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RESEARCH

Location Dependent Spectrum Pricing of Private LTE and 5G Networks in Europe

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Abstract

Emerging private LTE and 5G services and applications have created need for local radio spectrum licensing. The existing pricing models for licenses do not work well in this context. This paper introduces three new location dependent pricing methods that aim to produce more accurate pricing for local licenses. We use Traficom Frequency Fee as our base-case general spectrum pricing model, and we replace the population density based location coefficient with proxies such as employee density, value added per employee, and rent prices. By comparing the differences in the prices yielded by the models, we show that the new models can in some cases identify high demand areas like hospitals and industrial districts better than the original population density based model. Additionally, we conclude that the original population density based model and the new employee density based model could be used together to capture both the consumer and the industrial spectrum demand simultaneously.

Keywords: Private LTE; 5G; spectrum pricing; valuation

Introduction

Motivation

Private LTE and 5G networks serve enterprise business, government or education using mobile network technology. The studied mobile networks operate in the radio spectrum bands, which are defined by 3GPP in specification TS 36.101 [1]. The value of the mobile spectrum for private LTE and 5G networks is dependent on multiple factors, including the bandwidth, duration, area, and location. In this study, the specific interest is in the location of the network area.

For services targeted to consumers, the pricing follows the population density, but as no one lives in factories, ports, or in shopping malls, other location proxies should be found for spectrum pricing of private LTE and 5G networks. From the buyer perspective, the price is what is given up or sacrificed to get the value of the service or product for which the price is paid for according to [2]. Mobile Network Operators (MNOs) have spent billions on gaining exclusive access to spectrum assets and deploying network infrastructure needed to meet current and future consumer demand. LTE evolution and future 5G networks target location specific solutions to meet stringent wireless connectivity needs of distinct vertical use cases in the capacity bands. The 5G technologies bring drastic changes to how mobile spectrum is used [3]. A significant driver for this is the change in the demand for the licenses of mobile spectrum. During LTE era, the demand has mainly consisted of MNOs, which provide Mobile Broadband (MBB) services. However, the potential user-base of 5G is much more diverse. For example, 5G serves the specific communication needs of industries like manufacturing, logistics, and education [4]. The industry and site specific networks require local, private network deployments in contrast to the nation-wide public networks of MNOs. The danger of misuse of monopoly power is smaller in local private networks than in MNO networks. The monopoly is a single seller market structure. By definition, local, private licenses are assigned to a restricted location rather than to a whole market. Because of this, there is also a need for a change in the supply side. In [5] spectrum pricing for local 5G networks is discussed from the viewpoints of three central stakeholder roles: the regulator, the MNO and the entrant local 5G micro-operator. Found elements of spectrum value are offered services, spectrum allocation and assignment method, location specific characteristics, and band specific characteristics. Matinmikko et al. [5] state that “location specific characteristics in 5G will have a distinct role compared to prior generations, as the population density previously used for assessing the spectrum demand, network dimensions and service profits no longer necessarily applies to many upcoming 5G vertical use cases.” The

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recently proposed micro licensing model [6, 7], private LTE and 5G [8], and network slicing [9] are concepts for creating customized mobile communications services. Of these methods, micro licensing and private LTE and 5G allow the transaction of spectrum rights in a dynamic way that caters the needs of different user types. In practice, the allocation could be done through a marketplace that works as a centralised, efficient secondary market of private LTE and 5G licenses [10] or network slicing [11]. Cramton and Doyle [12] state that an open access market for spectrum would increase competition and make the process more efficient, transparent, fair, and simple. The possibility to deploy private LTE and 5G networks is highly dependent on the spectrum availability. The spectrum could become available through local licenses in the mobile spectrum bands or by allowing unlicensed access to 5G bands [13]. Furthermore, all commercial 5G licenses are advised to be subject to trading or leasing [14]. The novel regulatory approaches include locally licensed mobile spectrum (The Federal Network Agency Germany, 2019 [15]; The Swedish Post and Telecom Authority, 2019 [16]; Radiocommunications Agency Netherlands, 2018 [17]; Arcep of France, 2019 [18]; and Ofcom, 2019 [19]) wholesale spectrum provisioning, and the secondary market of spectrum. The pricing model in these regulations has not had any geographic distribution yet, but it has been either per base station (Netherlands), per area (Germany) or either of them (UK). Especially, the 2.3 GHz, 3.5 GHz, and 24 GHz frequency bands are likely to require different approaches to authorization, as they are expected to be the enablers for private LTE and 5G services and applications. The regulators foresee the need for more flexibility in 5G spectrum authorization approaches including the commons approach (general authorization, unlicensed), licensed shared use between different users, geographical sharing, or dynamic spectrum sharing in time, frequency, and location [14]. Sharing-based spectrum management approaches facilitate more efficient spectrum use by allowing two or more radio systems to operate in the same frequency band [20]. Prominent sharing concepts under standardization and trials are the European Licensed Shared Access (LSA) [21], the US based Citizens Broadband Radio Service (CBRS) [22], and the unlicensed LTE technologies: LAA [23], LTE-U [24], and MulteFire [25]. 5G convergence with IEEE family of technologies using unlicensed spectrum particularly indoors and dense urban area introduce new opportunities for the co-existence of the 3GPP and the IEEE Wi-Fi ecosystems [26]. The 3GPP study item "Study on New Radio (NR) based Access to Unlicensed Spectrum" determines a global solution for NR-based access to unlicensed spectrum [27]. Spectrum management aims at effectiveness by allocating

