISP RCM for high-speed plans.

According to the ISP RCM for median plans shown in panel (3)—which is most comparable to the linear models shown in panels (1) and (2)—the most expensive broadband offerings are in Australia, Iceland, and Luxembourg, and the least expensive offerings are in South Korea, the Slovak Republic, and Estonia. These results are rather similar to the results for the dummy TCPD and hedonic TCPD models—all the ten most expensive countries from the RCM model results are also found in the top ten countries in panel (1), and nine appear in the top ten countries in panel (2). Eight out of the ten least expensive countries according to the RCM, appear in the bottom ten countries of panel (1), and seven appear in the bottom ten of panel (2).

Price levels based on random coefficient models with different comparison base plans are shown in the two lower panels of figure 5. Perhaps the most striking result is that prices for basic plans are much more tightly distributed across countries than prices for high-speed plans. Prices for basic plans in the most expensive countries are roughly 2 times higher than the OECD average, whereas prices for high speed plans in the most expensive countries are five times higher than the OECD average. The results also show that the rankings of countries differ depending on the type of broadband plan beging compared, e.g., note greater differences between rankings of median and high-speed plans than differences between rankings of median and basic plans. For example, all ten countries that are estimated to be the most expensive when comparing median plans also appear in top ten for the ranking estimated for basic plans, and much fewer—only five—appear in the top ten most expensive countries for high-speed plans. Out of the ten least expensive countries for median plans, only seven are in the list of ten least expensive countries for both basic plans and high-speed plans.

USD price levels using PPP exchange rates. Figure 5 shows comparative price levels for residential fixed broadband in PPP terms. The conversion to PPP terms transforms the rankings shown in figure 5 by a factor related to what is called the Belassa-Samuelson effect. Internationally traded goods tend to have prices that are similar across countries, which implies that PPPs vary across countries mainly due to variation in prices for non-traded goods and services, which tend to be higher in countries with high per capita incomes. Non-traded goods and services are of course not completely delinked from traded goods, mainly because both use many of the same factor inputs and both are intermediate inputs to each other's production. This means that, to the extent the price of Internet access is determined by wages and other non-tradable inputs, there will be a positive correlation between estimated price levels in MER terms and the PPP consumer price ratio of OECD countries.[25]

