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Is Functional Separation the Right Policy Remedy to Break Telecommunications Monopoly and Improve Performance?

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Abstract: *How to break fixed network monopoly and increase competition is a grinding yet controversial topic for the telecommunications sector. In the past two decades, functional separation between wholesale network and retail service was brought to the table by countries intended to promote a healthier telecommunications market. It was first implemented in the United Kingdom in 2005 and we have witnessed many other OECD countries follow suit. However, until now, there is still no empirical evidence on the effectiveness of this solution. This paper aims to fill this gap by using country-level panel data covering the period from 2002 to 2016 to empirically evaluate the impacts of functional separation on fixed telecommunications market using different estimation methods. Our results show that functional separation does not cause any negative impacts as some previous literatures concerned. Instead, it stimulates healthy development of fixed broadband market by significantly decreasing price level and significantly upgrading network quality. After controlling for endogeneity, our findings are still robust, in addition, our results also reveal that impacts of functional separation are related to the degree of functional separation. A higher degree of functional separation results in more positive performance of fixed broadband market.*

Keywords: *Functional Separation, Fixed telecommunications network, Degree of Separation, Fixed broadband*

1. Introduction

The objective of this paper is to analyze the impacts of fixed network functional separation on telecommunications industry and provide empirical evidence on whether it contributes to the sustainable development of the industry. It has been almost a decade since functional separation was recommended by the European Union (EU) under new Article 13a as a policy remedy to liberalize bottleneck access and increase competition in fixed telecommunications network (Council of the European Union, 2008)[1]. After it was first implemented in British Telecommunications (BT) in 2005, we witnessed OECD member countries follow suit, including Sweden, Italy, New Zealand, Australia, Czech Republic, Mexico, etc. The 2015 OECD Digital Economy Outlook continued listing functional separation as a regulatory tool to increase competition in fixed telecommunications network (OECD, 2015) [2]. In the meantime, some countries such as Poland and Ireland had pondered whether to implement functional separation or not, but finally decided to opt it out for the time being. The analysis of this paper is intended not only to help countries already implemented functional separation to evaluate their results but also give some clues to other countries on whether or not and how to implement functional separation in the telecommunications sector.

Functional separation, or vertical separation, is not new to other industries characterized by monopoly network, such as railroad, gas and electricity. In fact, it has been widely implemented in the above sectors decades ago. The rationale behind is to separate the non-competitive network segment from the competitive service providing segment. Thus, the government can regulate the network provider and allow more service providers to enter the market and compete. Moreover, when the telecommunication incumbent is a monopoly fixed network provider, vertical separation can help break the monopoly and thus increase competition. However, given the political and economic importance and the complex technology involved, functional separation in the telecommunications sector was not brought into force until the recent two decades, much later compared to the above other sectors.

Functional separation in the telecommunications sector we discussed in this paper is defined as separation of the incumbent between the upstream wholesale physical telecommunications network and the downstream retail service department. After successful implementation of functional separation, the wholesale unit and the retail unit are separated regarding operating functions, employees and information (European Regulators Group, 2007) [3]. The earliest separation in telecommunications history was the horizontal separation of AT&T into seven regional Bell Operating Companies. However, since the separation happened way earlier and was later reversed, it is not included and discussed in this paper (ITU-infoDev, 2018) [4]. Instead, we choose to focus on the wave of functional separation followed by BT in 2005. Cave (2006) [5] defined three ways to separate an incumbent's monopoly activities: accounting separation, functional separation and ownership separation. Accounting separation is the mildest way by which the incumbent is only required to keep different balance sheets and income statements, while ownership separation is the most intense at the other end of the pole which requires separate ownership of wholesale network provider and retail service provider. Within the framework of functional separation, there are six degrees. Table 1 below shows different ways and degrees of separation defined by Cave (2006) [5]. Functional separation is the center of our discussion in this paper.

Table 1: Ways and degrees of separation by Cave (2006) [5]

Accounting separation	Functional/Operational separation						Ownership separation
	(1) Creation of a wholesale division	(2) Virtual separation	(3) Business separation	(4) Business separation with localized incentive	(5) Business separation with separate governance arrangement	(6) Legal separation	

Until now, there is still no consensus on whether functional separation is the right remedy for fixed network monopoly in the telecommunications sector. Although there has been some research on the potential effects of functional separation, relatively little empirical work has been done to evaluate the comprehensive influences of functionals separation on performance and how the degree of separation affects performance. In this paper, we study the impacts of functional separation on output, investment, price and quality. We start by briefly reviewing past debates and literatures in Section 2, followed with our analytical framework and data in Section 3. The results are presented in Section 4. Section 5 is the discussion.

Our regression estimations in Section 4 show that in general, functional separation significantly decreases fixed broadband price when using fixed effects regression. After using dynamic panel data models and Hausman Taylor estimator to control for endogeneity, our results are still robust. In addition, we find functional separation results in fixed broadband quality upgrade and output increase. At the same time, the degree of functional separation is related to market performance such that a higher degree of separation results in a larger price decrease and a higher output increase. After all, we do not observe any negative impact from functional separation on fixed telephone market, fixed broadband market and total investment level as some scholars concerned.

2. Literature Review

2.1. Different Opinions towards Functional Separation

There are conflicting opinions from scholars towards vertical separation in the telecommunications sector. Those who are in favor of separation believe that vertically integrated firms will always have incentives to exercise price or non-price discrimination to its downstream rivals in the absence of regulation (Mandy & Sappington, 2007) [6]. When the vertically integrated incumbent has monopoly power, it can prevent competitors from entering the retail market, thus vertical separation of telecommunications incumbents becomes a remedy to reduce entry barrier and increase market competition (Cave and Doyle, 2007; De Bijl,2005; Xavier and Ypsilanti, 2004) [7-9], and functional separation is an effective way to prevent non-price discrimination (Cave, 2006)[5]. Pollit (2008) [10] examines the energy market and concludes that vertical separation is a very successful reform, and the major reason that it is opposed by incumbents is because it facilitates competition. Cadman (2010) [11] believes that benefits of functional separation should be measured in its long-term ability to increase competition, even though it could increase short term cost. He also believes that functional separation of BT has reduced discrimination and has created "the right conditions for dynamic efficiency gains in access and downstream broadband markets".

Other scholars do not agree with the above argument. Riordan (2011) [12] believes that separation between upstream and downstream divisions can cause information asymmetries and disable effective coordination. The vertical integration of successive monopolies can eliminate double marginalization problem, resulting in "a lower price of the final good". By applying two-part retail tariff to their economic model, Brito et al. (Brito, Pereira and Vareda, 2012) [13] found that discrimination against entrant might still exist under functional separation and its impacts on welfare is ambiguous. Howell, Meade and O'Connor (2010) [14] did a comparative analysis between telecommunications sector and electricity sector in an effort to draw lessons for telecommunications companies from the electricity reforms. By applying transaction cost theory from Coase (1937)[15] and Williamson (1985) [16] and reviewing history of the electricity sector reforms, they conclude that in the telecommunications sector, vertically integrated firms, rather than vertically separated firms, would induce efficiency, investment and competition within the industry.