spectrum to the right use, and efficiency by assigning to those what value it the most [20]. Regulators aim at making the best value of spectrum in their decisions, but assessing the value of spectrum is a complex process with multiple perspectives [28, 29, 30]. Different wireless services, such as mobile broadband (MBB) communications, Private Mobile Radio (PMR), broadcast, and military use, have different basis for their value due to their distinct business models, technologies, and role in society. Ultimately, the spectrum management decisions are about maximizing the value of spectrum, its efficient utilization, and its benefits to society [20]. The mobile communication market has traditionally been centered around a small number of MNOs that have been granted long-term exclusive spectrum licenses, most recently through auctions with high up-front payments [31]. While auctions have resulted significant income for the governments in many countries, their impact on society goes beyond auction revenues and has turned out to be a complicated topic to analyze [31, 32, 4, 33]. For example, competition, which will ultimately lead to greater innovation and better and cheaper services, will likely generate greater governmental revenues in the long term compared to the sole auction revenues [31]. LTE evolution and future 5G networks are expected to change the mobile communication market structure and be increasingly locally deployed by new entrant stakeholders. Facility owners' role as a local operator serving MNOs' customers is highlighted by Zander in [34] and Ahmed, Markendahl and Ghanbari in [35] as a feasible solution for the deployment of building specific ultra-dense networks. Furthermore, local high-quality 5G wireless networks are gaining increasing attention as the solution to deliver guaranteed quality of service, particularly concerning the low latency requirements, in various use cases of vertical sectors and enterprises [36]. Private mobile communication networks as stand-alone solutions or collaboratively serving MNOs' customers are particularly envisaged to operate in shared spectrum bands [37]. Spectrum options for local indoor network deployments by local operators were assessed by Ahmed, Markendahl and Ghanbari [35] for different spectrum allocation options where the local operators were either collaborating closely with the MNOs or deploying their own independent networks.

Considered use case and contribution

The main contribution of this paper is to show that the geographic distribution of value of private LTE and 5G licenses varies from the consumer demand - based pricing. We give a practical example how to adjust current operational pricing model of Finland

to take into account the difference without a significant structural change in the pricing formula. We compare the current generic frequency fee pricing model to the proposed model and show how it changes the geographic distribution of the frequency fee price to match the value distribution of the radio license of a private LTE and 5G network. In Finland since 2009, the spectrum price of the mobile spectrum bands consists of auction price and yearly frequency fee, which is called Traficom frequency fee in this paper (Note that Finnish Communications Regulatory Authority merged with the Finnish Transport Agency, and as of 1.1.2019, the organisation is called TRAFICOM). Before 2009, instead of auctions the licenses were assigned through beauty contest. The cost of spectrum consists only of frequency fee in the licenses assigned before that. When the beauty contest licenses are renewed, the price will be a combination of Administrative Incentive Price (AIP) and frequency fee. The AIP and frequency fee formulas are the same with the basic fee coefficient value difference. Bozsóki in [38] has listed the following challenges of AIP: it can require considerable effort to approximate market values and it may not be suitable for all services. In this paper, we do not study the absolute price or value of the private LTE and 5G licenses, but their geographical distribution. In Finland, the difference of the absolute value compared to the consumer demand priced frequency fees is set in the Electronic Communications Act [39]. We assume the same total value of AIP frequency fees as in the Act but we modify the distribution. We also claim that AIP is very suitable for private LTE and 5G licenses because it enables commercial services and AIP is typically used for renewed mobile licenses, when the license assignment did not include auction or similar one-time payment.

In this paper, we use Traficom frequency fee with the modification that the population coefficient is replaced with employee density and with employee density factored with the industry specific value of an employee in the employee-dense areas. The final value of the spectrum is the higher one of Traficom frequency fee and our employment based Traficom frequency fee. The allocation of local licenses raises an interesting question about how they should be valued and priced. A marketplace requires a cost-effective and accurate method for valuating the licenses. Traditionally, the mobile spectrum licenses have been sold in large nation-wide bundles to MNOs through auctions. There has been less research on how the value of the licenses is distributed on a local level. The demand and value of licenses can drastically change between different locations. Moreover, the type of use also affects the price. While the current mobile licenses are primarily used for MBB, 5G technology can be used for

diverse use cases, including private networks. These should be taken into consideration in the pricing of the licenses. There are several challenges related to spectrum market, one of which is the pricing of the licenses. In this paper, we research different methods of pricing and compare the pricing results that the methods yield. The aim of this paper is to develop a location dependent pricing method of private LTE and 5G spectrum for industrial users. This study contributes to the literature the need to extend the private LTE and 5G spectrum pricing methods with an employment based, geographic distribution of the spectrum price. The remainder of this paper will continue as follows: first, spectrum pricing for private LTE and 5G is introduced, next the proposed pricing model is discussed together with description of data to validate the model. This part is followed by the analysis of achieved results, and finally the paper is concluded. In this paper we extend the contribution presented in [40]. Comparing to that one, we have provided more thorough analysis of the presented results and included the simulation results for two new cases, i.e., for German and UK regulator.