Figure 4. Price Levels in USD MER, Residential Plans, OECD Countries, 2011-2014

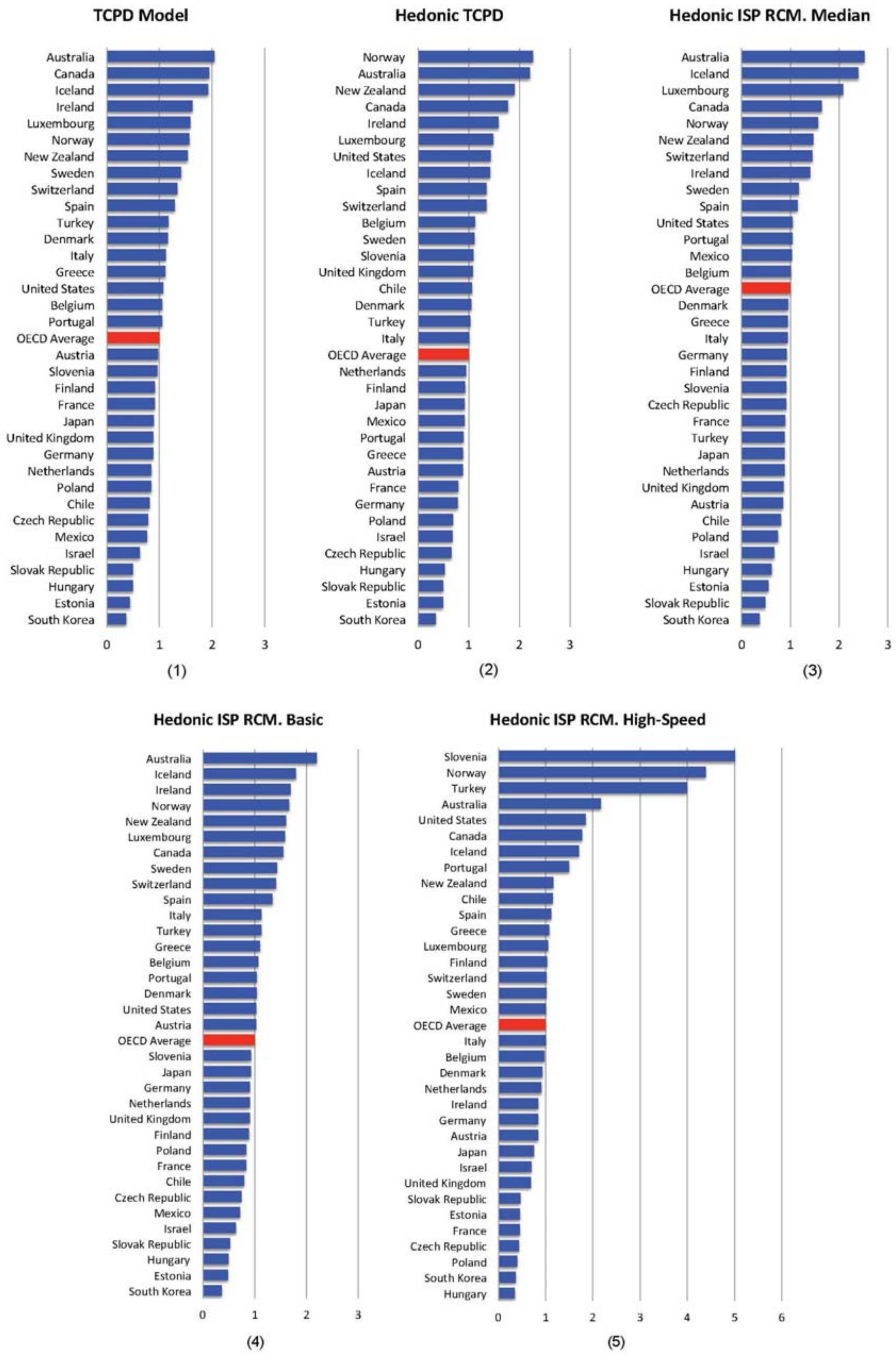


Figure 5. Price Levels in USD MER, Residential Plans, OECD Countries, 2011-2014

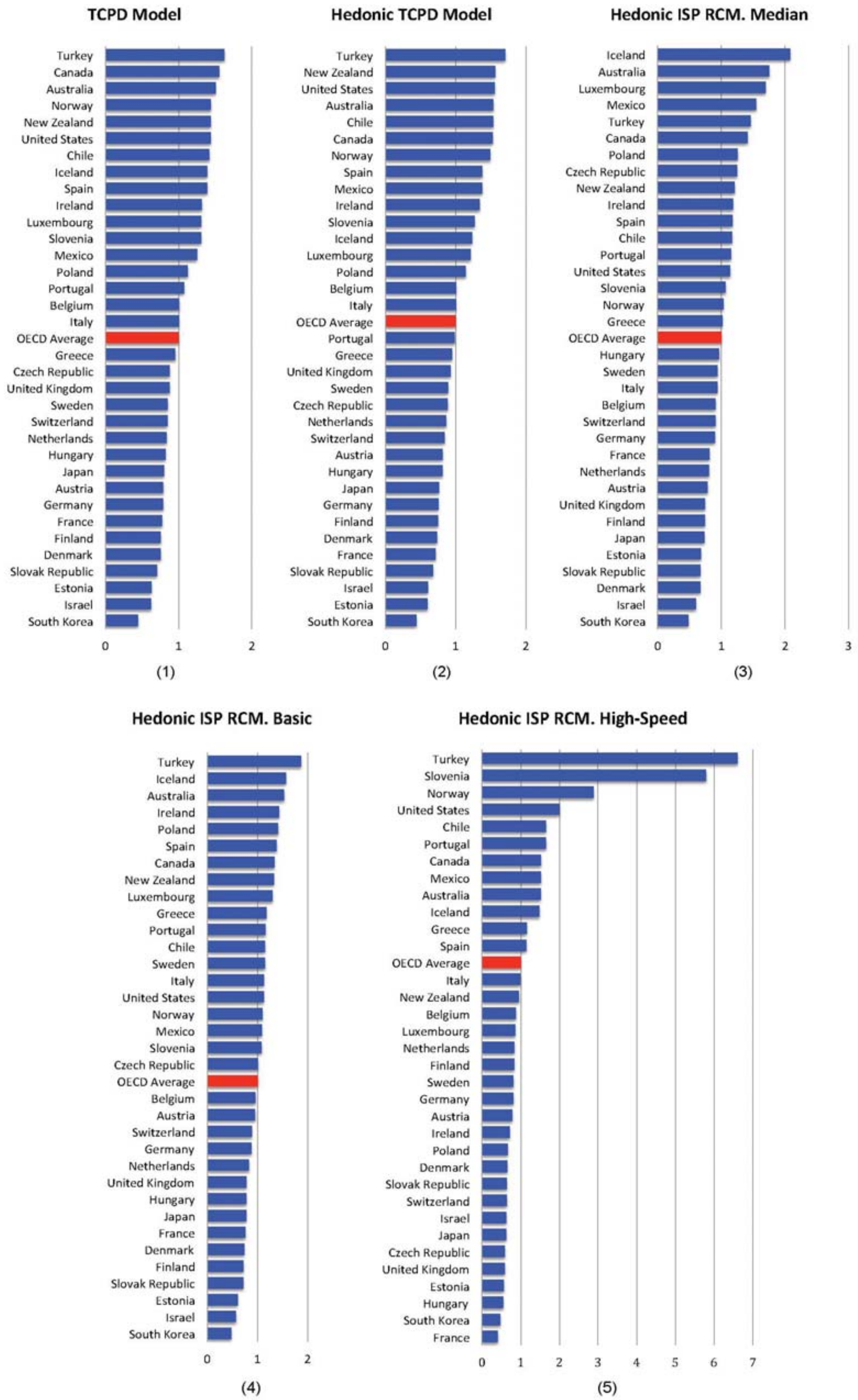
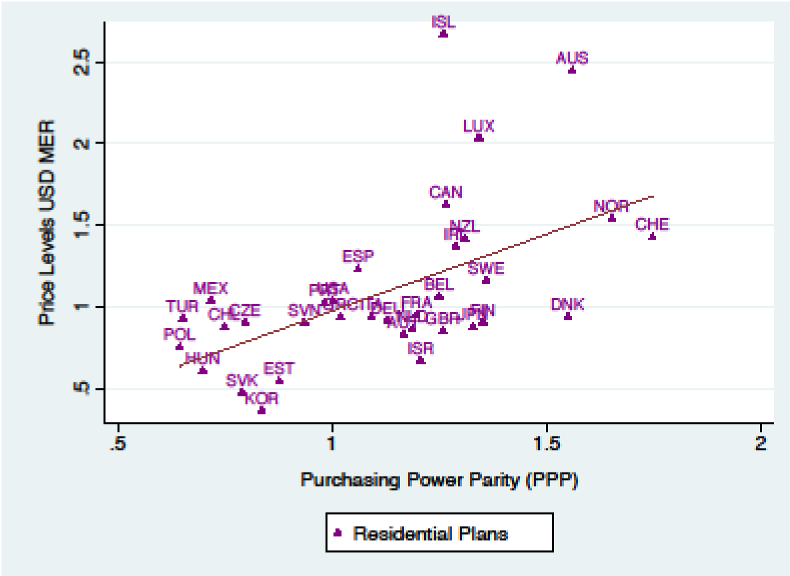