Scholars who believe functional separation brings more negative than positive effects are particularly focus on two issues: network quality and investment incentive. Crandall, Eisenach and Litan (2010) [17] applied evidences and statistics from countries that have implemented vertical separation to argue that mandated separation would discourage innovation and investment, and impose costs without increasing penetration. Buehler, Schmutzler and Benz (2004) [18] find that vertical separation reduces upstream supplier's incentive for quality investment. Tropina, Whalley, Curwen (2010) [19] believed it can potentially reduce investment by both incumbents and new entrants. De Bijl (2005) [8] comes up with the same conclusion that investment incentive is largely diminished under vertical separation and thus should be used only when there is a bottleneck in local access and when other regulation is not available.

Amid the debate, a bunch of scholars argue that functional separation could be a two-side sword. Teppayayon & Bohlin (2010) [20] used Sweden as an example of functional separation and pointed out the pros and cons of separation in the analysis. While it could increase transparency, reduce incentive to grant preferential, limit non-price discrimination and encourage competition, it is, in the meantime, irreversible, and may impose costs for operators, resulting in reduced incentive to invest and low quality of service. Nucciarelli & Sadowski (2010) [21] accessed backgrounds and criticalities of functional separation in the Italian case under the European Regulatory Framework and discussed different possibilities in their paper. Both Teppayayon & Bohlin (2010) [20] and Nucciarelli & Sadowski (2010) [21] leave no affirmative conclusion but an open discussion at the end of their analysis, indicating that the impacts of separation as well as the results depend largely on the regulation, the implementation processes and the unique telecom pictures of different countries. Goncalves & Nascimento (2010) [22] discussed and summarized how to balance from a regulation point of view, the large investment required for Next Generation Access Networks (NGAs) and the incentive to innovate in the telecom sector. They proposed that only when the following three conditions are met should a country enforce mandatory vertical separation: a) there is a significant market power for NGAs service b) there is almost no complementarities among services in the supply chain c) network separation is a better regulatory tool than other alternatives.

2.2. Degrees of Separation and Incentive Changes

There is no doubt that structural changes are accompanied by incentive changes, and ultimately, the profit maximization models and conditions of the telecommunications companies can result in performance changes. After Cave (2006) [5] defines the different degree of separation, how the degree of separation affects operators' investment incentives, market performance and total welfare has drawn lots of attention and scholars express diverse opinions. Avenali, Matteucci and Reverberi (2014) [23] explore how investment incentive change under different ways of separation and find that functional separation induces higher social welfare compared with other forms of separation. Hoffler and Kranz (2011) [24] conclude from their economic analysis that when price regulation is in place, legal unbundling provides wholesaler with investment incentive to reduce marginal cost and increase capacity and it is the optimal structure that yields the highest consumer surplus because upstream wholesaler would increase output to maximize profit. In a cross-country study focusing on investment of the electricity market, Gugler, Rammerstorfer, Schmitt (2013) [25] find that when functional separation establishes a wholesale market, it increases total investment. However, Cadman (2019) [26] uses British Telecom as an example to argue that in telecommunications sector, when "equivalence of input" obligation has already been imposed, legal separation does not change investment incentive at all.

Although Mandy and Sappington (2007) [6] describe the incentives of a vertically integrated company to sabotage its downstream rivals, and in the telecommunications industry, both Bertrand (price

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setting) and Cournot (quantity-setting) competition can result in cost increasing sabotage and induce downstream rivals to reduce output (Beard, Kaserman and Mayo, 2001)[27], literatures also stated that in reality, sabotage varies in different cases and it is an empirical matter that requires to be investigated industry by industry (Mandy, 2000; Weisman and Kang, 2001; Kondaurova and Weisman, 2003) [28-30]. Whilst we have heard both negative than positive opinions from scholars, until now, the actual impacts of functional separation have not been thoroughly measured by empirical studies. How functional separation affects the output of fixed telephony and broadband, and whether it reduce total investment and degrade quality in the telecommunications sector remains empirically untested. This paper would fill this gap by taking functional separation as a major reform in the telecommunications industry and empirically test its impacts on output, price, quality and investment.

3. Methods and Data

3.1. Empirical Strategies

Scholars point out that in reality, sabotage varies in different cases and it is an empirical matter that requires to be investigated industry by industry (Mandy, 2000; Weisman and Kang, 2001; Kondaurova and Weisman, 2003) [28-30]. Thus, we aim to use empirical methods to evaluate the impacts of functional separation and the degree of separation on the telecommunications sector.

The impacts of other kinds of reforms and policies of the telecommunications industry have been more widely measured and analyzed by empirical analysis. Li and Xu (2004)[31] used fixed effects model to test the impacts of competition and privatization in the telecommunications sector, where privatization and competition are presented in the model as dummy variables. Wallsten (2001) [32] empirically tests the impacts of privatization and regulation in Africa and Latin America countries under similar approach by taking privatization and regulation as dummy variables. Djiofack-Zebaze and Keck (2009) [33] use Hausman and Taylor estimator to examine the impacts of liberalization in Africa on telecommunications performance and economic growth. Gasmi et al. (2013) [34] focus on regional differences of privatization. They also applied fixed effects regression in their analysis and take reforms as dummy variables. Following their approaches, in this paper, we treat functional separation as a reform to the telecommunications sector and use dummy variables to present it and capture its effects on output, price, investment and quality in our econometric analysis.

To estimate the effects of functional separation on output, investment, price and quality, we use both static and dynamic panel data regression methods. First, we use fixed effects model and static panel data to estimate the impacts of separation. It can help us control unobserved heterogeneity among different countries. The results of the Durbin–Wu–Hausman test as well as the Mundlak's test suggest using fixed effects model over random effects models. In addition, we perform vif test and the result indicates there isn't multicollinearity problem in our data. Second, to further consider the influence from the initial base and to control the path dependence, we use the dynamic panel estimator Arellano Bond to estimate the impacts of functional separation. Last, we use Hausman-Taylor estimator to control for endogeneity and test sensitivity of our results. Stata is used to perform all the statistical analysis involved.

3.2. Baseline Model

To investigate the impacts of functional separation on fixed telecommunications network, we first employ fixed effects models to run regressions on fixed telephone penetration and price, fixed broadband penetration, price and quality, and investment respectively. The model is specified as follows:

$$Y_{it} = \beta' X'_{it} + \theta separation + \delta_i + T + \varepsilon_{it} \quad (1)$$

where i represents country and t represents year. Country fixed effects are captured by δ_i to control for heterogeneity across countries and time fixed effects are captured by time dummies T to control for time trend in the data. X_{it} is a set of control variables and β is their associated vectors. ε_{it} is the error term. For every country year, $separation$ is a dummy variable which equals 0 if the incumbent does not implement functional separation and equals 1 in the year of functional separation and all years after. In this model, we assume functional separation implemented in all the countries is homogenous in all aspects and estimate their results simultaneously. We cluster our standard errors by country to account for potential heteroscedasticity and within-country serial correlation.

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3.3. Intensity of Treatment Model

Cave (2006) [5] summaries different ways of separation regarding how intense the incumbent could be separated. Between accounting separation and ownership separation, functional separation comes in six degrees in the following table 2, and according to these standards, Italy, Australia, Sweden and Czech Republic are in degree (3) or (4), United Kingdom is in degree (5) and New Zealand should be in degree (6)[1].