Figure 6. Broadband Price Levels and PPP ratios, Residential Plans, OECD Countries, 2011–2014



The correlation between price levels in USD MER using the ISP RCM results where the median plan is the base for comparison and the consumption PPP ratio is displayed in figure 4. As may be seen, estimated residential broadband services prices are higher in countries with higher consumption PPPs, i.e., residential broadband prices are higher in countries with high per capita incomes. To the extent that a portion of the cost of providing broadband services is in the form of specialised servers and routers, there should be a tendency for trade in these electronic components to equalise the costs of providing broadband service. But there are other sources of international differences in production costs, such as population density and geography that are irreducible and prevent arbitrage via trade from taking place. Telecom policy analysts need to bear in mind the degree to which these irreducible elements are a determinant of the variance in the cross-country price estimates generated in this paper.

5 Conclusion

This paper developed a hedonic regression approach to estimating comparative prices for residential fixed broadband across OECD countries using a dataset of prices for nearly 16 000 standalone broadband plans and broadband plans bundled with other services (e.g., fixed voice, and/or TV) from 2011:Q1 to 2014:Q4. The dataset used in this paper is the dataset used by the OECD in its comparative analysis of telecom pricing using a basket, or matched-model approach.

Broadband services are highly differentiated within most countries, and finding matches for similar offerings across countries for direct price comparisons is difficult, suggesting that a hedonic approach the comparative analysis of telecom pricing has much to offer. In setting out the standard hedonic models used to estimate international product-level prices, the paper stressed that estimated hedonic functions for residential fixed broadband, which reflect a mix of demand and supply considerations, likely differ across countries. Observed offerings (as represented in the dataset) are very different across countries, and imposing fixity of underlying characteristics prices across countries—implying that only differences in quantities of characteristics can explain international price variation—is very restrictive. In some sense international/interarea differences in hedonic functions are the spatial analog to temporal instability of hedonic functions for IT products. The solution to both involves employing different functions and appropriate weights accordingly (Caves, Christensen, and Diewert, 1982; Pakes, 2003).

This paper used a random coefficient modeling (RCM) approach to address country-level variation in relationships between prices and characteristics of bundled fixed broadband services. The approach has many advantages. First, it is parsimonious compared with developing and searching for models with interactions that are as sufficient as results yielded by RCM. Second, it enabled exploitation of ISP-level information in the dataset, which produced results with much more predictive power than the standard hedonic models explored in this paper and represent the state of current practice. Third, estimating random coefficients at the ISP level likely mitigates the lack of information on subscriber weights. Finally, econometrics aside, modeling at the producer level is consistent with price determination in differentiated product markets, where producer markups and technological capacity impact both demand and supply, and thereby influence price.

In our discussion of estimation results, the versatility of the random coefficient model was illustrated by using its estimates of parities to generate comparative price levels based on different configurations of service. For instance, if telecom policy-makers had a goal of universal access to broadband, then comparative price levels for basic Internet access service would appear to be the most appropriate for policy analysis. There are other scenarios of course, including basing comparisons on price levels in PPP terms, which were also developed and used in this paper.

ANNEX 1. DATA CORRECTIONS/EXTENSIONS/DELETIONS

Changes to the Teligen data. Four major changes were made. First, information on the number of TV channels included in each plan with video services was extracted from the notes Teligen provided for each plan. Out of 5 871 bundles including a TV option in the OECD dataset, information was collected on the number of TV channels for 2 397 bundles. The availability of data on TV channels varies by country. Information was not available for Finland, Greece, Israel, Korea, New Zealand, Norway, Sweden, and Turkey, whereas information Chile, Estonia, France, Ireland, Italy, Luxembourg, Mexico, Switzerland, and the US was sufficient to cover more than 50% of the bundles that included TV. Information on the statistical impact of restricting the original sample to capture TV quality in the analysis is provided below.