Table 2 Six Degrees of Separation with respective countries

Accounting separation	Functional/Operational separation						Ownership separation
	(1) Creation of a wholesale division	(2) Virtual separation	(3) Business separation	(4) Business separation with localized incentive	(5) Business separation with separate governance arrangement	(6) Legal separation	
Country			Italy, Australia, Sweden, Czech Republic		United Kingdom	New Zealand	

While Cave (2006) [5] provides us with a comprehensive standard to tell the degree of separation of an incumbent, it is still hard to judge exactly which stage an incumbent is in because we don't have insider information regarding the incentive and reward package of the wholesale division. Thus, we reassign the scores according to the standards we can observe, see the following table 3.

Table 3 Intensity of Separation Scores

Score	Degree of separation	Country
1	Creation of a wholesale division to ensure equivalent access	Italy, Australia, Sweden, Czech Republic
2	Independent board to oversee compliance issues	United Kingdom
3	Legal separation between network and service department	New Zealand

Italy, Australia, Sweden and Czech Republic only meet the first criteria of creating a wholesale division and promising equivalent access, so they are given score 1 (Teppayayon & Bohlin , 2010; Nucciarelli & Sadowski, 2010) [20, 21]. In addition to stage 1, UK created an independent board to oversee compliance issues (Doyle, 2008) [35], so it is given score 2. What needs to notice is that although Italy, Sweden, Australia and Czech Republic created boards too, they were not considered as an independent board (Whalley and Curwen, 2009) [36] and they were regarded as a "loose form" of management (Cave, 2008) [37], so we only give them score 1. New Zealand adopted the most vigorous form of separation (Crandall, Eisenach and Litan, 2010; Cadman, 2019) [17,26] and were given score 3.

According to these scores, we expand our baseline model to estimate how intensity of separation could affect telecommunications performance. A total of six regressions with the same dependent variables as previous models are performed. The models are specified as follows:

$$Y_{it} = \beta' X'_{it} + \mu Intensity + \delta_i + T + \varepsilon_{it} \quad (2)$$

Control variables X_{it} are identical as those in the previous models. Time fixed effects are captured by T and country fixed effects are captured by δ_i. ε_{it} is the error term. $Insensity$ measures how intense functional separation is implemented, and the respecting scores for every country are shown in the above table 3. Here we assume functional separation is the same treatment but of different degrees for every country and we want to estimate how its degree affects output, price, quality and investment. A total of six regressions with different dependent variables on fixed telephone, fixed broadband and investment are estimated. Robust standard errors are used in all the regressions.

3.4. Dynamic Panel Estimator Arellano–Bond

In our previous analysis, we used static panel data estimation and did not account for potential influence from the lagged dependent variable. In this section, we use GMM estimator developed by

[1]A series of literature on functional separation were used to determine what degree a country is in, including Doyle (2008) [35]; Cave (2008) [37]; Whalley and Curwen (2009)[36]; Crandall, Eisenach and Litan (2010) [17]; Nucciarelli & Sadowski (2010) [21]; Teppayayon & Bohlin (2010) [20], Cadman (2019) [26] and operator's website.

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Arellano and Bond (1991) [38] and Arellano and Bover (1995) [39] to address this issue, controlling possible path dependence and correcting endogeneity by using lagged values of one period or more to instrument the explanatory variables. We run the standard regression with no constants first, do Sargan test overidentification test, and then the Arellano-Bond test, and at last use robust standard error to control for heteroskedasticity, rerun the regressions and report the results. Test results are shown in Appendix 3.

$$Y_{it} = f(Y_{i(t-1)},\ \beta' X'_{it},\ \theta separation) \tag{3}$$

Y_{it} is a set of performance indicators on fixed telephony, fixed broadband and investment, and are the same as previous models. Control variables X_{it} are also identical to those in the previous models, except that the time invariant variable STRI is not included. $separation$ is a dummy variable indicating if a country has implemented functional separation or not and is the same as those in equation (1).

3.5. Hausman and Taylor estimator

To control for the endogeneity of our policy variable and take into account the impacts from the time invariant Service and Trade Restriction Index (STRI), we use Hausman and Taylor estimator to further analyze our results. In particular, we relax the assumption that functional separation or the degree of functional separation is uncorrelated with the idiosyncratic error and use Hausman and Taylor estimator to re-estimate their impacts. The potential of a country's telecommunications sector to improve performance under functional separation should be an important factor in deciding whether to introduce functional separation or not. Regulatory authorities might make the separation decision when they observe the current status of this sector and expect post separation performance to improve. This reverse causation indicates our target variable is likely endogenous. Country specific effects are also likely to affect the separation decision because they are likely to be observed by the regulator and they represent part of the performance potential of a country. Hausman and Taylor estimator allows us to control for country fixed effects while at the same time retaining our time-invariant control variable STRI (Hausman and Taylor, 1981) [40]. It controls endogeneity by using generalize instrumental variables and assuming that the individual effects are correlated with some of the explanatory variable (Wooldridge, 2002) [41]. In this model, we consider the decisions to adopt functional separation and to design the degree of separation is endogenous and are correlated to both the time variant and time invariant control variables.

We follow Djiofack-Zebaze and Keck (2009) [33]'s study on telecommunications sector to identify exogenous and endogenous variables for our regression analysis. In our regressions, the dependent variables are the performance indicators for fixed telephone, fixed broadband and investment, identical to those in our previous models. Our control variables are the same as previous models and are listed in Table 4. Time varying exogenous variables include natural log of GDP per capita and population, urbanization, regulator, mobile hhi, mobile density, political risk, economic risk, financial risk and time dummies. Time invariant exogenous variable is STRI. The endogenous variable is functional separation or the degree of separation.

3.6. DATA

The definition and source of the variables included in the following models are presented in Table 4. The sample data has a cross-sectional-time-series structure, containing 25 or 31 OECD countries over the period from 2002 to 2016[2]. We choose OECD countries as control groups because all countries that implemented functional separation on fixed telecommunications industry are OECD member countries. United States were excluded because it implemented vertical separation much earlier compared with other countries in our analysis and in a very different form, and thus it is less comparable to other countries. The complete list of countries included is shown in appendix 1.

We choose country level data because in the telecommunications industry, country level data well reflects the collective outcome of reforms and the competitive pressure companies faced (Li and Xu, 2004) [31], and above all, we are also more concerned about how implementation of functional separation of the incumbent can affect the whole fixed telecommunications sector performance of a country.

The dependent variables are performance measurements of fixed telephone market and fixed broadband market, see Table 4. Outputs are measured by fixed telephone penetration and fixed broadband penetration. Level of investment is measured by investment per capita. Price is measured by fixed telephone three-minute call peak rate and fixed broadband monthly subscription rate. Quality index is

[2]Depending on data availability, the number of countries included in every model might be slightly different, and the accurate number of countries involved in every model is listed in relating regression results table.

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constructed by the authors using data from ITU[3]. It is measured by high speed broadband subscriptions as a percentage to total broadband subscriptions. Data source and duration is also listed in Table 4.

Table 4 Variables and variable description in Regression Analysis

	Variables	Variable Description	Data Source and Duration
Dependent Variables	Telecommunications Output	Fixed telephone penetration	ITU (2002 – 2016)
		Fixed broadband penetration	ITU (2002 – 2016)
	Investment	Investment per capita (CPI adjusted)	ITU (2002 – 2016)
	Price	Fixed telephone price: price of a three-minute call peak rate (CPI adjusted) Fixed broadband price: monthly subscription rate (CPI adjusted)	ITU (2002 – 2016) ITU (2003 – 2016)
	Quality	High speed broadband subscription as a percentage of total broadband subscriptions	ITU (2003 – 2016)
Independent Variables	Variables affect the demand of telecommunications service	GDP per capita. Population. Percentage of urban population	World Bank
	Variables affect the supply of fixed telecommunications service	Mobile telecommunications players HHI. Mobile density. Service and Trade Restriction Index of telecommunications industry (STRI);	GSMA Intelligence; ITU World Bank
	Variables on telecommunications reforms	Creation of an independent regulator. Functional Separation.	ITU World Telecommunications Regulatory database; Crandall, Eisenach and Litan (2010) [17]; Nucciarelli & Sadowski (2010) [21]; Teppayayon & Bohlin (2010) [20], and operator's website.
	Other variables	Political risk. Financial risk. Economic risk.	IRGC Risk ranking (2002 – 2016)

Independent variables included for regression analysis can be summarized and divided into four groups.

The first group consists of variables that affects the demand of fixed telecommunications services, and includes GDP per capita, population and urban population percentage. These variables are widely used by previous empirical studies as control variables on telecommunications industry (Li and Xu, 2004; Wallsten, 2001; Gasmi et al., 2013) [31,32,34].

The second group consists of variables that affects the supply of fixed telecommunications service and includes mobile players' market concentration measured by HHI, liberalization measured by telecommunications service and trade restriction index (STRI). Mobile HHI is the Herfindahl-Hirschman Index, which measures competition from mobile telecommunications sector. Mobile density measures mobile cellular subscription per 100 inhabitants and allows us to control for any potential substitute or compliment effects from the mobile sector. These variables are also widely used by empirically studies in the telecommunications sector (Gasmi et al., 2013; Ezzat, 2018) [34,42].

The third group of control variables consists of variables on reforms of telecommunications industry, including creation of an independent regulatory agency and functional separation. Regulator is a dummy variable which equals 0 if there is not an independent regulator and equals 1 in the year an independent

[3]See Appendix 2 for details on measurement of high-speed broadband.

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regulator is established and all years after. Functional separation equals 1 in the year separation is implemented and all years after, and equals 0 otherwise.

The last group of control variables measure the political, economic and financial stability of a country and literatures have illustrated their impacts on telecommunications industry, especially regarding investment choice and output (Li and Xu, 2004; Wallsten, 2001; Gasmi et al., 2013) [31,32,34]. They also allow us to better control for the heterogeneity of different countries.

STRI is a comprehensive index measured by the World Bank as a restrictive regulatory policy index in the telecommunications sector has been proven to affect telecommunication output significantly, especially in fixed network sector (Ezzat, 2018) [42], and we also believe that restrictive regulation can affect investment and ultimately affect performance of the whole telecommunications sector. Since STRI measures and scores a country's telecommunications sectors on various aspects from market entry, ownership restriction to license fee, covering various aspects, it can also describe the liberalization and openness of a country's telecommunications sector. Moreover, we believe STRI can help us control for a country's regulatory tendency, which has already been in place before the adoption of functional separation and will serve as a supplement to the independent regulator dummy variable mentioned later.

Since variable STRI is time invariant, it is not included in our GMM regressions and cannot be added directly into our fixed effects regression. In our fixed effects models, we interact it with time dummy so that it can be regressed in the form of an interaction term. In this way, we can estimate how its impact change with time to consider whether there is a time-varying trend. We directly include this variable in our Hausman and Taylor regression.

We use ITU regulatory database on functional separation and previous literatures (Crandall, Eisenach and Litan, 2010; Teppayayon & Bohlin, 2010; Nucciarelli & Sadowski, 2010) [17,20,21] to identified countries that have implemented functional separation. ITU's data is based on questionnaires and three questions were asked: first, whether functional separation is required by law; second, if yes, please indicate the name of the operators that are subject to this regulatory measure; third, please indicate the website where this regulation can be found. At the end, six countries (Czech Republic, Australia, Italy, New Zealand, Sweden, United Kingdom) fit our time spam (2003-2016) and definition of implementing functional separation and are included in our analysis. Table 5 contains a summary statistic of all the data we included in the analysis.

Table 5 Summary Statistics

Variable	Designation	Obs.	Mean	Std.Dev	Min.	Max.
loggdppercap	log of Gdp per capita	510	10.415	0.381	9.477	11.491
logpop	log of Population	510	16.283	1.459	12.569	18.668
urbanization	Urbanization	510	76.848	11.441	49.627	97.897
fixphone	Fixed telephone penetration	510	41.697	14.011	8.310	74.374
fixbroadband	Fixed broadband penetration	508	21.394	11.609	0.033	44.914
loginv	log of investment per capita in USD	441	4.760	0.672	1.113	6.539
logfixphone_price	log of fixed telephone three-minute peak price in USD, cpi adjusted	453	-1.752	0.577	-4.000	0.268
fixbroadband_price	log of broadband price in USD, cpi adjusted	335	3.328	0.427	1.699	4.548
quality	Quality	267	34.960	21.856	0.000	94.469
mobile hhi	Mobile hhi	456	3637.213	800.253	2249.000	6274.000
mobiledensity	mobile cellular penetration	578	100.222	28.719	13.840	172.179
Regulator	Regulator	508	0.860	0.347	0.000	1.000
Politicalrisk	Political risk	484	80.323	8.143	52.167	94.667
Econrisk	Economic risk	510	38.836	4.094	19.875	48.417
Finarisk	Financial risk	510	37.724	4.590	20.417	49.042
stri	Service trade restriction index	375	10.500	16.860	0.000	50.000

4. Results

It is believed that functional separation mostly affects fixed broadband market because the policy mainly focuses on broadband market rather than fixed telephone market (De Bijl, 2005) [8]. However,

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we are still curious about whether it affects fixed telephone market as well. Thus, we include fixed telephone market performance indicators in our regressions. We believe the results could help us compare these two markets and give us a clear view on whether this treatment is truly effective.

4.1. Baseline Model

Table 6 present results from the baseline fixed effects model. When we regard functional separation as homogenous in all countries, the estimates suggest that it has no significant impact on fixed telephone penetration and price. It also does not have significant impact on fixed broadband penetration and quality, but it significantly decreases fixed broadband price. Investment level is also not affected by separation.