Second, in 26 instances, plans that were coded as bundle plans were in fact standalone plans (and therefore recoded). The recoded plans include 24 packages in Austria offered by Tele2, two packages in Slovenia offered by Telekom Slovenije, and one package in the UK offered by BT.

Third, we subtract the sales tax applied to US standalone broadband plans. The data for the US were collected in New York and Los Angeles, and Internet access is not taxed in these states.

Finally, the names of several carriers were corrected to perform accurate multilevel analysis. For example, in Israel, “Bezeq/012 Smile” and “Bezeq/012Smile" were merged in one carrier, as well as “Hot/012 Smile" and “Hot/012Smile." In Portugal, “PT comunica es" was renamed to “PT."

Representativity of the Sample Used in the Estimation. A significant number of observations are dropped due to missing data, and of these, most are discarded because of missing data on the number of TV channels. As discussed in the text, Teligen does not systematically collect data on video quality.

After adding TV component data only 84% of the residential plans were retained in the final sample. The product dummy and hedonic characteristic TCPD models are estimated using the whole sample as well as the restricted sample for comparison purposes.

Table A1 presents the results of these estimations. Columns (1) and (2) display results for product dummy TCPD models for the whole sample and restricted sample respectively. In these models logarithm of price is regressed on product dummies, time dummies, and country dummies. The estimated country coefficients are very similar for these two models. Next, hedonic characteristic TCPD models are estimated on the restricted sample and whole dataset, and results shown in columns (3) and (4). The results show that the country dummy coefficients are similar, and also that the coefficients on hedonic characteristics are very close.

Table A1: Comparison of Whole Sample and Subsample. Residential Plans

	(1) TCPD Whole Sample β / SE	(2) TCPD Subsample β / SE	(3) Hedonic TCPD Whole Sample β / SE	(4) Hedonic TCPD Subsample β / SE
Download Speed < 5 Mb/s			0.176*** (0.029)	0.176*** (0.030)
Download Speed ≥ 5 and < 10 Mb/s			0.265*** (0.034)	0.266*** (0.036)
Download Speed ≥ 25 and < 50 Mb/s			0.440*** (0.041)	0.456*** (0.042)
Download Speed ≥ 50 and < 90 Mb/s			0.544*** (0.045)	0.561*** (0.046)
Download Speed ≥ 90 and < 120 Mb/s			0.676*** (0.044)	0.700*** (0.046)
Download Speed ≥ 120 Mb/s			1.002*** (0.136)	1.090*** (0.168)
Cable			−0.174*** (0.029)	−0.178*** (0.034)
Fibre			−0.207*** (0.036)	−0.225*** (0.040)
Data cap > 10 and ≥ 100 GB			0.162*** (0.051)	0.177*** (0.052)
Data cap > 100 and ≥ 500 GB			0.373*** (0.057)	0.374*** (0.062)
Data cap > 500 and ≥ 3000 GB			0.591*** (0.108)	0.620*** (0.098)
Data cap > 3000 GB			0.423*** (0.104)	0.460*** (0.109)
Speed Slow Down			0.000 (0.041)	−0.008 (0.038)
Contract Length 1-2 Years			−0.042 (0.031)	−0.060* (0.036)
Contract Length 2-3 Years			0.070 (0.152)	0.059 (0.149)
BB+Fixed Voice			0.000 (0.031)	−0.003 (0.030)
BB+Fixed Voice+Mobile Calls			0.011 (0.042)	0.004 (0.048)
BB+TV			0.186*** (0.041)	0.203*** (0.055)
BB+Fixed Voice+TV			0.252*** (0.038)	0.216*** (0.047)
BB+TV+Fixed Voice+Mobile Calls			0.314*** (0.065)	0.364*** (0.085)
International Calls			−0.022 (0.064)	−0.051 (0.076)
Promotional Price			0.036 (0.037)	0.048 (0.047)
Australia	0.488*** (0.097)	0.561*** (0.100)	0.296*** (0.099)	0.399*** (0.101)
Austria	−0.872*** (0.057)	−0.790*** (0.069)	−0.917*** (0.079)	−0.817*** (0.089)
Belgium	−0.503*** (0.065)	−0.445*** (0.080)	−0.628*** (0.062)	−0.557*** (0.075)
Canada	0.276** (0.121)	0.320** (0.128)	0.206** (0.095)	0.210** (0.091)
Chile	5.945*** (0.052)	5.947*** (0.054)	5.887*** (0.062)	5.929*** (0.064)
Czech Rep.	2.052*** (0.159)	2.135*** (0.194)	2.034*** (0.150)	2.126*** (0.180)
Denmark	1.415*** (0.058)	1.435*** (0.077)	1.371*** (0.070)	1.383*** (0.086)
Estonia	−1.374*** (0.046)	−1.312*** (0.056)	−1.469*** (0.046)	−1.416*** (0.061)
Finland	−0.735*** (0.070)	−0.689*** (0.077)	−0.814*** (0.064)	−0.760*** (0.075)
France	−0.825*** (0.066)	−0.727*** (0.063)	−0.955*** (0.090)	−0.826*** (0.096)
Germany	−0.894*** (0.082)	−0.831*** (0.085)	−0.994*** (0.076)	−0.935*** (0.087)
Greece	−0.795*** (0.073)	−0.744*** (0.076)	−0.844*** (0.080)	−0.806*** (0.078)
Hungary	4.334*** (0.078)	4.403*** (0.095)	4.262*** (0.070)	4.340*** (0.079)
Iceland	4.860*** (0.078)	4.923*** (0.081)	4.731*** (0.072)	4.814*** (0.079)
Ireland	−0.243* (0.137)	−0.172 (0.135)	−0.305** (0.139)	−0.227* (0.136)
Israel	0.564*** (0.068)	0.598*** (0.066)	0.482*** (0.076)	0.515*** (0.076)
Italy	−0.668*** (0.099)	−0.595*** (0.099)	−0.714*** (0.111)	−0.654*** (0.116)