Table 6 Baseline model regression parameter estimates

	Fixed telephone		**Fixed broadband**			**Investment**
Yit	Penetration	Price	Penetration	Price	Quality	Investment per capita
separation	-0.480	-0.0873	1.343	-0.408**	8.189	-0.0926
	(2.742)	(0.0953)	(1.604)	(0.176)	(9.503)	(0.170)
loggdppercap	1.700	-0.697	-1.320	-1.912**	26.00	1.080
	(11.78)	(0.591)	(5.690)	(0.902)	(42.96)	(0.685)
logpop	-7.123	2.397	-48.53***	-3.695	170.5*	4.247*
	(24.09)	(1.700)	(15.21)	(2.989)	(82.43)	(2.151)
urbanization	0.981**	0.0366	-0.523	-0.0855	-2.535*	0.0164
	(0.473)	(0.0471)	(0.314)	(0.0509)	(1.419)	(0.0457)
regulator	0.139	0.373***	0.926	-0.0849	-5.459	-0.426**
	(2.052)	(0.111)	(1.091)	(0.171)	(7.261)	(0.171)
mobilehhi	0.000172	5.48e-07	0.00110	-9.79e-05	0.000642	4.99e-05
	(0.00139)	(0.000111)	(0.00106)	(0.000150)	(0.00479)	(9.49e-05)
mobiledensity	-0.0240	0.000125	-0.124***	-0.00996**	0.391**	0.000847
	(0.0715)	(0.00315)	(0.0227)	(0.00375)	(0.184)	(0.00300)
politicalrisk	-0.0896	0.0145	-0.0554	0.0185	-1.809***	0.00326
	(0.208)	(0.0162)	(0.124)	(0.0128)	(0.528)	(0.0181)
econrisk	0.116	-0.0137	-0.262**	-0.0160	1.517	0.0329*
	(0.287)	(0.0119)	(0.104)	(0.0134)	(1.001)	(0.0175)
finarisk	-0.237	-0.0358**	0.0580	0.00935	-0.462	0.0232
	(0.380)	(0.0136)	(0.172)	(0.0183)	(0.889)	(0.0167)
stri_time	0.0165	-0.00223**	0.00212	0.00186	0.0190	0.000398
	(0.0172)	(0.000915)	(0.00471)	(0.00147)	(0.0275)	(0.000766)
Time	Yes	Yes	Yes	Yes	Yes	Yes
Observations	326	278	324	206	272	291
R-squared	0.502	0.312	0.945	0.417	0.706	0.518
Number of id	24	22	24	24	24	24

Robust standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$

This model assumes functional separation is an identical reform for every country and allows us to have a general look at its impacts as well as how other factors affect the fixed telecommunications market. The fixed telephone market among OECD countries seems to be a relatively mature market and its penetration rate is unaffected by most of our control variables, except that it has a positive relation with urbanization level. When controlling other factors, functional separation does not affect fixed telephone penetration and price.

In fixed broadband market, we observe a positive coefficient correlation of functional separation on penetration level, but it is not statistically significant. At the same time, when controlling other factors, functional separation significantly decreases fixed broadband price. The impact on quality, which is measuredly by high speed broadband penetration, is also positive but not significant, indicating it does not create a quality degradation as some scholars concerned (Buehler, Schmutzler and Benz, 2004; Teppayayon & Bohlin, 2010) [18, 20]. At last, we do not see any significant impact from functional separation on investment level.

There are two major arguments that separation would cause price increase, which are double marginalization effects (Gugler, Rammerstorfer, Schmitt, 2013) [25] and transaction cost hypothesis (Crandall, Eisenach and Litan, 2010) [17]. Gugler, Rammerstorfer, Schmitt (2013) [25] believe when the assumptions of linear pricing and market power downstream are met while cost-based price regulation is absent, functional separation can cause double marginalization problem. Crandall, Eisenach and Litan

(2010) [17] believe that transaction cost between upstream wholesaler and downstream retailer will cause price increase. In addition, the separation process also induces management and other cost that could potentially drive up price level. However, our results indicate these circumstances might not hold. Some scholar like Hoffler and Kranz (2011) [24] believe that after legal unbundling, the wholesaler's incentive is different, and in order to maximize profit, it will increase capacity and reduce marginal cost to boost sales and to compete with potential competitors, and thus drive down retail price. We believe this might fit our case for the fixed broadband market. When the market is quickly expanding, wholesaler increases capacity and drives down price to prevent potential competitors from entering the market and grabbing its profit. We also believe the price decrease might be caused by the "equivalent of access" obligation, under which the wholesaler is obliged to offer every retailer the same product for the same price. It helps break monopoly and results in increased downstream competition and drive down the retail price.

4.2. Intensity of Treatment Model

Although all our treatment countries have implemented functional separation, the degree of functional separation is not entirely the same across every country. Thus, we employ the intensity of separation parameter to estimate whether market performance is associated with the degree of functional separation. Table 7 presents regression results of our intensity of treatment model. In the fixed telephone market, the intensity level of functional separation does not have any impact on fixed telephone penetration and fixed telephone price, which indicate that functional separation policy does not affect the fixed telephone market after all. However, in fixed broadband market, intensity level of separation is significantly and positively related to penetration. When controlling for other factors, one unit increase in separation intensity score results in about 1.5% increase in penetration. The degree of separation is also significantly associated with broadband price. The higher the degree of functional separation is, the larger the fixed broadband price decreased. The effects on quality is still insignificant when we use fixed effects regression, and we do not observe any impact on investment level from the degree of separation.

Table 7 Intensity of Treatment Model Regression parameter estimates

	Fixed telephone		**Fixed broadband**			**Investment**
Yit	Penetration	Price	Penetration	Price	Quality	Investment per capita
Intensity of separation	0.844	-0.0493	1.535**	-0.335**	0.154	0.0678
	(1.371)	(0.0768)	(0.585)	(0.122)	(5.572)	(0.107)
loggdppercap	3.114	-0.666	-0.943	-1.829**	18.10	1.236*
	(11.58)	(0.582)	(5.326)	(0.879)	(46.36)	(0.613)
logpop	-8.134	2.355	-47.39***	-3.637	185.2**	4.135**
	(25.41)	(1.684)	(14.73)	(2.918)	(80.42)	(1.974)
urbanization	1.062**	0.0381	-0.464	-0.0842	-2.871**	0.0278
	(0.470)	(0.0468)	(0.291)	(0.0504)	(1.362)	(0.0457)
regulator	-0.0956	0.367***	0.921	-0.0733	-4.881	-0.455**
	(2.084)	(0.120)	(1.060)	(0.165)	(7.986)	(0.190)
mobilehhi	0.000347	2.88e-06	0.00128	-7.70e-05	0.000198	7.81e-05
	(0.00138)	(0.000111)	(0.000998)	(0.00014)	(0.00463)	(9.04e-05)
mobiledensity	-0.0194	0.000231	-0.121***	-0.0100**	0.367*	0.00129
	(0.0718)	(0.00309)	(0.0222)	(0.00376)	(0.190)	(0.00315)
politicalrisk	-0.0991	0.0139	-0.0477	0.0170	-1.664***	0.00209
	(0.219)	(0.0162)	(0.121)	(0.0132)	(0.552)	(0.0166)
econrisk	0.114	-0.0144	-0.243**	-0.0174	1.641	0.0321*
	(0.290)	(0.0122)	(0.102)	(0.0133)	(1.024)	(0.0172)
finarisk	-0.289	-0.0357**	0.00167	0.0101	-0.347	0.0187
	(0.380)	(0.0133)	(0.160)	(0.0184)	(0.911)	(0.0153)
stri_time	0.0159	-0.00224**	0.000831	0.00193	0.0168	0.000332
	(0.0166)	(0.000913)	(0.00409)	(0.00148)	(0.0283)	(0.000726)
Time	Yes	Yes	Yes	Yes	Yes	Yes
Observations	326	278	324	206	272	291
R-squared	0.505	0.311	0.948	0.418	0.700	0.520
Number of id	24	22	24	24	24	24

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

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4.3. Dynamic Panel: Arellano and Bond estimator

Our previous fixed effects models assume that all variables are exogenous and we do not take into account the impacts from the lagged dependent variable. Here we use Arellano and Bond estimator to perform GMM regressions to alleviate those concerns. Table 8 presents the results of our regression estimates. Through the results, we find strong statistical significance from most of our lagged dependent variables except fixed broadband price. In fixed telephone market, functional separation still does not create any significant influence on market penetration rate and price. In fixed broadband market, penetration is also not affected by separation, but unlike using fixed effects regression, here we can see that apart from causing a significant price decrease, separation also causes a significant quality increase. As of investment level, the influence is still statistically insignificant.

Sargan test results suggest that except for broadband penetration and quality model, there is no overidentification problem. Thus, we use robust standard errors to control for heteroskedasticity[4]. For all models, there is no evidence of serial correlation at order 2, implying that the moment condition we used is valid. Test results are shown in Appendix 3.

The regression estimates indicate that functional separation not only contributes to broadband price decrease, but also, at the same time, increase broadband quality. We believe there are three reasons why quality is increased under functional separation. First, when the upstream wholesaler is separated from retail service, it becomes more specialized in its network function and specialization makes it more focus on its core function. Second, after separation, the downstream retailer no longer shares the same incentive and profit maximization package with the upstream wholesaler, thus, in order to increase its own profit, the downstream retailer will push the upstream wholesaler to upgrade its network. Third, functional separation breaks regional monopoly and makes it easier for potential competitors to enter the market, so in order to prevent potential competitors from entering the market, the wholesaler will choose to decrease price and/or increase quality to deter potential competitors.

Table 8 Dynamic panel model regression parameter estimates

	Fixed telephone		**Fixed broadband**			**Investment**
Yit	Penetration	Price	Penetration	Price	Quality	Investment per capita
L.	0.864***	0.334**	0.763***	0.205	0.675***	0.448***
	(0.0475)	(0.162)	(0.0384)	(0.132)	(0.0803)	(0.0870)
separation	0.574	-0.0864	-0.0965	-0.435***	10.57**	-0.169
	(1.215)	(0.115)	(0.966)	(0.123)	(5.334)	(0.117)
loggdppercap	0.319	-1.304	10.20**	-1.377*	-4.834	0.970
	(4.147)	(1.077)	(4.365)	(0.831)	(29.37)	(0.701)
logpop	-10.00	-0.0919	14.31**	2.885*	-168.1*	0.330
	(6.516)	(1.546)	(7.193)	(1.627)	(99.39)	(1.528)
urbanization	0.289**	0.0616	0.116	-0.0263	-2.901**	0.0200
	(0.116)	(0.0463)	(0.169)	(0.0418)	(1.386)	(0.0449)
regulator	0.128	-0.348*	2.704***	-0.129	-6.150	0.154
	(0.654)	(0.207)	(0.581)	(0.164)	(4.200)	(0.164)
mobilehhi	-0.000184	-0.000152	0.000447	-9.55e-05	-0.00450	9.55e-05
	(0.000562)	(0.000203)	(0.000460)	(0.000113)	(0.00528)	(9.58e-05)
mobiledensity	-0.0313**	-0.000560	0.00985	-0.000734	0.376**	0.00467**
	(0.0146)	(0.00344)	(0.0155)	(0.00250)	(0.166)	(0.00184)
politicalrisk	0.125**	-0.00728	-0.0627	0.0156	0.818**	0.0145
	(0.0596)	(0.0144)	(0.0387)	(0.0100)	(0.355)	(0.0126)
econrisk	-0.148*	0.0115	0.0202	0.00460	0.0900	0.0111
	(0.0875)	(0.0144)	(0.0419)	(0.0100)	(0.418)	(0.00774)
finarisk	0.0835	-0.000843	0.00770	0.0199	0.126	0.00394
	(0.145)	(0.0160)	(0.0679)	(0.0130)	(0.462)	(0.0117)
Constant	143.5	10.33	-350.2***	-31.11	3,011*	-17.24
	(103.3)	(25.86)	(132.9)	(25.08)	(1,675)	(25.11)
Observations	278	222	274	141	199	228
Number of id	24	22	24	24	24	24

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

[4]For fixed broadband penetration and fixed broadband quality models, after we use two-step estimator instead of one-step, the Sargan test results show there is not overidentification problems. The results are not fundamentally different between one step and two step GMM. We report the results in Appendix 4.

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4.4. Hausman and Taylor estimator.

Our previous fixed effects model assumes all variables are exogenous and no influence from time-invariant variables. In this model, we relax these two assumptions. Table 9 shows the results of our Hausman and Taylor regression estimates. In fixed telephone market, the results are the same as the previous fixed effects and GMM regressions that functional separation has no impact on penetration and price. In fixed broadband market, after controlling for endogeneity, the regression results are different from the previous models, and we observe a significant positive impact of functional separation on fixed broadband penetration, indicating that functional separation increases fixed broadband output. The regression estimates for fixed broadband price and quality is somewhat similar to that of GMM regressions. Separation results in a significant decrease in fixed broadband price and a significant increase in quality.

Table 9 Hausman and Taylor Regression Parameter Estimates

	Fixed telephone		**Fixed broadband**			**Investment**
Yit	Penetration	Price	Penetration	Price	Quality	Investment per capita
separation	-0.506	-0.0339	1.164*	-0.354**	9.383**	-0.0718
	(1.215)	(0.0977)	(0.652)	(0.139)	(3.915)	(0.0792)
loggdppercap	2.072	0.126	-3.405	-1.875***	35.95*	1.177***
	(5.693)	(0.304)	(3.236)	(0.459)	(18.76)	(0.369)
logpop	3.210	-0.00729	-31.70***	-0.255	104.8***	3.270***
	(4.120)	(0.0954)	(5.230)	(0.275)	(28.58)	(0.619)
urbanization	0.995***	0.00895	-0.463***	-0.00972	-2.246**	0.0215
	(0.240)	(0.00892)	(0.144)	(0.0229)	(0.912)	(0.0182)
regulator	-0.390	0.276**	1.105	-0.0606	-6.362	-0.439***
	(1.514)	(0.119)	(0.810)	(0.170)	(5.011)	(0.100)
mobilehhi	9.76e-05	-2.19e-05	0.00120***	-0.000157*	-0.000136	4.40e-05
	(0.000798)	(6.55e-05)	(0.000426)	(8.83e-05)	(0.00263)	(5.63e-05)
mobiledensity	-0.0179	-0.00361	-0.117***	-0.00838***	0.382***	0.00111
	(0.0295)	(0.00226)	(0.0159)	(0.00258)	(0.0920)	(0.00190)
politicalrisk	0.0708	0.00323	-0.0236	0.0353***	-1.682***	0.00738
	(0.119)	(0.00919)	(0.0632)	(0.00977)	(0.378)	(0.00730)
econrisk	0.0210	-0.0211*	-0.230***	-0.0184	1.119**	0.0279***
	(0.155)	(0.0120)	(0.0857)	(0.0127)	(0.510)	(0.00966)
finarisk	-0.113	-0.045***	0.0625	0.0145	-0.293	0.0277***
	(0.147)	(0.0116)	(0.0781)	(0.0143)	(0.488)	(0.00916)
stri	-0.353	-0.0109	0.427	-0.000362	-0.517	-0.0484
	(0.311)	(0.00988)	(0.636)	(0.0204)	(2.897)	(0.0749)
Constant	-117.2	-1.289	649.6***	26.94***	-1,886***	-66.60***
	(91.29)	(3.243)	(90.39)	(6.892)	(498.6)	(10.70)
Time	Yes	Yes	Yes	Yes	Yes	Yes
Observations	326	278	324	206	272	291
Number of id	24	22	24	24	24	24

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.The Wald test is significant at 1% level. Estimation technique: Hausman and Taylor (1981)[40].