	(1) TCPD Whole Sample β / SE	(2) TCPD Subsample β / SE	(3) Hedonic TCPD Whole Sample β / SE	(4) Hedonic TCPD Subsample β / SE
Japan	4.082***	4.124***	3.984***	4.022***
	(0.095)	(0.098)	(0.108)	(0.110)
Korea	5.509***	5.543***	5.426***	5.517***
	(0.084)	(0.096)	(0.100)	(0.071)
Luxembourg	−0.225**	−0.158	−0.355***	−0.299***
	(0.095)	(0.100)	(0.091)	(0.104)
Mexico	2.043***	2.096***	2.038***	2.103***
	(0.055)	(0.057)	(0.059)	(0.070)
Netherlands	−0.733***	−0.765***	−0.786***	−0.752***
	(0.038)	(0.052)	(0.054)	(0.066)
New Zealand	0.448***	0.510***	0.371***	0.441***
	(0.101)	(0.105)	(0.092)	(0.104)
Norway	2.165***	2.195***	2.163***	2.190***
	(0.122)	(0.125)	(0.144)	(0.151)
Poland	0.349***	0.408**	0.304***	0.367***
	(0.132)	(0.159)	(0.107)	(0.142)
Portugal	−0.718***	−0.641***	−0.827***	−0.812***
	(0.055)	(0.060)	(0.058)	(0.065)
Slovakia	−1.383***	−1.328***	−1.457***	−1.409***
	(0.044)	(0.058)	(0.050)	(0.066)
Slovenia	−0.633***	−0.536***	−0.685***	−0.601***
	(0.089)	(0.119)	(0.108)	(0.131)
Spain	−0.436***	−0.351***	−0.464***	−0.387***
	(0.047)	(0.068)	(0.067)	(0.089)
Sweden	1.591***	1.617***	1.568***	1.606***
	(0.088)	(0.112)	(0.086)	(0.110)
Switzerland	−0.118	−0.066	−0.197*	−0.157
	(0.093)	(0.084)	(0.108)	(0.107)
Turkey	0.335***	0.392***	0.225***	0.301***
	(0.059)	(0.061)	(0.051)	(0.059)
UK	−0.837***	−0.786***	−0.848***	−0.789***
	(0.068)	(0.097)	(0.056)	(0.075)
2011 Q2	0.012	0.012	0.008	0.004
	(0.017)	(0.019)	(0.017)	(0.020)
2011 Q3	0.023	0.023	0.027	0.030
	(0.021)	(0.024)	(0.024)	(0.024)
2011 Q4	0.010	0.007	0.022	0.024
	(0.021)	(0.024)	(0.024)	(0.024)
2012 Q1	0.007	0.003	0.022	0.017
	(0.023)	(0.026)	(0.025)	(0.027)
2012 Q2	−0.008	−0.018	0.007	−0.004
	(0.021)	(0.025)	(0.026)	(0.027)
2012 Q3	−0.010	−0.019	0.001	−0.003
	(0.021)	(0.023)	(0.026)	(0.026)
2012 Q4	−0.020	−0.030	−0.009	−0.015
	(0.022)	(0.024)	(0.027)	(0.026)
2013 Q1	−0.023	−0.028	−0.020	−0.026
	(0.025)	(0.028)	(0.027)	(0.028)
2013 Q2	−0.039	−0.048	−0.042	−0.046
	(0.026)	(0.029)	(0.028)	(0.030)
2013 Q3	−0.047	−0.060	−0.049	−0.060
	(0.032)	(0.036)	(0.032)	(0.035)
2013 Q4	−0.049	−0.063	−0.050	−0.064
	(0.031)	(0.035)	(0.032)	(0.034)
2014 Q1	−0.049	−0.062	−0.050	−0.063
	(0.034)	(0.038)	(0.034)	(0.037)
2014 Q2	−0.080	−0.083	−0.079	−0.086
	(0.034)	(0.039)	(0.036)	(0.039)
2014 Q3	−0.055	−0.057	−0.056	−0.057
	(0.035)	(0.039)	(0.036)	(0.039)
2014 Q4	−0.079	−0.070	−0.078	−0.069
	(0.041)	(0.040)	(0.046)	(0.043)
Constant			3.741***	3.656***
			(0.120)	(0.129)
Root MSE	0.287	0.295	0.326	0.332
Product Dummies	Yes	Yes	No	No
Observations	18588	15629	18588	15629
Log Likelihood	-3198	-3108	-5529	-4936

Note: Regressions are estimated using Stata 14 *xtmixed* routine with robust clustered standard errors. Standard errors in parentheses; significant at: * = 0.10, ** = 0.05, *** = 0.01. Significance of time coefficients is not reported, because no test was undertaken as there is no natural zero, or other number, to act as the null hypothesis for the parameter on time.