Table 10 shows the results when we replace separation variable with intensity of separation variable and test how the degree of separation affects telecommunications performance. Our regression estimates show that degree of separation still does not affect fixed telephone market, but in fixed broadband market, a higher degree of separation causes penetration increase and price decrease. The results indicate that the higher the degree of separation is, the larger price decrease and output increase functional separation brings to a country. What’s more, the regression estimates reveal a statistically significant impact from the degree of separation on investment level. A higher degree of separation is associated with investment increase, indicating that when the upstream wholesaler is more independent, investment level increase more, which echoes Hoffler and Kranz (2011) [24]’s theoretical deduction.

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Table 10 Hausman and Taylor Regression Parameter Estimates for Intensity of Separation

	Fixed telephone		**Fixed broadband**			**Investment**
Yit	Penetration	Price	Penetration	Price	Quality	Investment per capita
Intensity of separation	1.061	0.000800	1.475***	-0.281**	1.098	0.0856*
	(0.698)	(0.0765)	(0.365)	(0.111)	(2.610)	(0.0455)
loggdppercap	3.853	0.126	-2.595	-1.748***	28.78	1.355***
	(5.616)	(0.305)	(3.147)	(0.451)	(18.93)	(0.366)
logpop	2.937	-0.0112	-33.03***	-0.262	115.6***	3.022***
	(3.852)	(0.0961)	(5.168)	(0.253)	(29.40)	(0.605)
urbanization	1.033***	0.00897	-0.421***	-0.00486	-2.61***	0.0316*
	(0.234)	(0.00896)	(0.140)	(0.0218)	(0.920)	(0.0181)
regulator	-0.721	0.266**	1.071	-0.0523	-5.689	-0.466***
	(1.498)	(0.119)	(0.786)	(0.170)	(5.055)	(0.0993)
mobilehhi	0.000338	-2.09e-05	0.00138***	-0.000144	-0.00049	7.37e-05
	(0.000803)	(6.55e-05)	(0.000420)	(8.86e-05)	(0.00269)	(5.69e-05)
mobiledensity	-0.0136	-0.00351	-0.115***	-0.0084***	0.355***	0.00150
	(0.0293)	(0.00225)	(0.0155)	(0.00257)	(0.0927)	(0.00189)
politicalrisk	0.0472	0.00275	-0.0318	0.0344***	-1.57***	0.00532
	(0.118)	(0.00914)	(0.0616)	(0.00970)	(0.382)	(0.00725)
econrisk	0.0314	-0.0210*	-0.210**	-0.0201	1.262**	0.0277***
	(0.155)	(0.0121)	(0.0837)	(0.0127)	(0.513)	(0.00961)
finarisk	-0.188	-0.0445***	-0.00296	0.0148	-0.221	0.0220**
	(0.151)	(0.0116)	(0.0785)	(0.0143)	(0.503)	(0.00942)
stri	-0.357	-0.0108	0.433	0.00110	-0.646	-0.0469
	(0.289)	(0.00993)	(0.649)	(0.0188)	(3.060)	(0.0711)
Constant	-131.8	-1.209	661.5***	25.42***	-1,98***	-64.89***
	(87.68)	(3.261)	(89.38)	(6.551)	(512.2)	(10.51)
Time	Yes	Yes	Yes	Yes	Yes	Yes
Observations	326	278	324	206	272	291

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. The Wald test is significant at 1% level.

To conclude, from our regression results under three different kinds of regressions above, we find that the fixed telephone market in OECD countries is quite mature and stable, and its outputs are not affected by our policy variables or most of other control variables. In the meantime, fixed broadband market is strongly affected by the functional separation policy. Across all our regression models, functional separation significantly decreases fixed broadband price, and the regression results are robust across different models and specifications. After controlling for endogeneity using GMM regression models and Hausman Taylor regression, functional separation also significantly increase fixed broadband quality. At last, when we use Hausman Taylor estimator to control for endogeneity and after adding in time invariant policy and liberalization control variables for the telecommunications sector while allowing functional separation or the degree of functional separation to be endogenous, we find that functional separation also increases broadband penetration, and at the same time, a higher degree of separation results in higher fixed broadband penetration and a higher investment level.

5. Discussion

How to break regional monopoly and to increase competition in fixed telecommunications market, and especially, how to promote sustainable development of the fixed broadband market is still a continuous battle for regulators in almost all countries. Policy tools such as liberalization and privatization have been widely applied in OECD countries (Gasmi et al., 2013) [34], yet telecommunications incumbents with strong market power still exists in many countries (Cadman, 2019) [26]. Against this backdrop, the idea of functional separation was put forward and was enforced in some OECD member countries including UK, Sweden, Australia, New Zealand, Italy and Czech Republic.

Even before functional separation was first implemented in UK's telecommunications sector, debates on its effectiveness had begun. Opponents called it "a cure worse than the disease" (Masse, 2008)[43]

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and argued that it can impose additional cost and diminish network provider's incentives to invest (Riordan, 2011; Brito, Pereira and Vareda, 2012; Howell, Meade and O'Connor, 2010; Crandall, Eisenach and Litan, 2010; Buehler, Schmutzler and Benz, 2004) [12-14,17-18], while supporters believed it was an effective remedy to increase competition and prevent price discrimination and non-price discrimination in the wholesale telecommunciations market (Cave, 2006; Cave and Doyle, 2007; Xavier and Ypsilanti, 2004; Pollit, 2008; Cadman, 2010) [5,7,9,10-11]. Thus, in light of this decade-long debate, we use country level panel data and different empirically methods to test the above hypotheses and to provide evidences on whether it was a right decision to enforce functional separation in the telecommunications market, and if the degree of separation, or the ways of separarion affect performance.

First, we find functional separation does not create any negative impact on fixed telephone market, fixed broadband market and total telecommunications investment level as some scholars concerned (De Bijl, 2005; Riordan, 2011; Brito, Pereira and Vareda, 2012; Howell, Meade and O'Connor, 2010; Crandall, Eisenach and Litan, 2010; Buehler, Schmutzler and Benz, 2004; Masse, 2008) [8,12-14,17-18,43]. None of our estimation results indicate there is any negative impact of functional separation on output, price, quality and investment in the telecommunications sector. Instead, our empirical results suggest that functional separation significantly decreases fixed broadband price, indicating that it is an effective way to increase fixed broadband competition. The significant decrease of fixed broadband price is robust under different regression methods. In addition, after we use Hausman Taylor and GMM estimator to control for endogeneity, we find functional separation results in quality upgrade of fixed broadband, that is, it increases high speed fixed broadband penetration rate.