ANNEX 2. PRICE LEVELS IN US DOLLAR (USD) TERMS

Figures 5 and 6 display comparative price levels constructed from price parities (coefficients of country dummy variables) obtained from regression results presented in table 6. The price levels are expressed in US dollars using both the market exchange rate and the PPP exchange rate.[26] The conversion into one currency is necessary to compare price levels across the OECD countries, and for this purpose the average market exchange rate[27] and average PPP exchange rate[28] from 2011:Q1 to 2014:Q4 has been used.

The average exchange rate is given by

$$e_i = \sum_{t=1}^{T} \tilde{e}_{i,t}, \qquad (9)$$

where $\tilde{e}_{i,t}$ is either the quarterly market exchange rate or the quarterly PPP exchange rate for country i .

The estimated price parities are converted into comparative price levels in four steps as follows:

Step 1. Calculate the antilog of country's i dummy coefficient γ_i and divide by the geometric mean of the exchange rates $e_1,...,e_N$, where exchange rates might or might not be adjusted for PPP, and N is the total number of countries in the data sample:

$$\alpha_i = \frac{exp(\gamma_i)}{(\prod_{i=1}^{N} e_i)^{\frac{1}{N}}} \qquad (10)$$

Step 2. Divide α_i from equation (10) by the geometric mean of $\alpha_1,...,\alpha_N$:

$$\pi_i = \frac{\alpha_i}{(\prod_{i=1}^{N} \alpha_i)^{\frac{1}{N}}} \qquad (11)$$

Step 3. Divide π_i from equation (11) by the exchange rate for country i :

$$\xi_i = \frac{\pi_i}{e_i} \qquad (12)$$

Step 4. Finally, divide ξ_i from equation (12) by the geometric mean of $\xi_1,...,\xi_N$:

$$\text{price level}_i = \frac{\xi_i}{(\prod_{i=1}^{N} \xi_i)^{1/N}} \qquad (13)$$

NOTES

1 Center for Business and Public Policy, McDonough School of Business, Georgetown University.

2 We are grateful to support from the OECD; to workshop participants at Georgetown University, the OECD and FCC; to Bettina Aten for helpful discussions on approach and estimation methods; and to Paroma Sanyal, Mick Silver, and Scott Wallsten for comments on an earlier draft. We extend special thanks to Agustín Días-Pinés who, until he left the OECD in June 2015, was extremely helpful in answering our questions about the strengths and limitations of the dataset used in this study.

3 This analysis is reported biannually in the OECD's *Communications Outlook* (e.g., OECD, 2013).

4 This property of hedonic models applied to international price comparisons is discussed in Fixler and Zieschang (1992); Kokoski, Moulton, and Zieschang (1999); and Heston, Silver, and Heravi (2003).

5 Kravis, Heston, and Summers (1982) originally noted the correspondence between CPD models and hedonic characteristics models used in the temporal price literature.

6 As emphasized by Aizcorbe, Corrado, and Doms (2003) in the temporal context, the data needed for the product dummy approach, i.e., the data used to define each Z_i in (1), are essentially the same data (the X_{ik} measures) needed for estimating a hedonic characteristics regression model such as (2).

7 In this sense, index number theory/statistical theory provides some guidance about how to specify a hedonic regression at the item level, namely, that the dependent variable should be in logarithmic form; see Diewert (2002) for an extended discussion of this and related issues.

8 Note the result given by equation (4) is generally well known, appearing, e.g., in footnote 10 in Aizcorbe and Aten (2004). Its counterpart in the temporal literature has also been the subject of much discussion, e.g., Cole et al. (1986), Feenstra (1995), and Silver and Heravi (2005).

9 The time-extended CPD model also is seen as a spatially-extended version of the product dummy model introduced in the temporal price measurement literature by Aizcorbe, Corrado, and Doms (2000).

10 Averages refer to geometric means.

11 A large number of groups appears to be more important than a large number of observations per group, however. See Maas and Hox (2005) for a study of sufficient sample sizes. For a general reference on multilevel statistical modeling, see Snijders and Bosker (1999).

12 Note further that many telecommunication operators have subsidiaries with different brands that do not necessarily offer the same quality of service as their core brand. The dataset includes only offers clearly identified as being from the operators with the largest market shares to ensure comparability across operators in different countries.

13 Recent work covering three OECD countries—France, the United Kingdom, and the United States—suggests that premium television content exerts a strong influence on the price of a broadband plan. (Pinà and Fanfalone, 2015).

14 Note that although the OECD dataset has been rigorously constructed and maintained by the organisation, it has not been rigorously compared with similar datasets compiled by other organisations. Towards this end, some of tables used in this section, including table 1, follow Riso and Wallsten (2010a), Riso and Wallsten (2010b), and Wallsten and Riso (2014) who use data supplied by Point Topic. Broadly speaking, the Point Topic and OECD datasets are very similar but as just noted, a rigorous comparative analysis has not been undertaken.

15 According to a BBC News report, TV license fees are found in about two-thirds of European countries. The practice is less common in Africa and Asia, and unknown in North America. See Masters (2014)

16 For example, in January 2006, the UK Office of National Statistics classified the TV license fee as a tax (as opposed to a service charge) and the tax has entered the UK's CPI for radio and TV broadcasting services since then.

17 In this plot the red mark for each entry represents the median price, the box around it shows the second and third quartiles of the distribution, the whisker on the left shows the lowest price, and the whisker on the right shows the highest price excluding outliers. The dots are outliers, defined as more than 3/2 times the upper quartile median.

18 In the original dataset, there were a few observations on bundled plans for these countries (less than 8% of the total), but the observations were dropped because of missing information on plans' characteristics.

19 The match rate was calculated as the number of unique plans that have a match in another country divided by total number of unique plans in the country.

20 Note that all plans in our dataset are divided in groups according to their unique set of features, which include the download speed categories, technology (ADSL, cable, or fibre), the data allowance categories, an indicator that speed slows down after data allowance is reached, contract length, an indicator of free international calls or promotional prices on fixed voice, type of bundle, and number of TV channels. Clearly not all combinations of the 20+ characteristics are found in the data.

21 Note that the common correlated effects estimator due to Pesaran (2006) is another way to handle slope differences in functions across a level in a dataset, but the approach does not lend itself to the hedonic regression context where panel data do not prevail.

22 For further evidence, see column (4) of table A1 in the paper's appendix, which reports a regression that does not include the TV channel variable. In this regression, the indicator variables for bundles with TV service are significant and the regression's log likelihood is (slightly) smaller.

23 For a few countries Teligen collects data from different cities, with different ISPs representing different cities. For example, data for the US were collected from Verizon for New York City and from AT&T and Comcast for Los Angeles. Data for Canada were collected from Shaw for Alberta and from Bell Canada for Ontario. These cities/provinces in principal are different markets, and allowing coefficients to vary across ISPs might fit the data better.

24 In the OECD dataset, based on characteristics considered on a one-by-one basis, the "median" residential plan is a standalone broadband plan with download speed 25-50 Mb/s, provided through ADSL, with unlimited data, and with a contract length of one year or less. Basic plans are standalone broadband plans with download speed under 5 Mb/s, unlimited data, no decrease in download speed after the data cap is reached, and with a contract length of one year or less. A high-speed plan is considered to be a standalone broadband plan with the download speed higher than 120 Mb/s, provided though fibre, with no data limit, and with a contract length of one year or less.

25 There is more to the Belassa-Samuelson hypothesis having to do with productivity level differences across countries and the fact that wages are driven by marginal products. But all told, the basic effect is the empirical observation that price levels in richer countries are systematically higher than in poorer ones (known also as the Penn effect).

26 We are grateful to Bettina Aten for a helpful explanation of the methods used to convert price parities into one currency (US dollars).

27 Statistics on the quarterly market exchange rate are taken from the OECD Monthly Monetary and Financial Statistics (MEI). See more details at http://stats.oecd.org/index.aspx?queryid=169.

28 The quarterly PPP exchange rate is from the OECD dataset.

REFERENCES

Aizcorbe, A. and B. H. Aten (2004), *An Approach to Pooled Time and Space Comparisons*, Paper presented at the SSHRC international conference on index number theory and the measurement of prices and productivity, Vancouver, BC.

Aizcorbe, A., C. Corrado, and M. Doms (2000), *Constructing Price and Quantity Indexes for High Technology Goods*, Paper presented at the 2000 CRIW Workshop at the NBER Summer Institute, Cambridge, Mass.

Aten, B. H. (2006), "Interarea price levels: An experimental methodology", *Monthly Labor Review* (September), 47–61.

Berndt, E. R., Z. Griliches, and N. J. Rappaport (1995), "Econometric estimates of price indexes for personal computers in the 1990's", *Journal of Econometrics 68*(1), 243–268.

Caves, W., L. R. Christensen, and W. Diewert (1982), "Multilateral comparisons of output, input, and productivity using superlative index numbers", *Economic Journal 92*, 73–86.

Cole, R., Y. Chen, J. Barquin-Stolleman, E. Dulberger, N. Helvacian, and J. Hodge (1986), "Quality-adjusted price indexes for computer processors and selected peripheral equipment", *Survey of Current Business 65*, 41–50.

Court, A. T. (1939), "Hedonic price indexes with automotive examples", In *The Dynamics of Automobile Demand*, pp. 99–117. New York: General Motors Corporation.

Díaz-Pinés, A. and A. G. Fanfalone (2015), *The Role of Triple- and Quadruple-play Bundles: Hedonic Price Analysis and Industry Performance in France, the United Kingdom, and the United States,* Paper presented at 43rd research conference on communications, information and internet policy, George Mason University School of Law, Arlington, VA.