Second, when we evaluate functional separation by its intensity level, our empirical results show that a higher degree of separation results in a larger broadband price decrease and a higher broadband penetration level, indicating that the higher the degree of separation, the lower the price and the higher the penetration rate. These results are robust after we use Hausman Taylor estimator to control for endogeneity and the influence of time-invariant policy variables.

However, we do not observe any significant impact of functional separation on fixed telephone market. We believe that the fixed telephone markets of OECD countries are quite stable, and since it is also not the main policy focus of functional separation reform. Even if fixed telephone wholesale market is opened after separation, since it is a shrinking market, potential competitors are not highly interested in entering this field, so it is reasonable that we do not observe any policy impacts. It can serve as a comparison of our fixed broadband performance indicators and the results demonstrates that functional separation does improve broadband market performance for our treatment countries.

After comparing different regression methods, we believe the Hausman Taylor models best measure the impacts of functional separation since it considers endogeneity, country specific effects and time invariant regulatory variables at the same time. Our regression estimates indicate that in reality, when the wholesale company is separated from its former retail ally, it still has plenty of incentive to invest in quality upgrade and production enlargement in order to maximize its own profit, and when the wholesale department is more intensely separated from its former retailer, the more incentives it has to decrease price and increase production.

Although functional separation can cause short term cost increase, its real impact should be measured by its long-term effects on telecommunications market performance. We hope the results of our empirical study can give some clues to other OECD countries in their evaluation for whether to implement functional separation on fixed telecommunications incumbent or not. Our study also provide positive empirical evidences to countries that already implemental functional separation, indicating that functional separation is a right remedy to break fixed telecommunications regional monopoly and to increase overall competitiveness in these countries. Although we see conflicting opinions on separation, our estimation results have shown more positive than negative impacts. For countries intended to vertically separate their fixed telecommunications incumbent, we would recommend a more intense form of functional separation, which should at least include creating an independent board to oversee compliance issue, since our results as well as previous literatures (Avenali, Matteucci and Reverberi , 2014; Hoffler and Kranz, 2011; Gugler, Rammerstorfer, Schmitt, 2013) [23-25] have proven that a higher degree of separation provide more incentives for the wholesale company to increase production and to lower price, and it also results in higher broadband penetration rate and a higher investment level. Above all, our study has cleared the pessimistic concerns on functional separation of the fixed telecommunications sector.

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Appendix 1: Countries included and excluded in regressions

OECD member states included in our regression: Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea (Rep. of), Latvia, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom

OECD member states excluded because of data availability or becaue there is no STRI data: Estonia, Iceland, Israel, Latvia, Luxembourg, Norway, Slovak Republic, Slovenia, Switzerland

Appendix 2: Construction of the quality index

Year 2003 to 2007: broadband subscription per 100 inhabitants.

Year 2008 to 2016: above 2M/s broadband subscriptions as a percentage of total broadband subscriptions.

There are two reasons why we construct this index from 2003 to 2007 this way. First, we believe before 2007, the speed of broadband does not vary a lot, and having a broadband connection is already a quality option. Second, ITU does not collect broadband speed data before 2007. When ITU starts collecting broadband speed data in 2008, the highest speed category is 2M/s to 10M/s subscriptions. (2M/s or 10M/s refers to per second speed. For example, the network carrier's promised bandwidth is 20M, then the speed is $20 \times 1024 \div 8 = 2560 \text{KB/s}$)

Appendix 3: Sargan test results for overidentifications and Arellano-Bond test for zero autocorrelation in first-differenced errors test results for dynamic GMM.

(1) Sargan test results. (H0: overidentifying restrictions are valid)

Model fixed telephone penetration

chi2(79) = 70.62431

Prob > chi2 = 0.7382

Model fixed telephone price

chi2(75) = 84.87019

Prob > chi2 = 0.2041

Model fixed broadband penetration

chi2(79) = 119.0386

Prob > chi2 = 0.0024

Model fixed broadband price

chi2(58) = 74.9695

Prob > chi2 = 0.0662

Model fixed broadband quality

chi2(68) = 153.2021

Prob > chi2 = 0.000

Model investment

chi2(79) = 70.11465

Prob > chi2 = 0.7523

(2) Arellano-Bond test results for GMM regressions

Table 11 Arellano-Bond test for zero autocorrelation in first-differenced errors. (H0: no autocorrelation)

Model	Order	z	Prob > z
Fixed telephone penetration	1	-5.6696	0.0000
	2	-0.9340	0.3503
Fixed telephone price	1	-6.1954	0.0000
	2	0.5400	0.5892
Fixed broadband penetration	1	-4.8327	0.0000
	2	1.8609	0.0628
Fixed broadband price	1	-2.6735	0.0075
	2	-1.5308	0.1258
Fixed broadband quality	1	-5.1940	0.0000
	2	0.3021	0.7626
Investment	1	-4.9901	0.0000
	2	0.6779	0.4978

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Appendix 4: Regression results for broadband penetration model and broadband quality model when using two-step GMM

Table 12 Regression estimates for two-step GMM model

Yit	Fixed broadband penetration		Fixed broadband quality	
	Two-step robust	Two-step	Two-step robust	Two-step
L.	0.833**	0.833***	0.544	0.544***
	(0.343)	(0.0504)	(0.403)	(0.0954)
separation	-1.776	-1.776	31.58	31.58**
	(1.619)	(1.134)	(37.99)	(14.50)
loggdppercap	16.72	16.72***	4.435	4.435
	(15.53)	(6.194)	(201.5)	(29.64)
logpop	4.227	4.227	-410.9	-410.9***
	(49.40)	(14.14)	(375.4)	(130.4)
urbanization	-0.167	-0.167	2.521	2.521
	(2.828)	(0.405)	(21.05)	(3.311)
regulator	6.224	6.224**	-6.383	-6.383
	(5.883)	(2.662)	(23.39)	(10.51)
mobilehhi	0.000262	0.000262	-0.00423	-0.00423**
	(0.000907)	(0.000241)	(0.00973)	(0.00210)
mobiledensity	-0.00613	-0.00613	0.504	0.504***
	(0.0866)	(0.0133)	(0.553)	(0.187)
politicalrisk	-0.0623	-0.0623**	2.125	2.125***
	(0.193)	(0.0248)	(3.694)	(0.795)
econrisk	-0.0600	-0.0600	-0.880	-0.880
	(0.128)	(0.0471)	(5.515)	(0.646)
finarisk	-0.00897	-0.00897	0.285	0.285
	(0.158)	(0.0415)	(1.859)	(0.750)
Constant	-224.6	-224.6	6,492	6,492***
	(691.6)	(176.0)	(3,957)	(1,967)
Observations	274	274	199	199
Number of id	24	24	24	24

Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Appendix 5: Sargan test results for two-step GMM model

Model fixed broadband penetration	Model fixed broadband quality
chi2 (79) = 119.0386	chi2 (68) = 153.2021
Prob > chi2 = 0.0024	Prob > chi2 = 0.0000

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