Diewert, W. E. (1976), "Exact and superlative index numbers", *Journal of Econometrics 4*(2), 115–145.

Diewert, W. E. (2002), "Hedonic regressions: A review of some unresolved issues", *Mimeo*, University of British Columbia, Vancouver, B.C.

Diewert, W. E. (2005), "Weighted country product dummy variable regressions and index number formulae", *Review of Income and Wealth 51*(4), 561–570.

Feenstra, R. (1995), “Exact hedonic price indexes”, *Review of Economics and Statistics 77*(4), 634–53.

Fixler, D. and K. D. Zieschang (1992), “Incorporating ancillary measures of process and quality change into a superlative productivity index”, *Journal of Productivity Analysis 2*(4), 245–267.

Gelman, A. (2006), “Multilevel (hierarchical) modeling: What it can and cannot do”, *Technometrics 48*(3), 432–435.

Gillingham, R. (1975), “Place to place rent comparisons”, *Annals of Economic and Social Measurement 4*, 153–173.

Griliches, Z. (1961), “Hedonic price indexes for automobiles: An econometric analysis of quality change”, In *The Price Statistics of the Federal Goverment*, Report of the Price Statistics Review Committee, pp. 173–196. NBER.

Hausman, J. (2003), “Sources of bias and solutions to bias in the consumer price index”, *The Journal of Economic Perspectives 17*(1), 23–44.

Heravi, S., A. Heston, and M. Silver (2003), “Using scanner data to estimate country price parities: A hedonic regression approach”, *Review of Income and Wealth 49*(1), 1–21.

Hulten, C. R. (2003), “Price hedonics: A critical review”, *FRBNY Economic Policy Review* (September), 5–15.

Kokoski, M. F., B. R. Moulton, and K. D. Zieschang (1999), “Interarea price comparisons for heterogeneous goods and several levels of commodity aggregation”, In A. Heston and R. E. Lipsey (Eds.), *International and Interarea Comparisons of Income, Output, and Prices*, Studies in Income and Wealth No. 61, pp. 123–169. University of Chicago Press, Chicago.

Kravis, I. G., A. Heston, and R. Summers (1982), “*World Product and Income: International Comparisons of Real Gross Domestic Product*”, Johns Hopkins Press, Baltimore.

Maas, C. J. and J. J. Hox (2005), “Sufficient sample sizes for multilevel modelling”, *Methodology 1*(3), 86–92.

Masters, T (2014), “How is TV funded around the world?”, BBC, London, http://www.bbc.com/news/entertainment-arts-26546570 (accessed on 26 April 2016).

Moulton, B. R. (1995), “Interarea indexes of the cost of shelter using hedonic quality adjustment techniques”, *Journal of Econometrics 68*(1), 181–204.

OECD (2013), *OECD Communications Outlook 2013*, OECD Publishing, Paris, DOI: http://dx.doi.org/10.1787/19991460.

Pakes, A. (2003), "A reconsideration of hedonic price indexes with an application to PC's", *American Economic Review 95*(5), 1578–1596.

Pesaran, M. H. (2006), "Estimation and inference in large heterogenehet panels with a multifactor error structure", *Econom 74*(4), 967–1012.

Rao, D. S. P. (2005), "On the equivalence of weighted country product (CPD) method and the Rao System for multilateral price comparisons", *Review of Income and Wealth 51*(4), 571–580.

Rosen, S. (1974), "Hedonic prices and implicit markets: Product differentiation in pure competition", *Journal of Political Economy 82*(1), 34–55.

Silver, M. and S. Heravi (2001). "Scanner data and the measurement of inflation", *The Economic Journal 111, Issue 472*, 384–405.

Silver, M. and S. Heravi (2003), "The measurement of quality-adjusted price changes", In M. Shapiro and R. Feenstra (Eds.), *Scanner Data and Price Indices*, Volume NBER Studies in Income and Wealth, University of Chicago Press, Chicago.

Silver, M. and S. Heravi (2005) "A failure in the measurement of inflation: Results from a hedonic and matched experiment using scanner data", *Journal of Business and Economic Statistics 23*(3), 269–281.

Snijders, T. and R. Bosker (1999), *Multilevel analysis: An introduction to basic and advanced multilevel modelling*, Sage, Thousand Oaks, CA.

Summers, R. (1973), "International comparisons based upon incomplete data", *Review of Income and Wealth 19*(1), 1–16.

Triplett, J. E. (2004), "Handbook on hedonic indexes and quality adjustments in price indexes: Special application to information technology products", STI Working Paper 2004/9, OECD, Paris, France.

Wallsten, S. and J. Riso (2014), "How do attributes of broadband plans affect price?", *Review of Network Economics 13*(1), 95–119.

Wallsten, S. J. and J. Riso (2010a), *Residential and Business Broadband Prices part 1: An Empirical Analysis of Metering and other Price Determinants*, Working paper, Technology Policy Institute.

Wallsten, S. J. and J. Riso (2010b), *Residential and Business Broadband Prices part 2: International Comparisons*, Working paper, Technology Policy Institute.