Methods and Experimental

In this paper, the following research methodology was applied. All of the proposed spectrum pricing methods have been tested by means of extensive computer simulations, and compared with the reference approach. Moreover, in order to guarantee high credibility and veracity of the results, real data have been used for experiments when possible.

Spectrum pricing for private LTE and 5G

Conventional pricing Methods

The commercial value is the price of a private LTE and 5G radio spectrum license should it be for sale. We focus on the commercial value of local licenses for private LTE and 5G networks. The value is determined by the expected future cash flows that the license generates to its holder. These cash flows are generated through additional increases in revenues or reductions in costs. The license can for example be used to offer a new product to increase revenues, or to implement a new manufacturing method to reduce costs. Licenses can also be used defensively to limit competition. By blocking competition, the license holders can use their improved market power to increase cash flows. Additionally, Marks *et al.* in [41] note that radio spectrum licenses hold a significant option value. The pricing of licenses should be based on the above mentioned underlying economic factors. Conventionally, the price of a mobile license is determined through auctions. Given

a sufficient number of buyers, auctions result in relatively accurate pricing as the buyers can use sophisticated, context specific financial models to estimate the economic factors. However, due to the small value and illiquidity of licenses for private LTE and 5G networks, auctions are often not a viable method of pricing. One local license can for example only cover the area of a single factory or port, which means that the license has only one potential buyer. Small number of buyers makes auctions inefficient [42]. Additionally, the context specific financial models used by the buyers in auctions, as well as in the bidding process, can be very resource intensive. These costs can be relatively large compared to the commercial value generated by the trade of a local license for private LTE and 5G networks. Benchmarking is another market-based approach for pricing radio spectrum licenses. Benchmarking would solve the problem of high valuation costs as it can gather large amounts of market information cost effectively. However, the markets for local 5G licenses do not currently exist in large extent, so due to the immaturity of the market, benchmarking is not viable in the early stages of 5G. Furthermore, even if the market was more mature, it could prove to be very difficult to find sufficiently similar comparables for the licenses as the value of the license is determined by many context specific factors. Thus, if benchmarking was to be used, it should be adjusted to account for these factors.

General Spectrum pricing Model

As the market-based pricing methods accommodate the market for local 5G licenses poorly, we seek to find a general pricing model that uses the characteristics of the spectrum to determine a price for the license. The commercial value is not directly based on these intrinsic characteristic, it is based on the case specific economic factors such as expected change in cash flows as noted above. However, in this paper we study whether some set of intrinsic characteristics can be used as proxies to estimate the commercial value with a sufficient accuracy. Typically, general spectrum pricing models used by regulators consist of the following variables: the opportunity cost for a given band and location, the amount of spectrum used, the type of service, the frequency band, and the location [41]. Kokkinen et al. in [43] used the frequency fee developed by the Finnish Communications Regulatory Authority to price spectrum licenses. Table 1 shows that the formula used by Traficom [39] fits well to the general model. Both models measure similar intrinsic commercial value drivers.

Traficom fee uses population density as a measure for location value. However, as noted by Kokkinen et al. [43], population density might not accurately estimate the commercial value of local 5G licenses as these

are often used in industrial districts and sites such as factories and ports. These locations typically have a low population density even though the willingness to pay and demand for licenses might be high. Thus, using population density might underestimate the value of local 5G licenses. In this paper, we present alternative proxy measures to estimate the location value for local 5G licenses. We sought to find alternative measures that are based on globally available open data. We research potential measures that would be based on proxies such as land prices, property tax records, density of business activity, and value added locally. However, we selected employee density and commercial property rental prices as proxies for location value because the availability of data and our hypothesis that including either one or both of these measures in the pricing formula would improve its accuracy in pricing of local 5G licenses. The employee density was chosen because employees are the natural business substitutes for inhabitants, which are used to derive the geographic distribution of the consumer demand -based pricing.

Optimal Price Range and Transaction Costs

The pricing method should ensure that the licenses are allocated to the party that gets the highest economic benefit from them. In the context of licenses for private LTE and 5G networks, there is often only one buyer and one seller. In this case, the transaction occurs if the price is higher than the seller's willingness to pay but lower than the buyer's willingness to pay. Thus, there is a range of prices that maximise the total surplus, assuming that there are no transaction costs. However, if the transaction costs are high compared to the difference between the seller's and the buyer's pricing there will be no trade and the allocation remains inefficient. If the transaction costs can be decreased, there is a possibility for trade. Significant portion of transaction costs related to the trade of local micro licenses come from the pricing of the licenses. Decreasing the pricing costs might decrease the transaction costs enough to allow mutually beneficial trade between the buyer and seller. However, it is reasonable to assume that decreasing the spending in pricing decreases the accuracy of pricing. Thus, a balance between cost and accurate pricing should be found. If the pricing costs are too high, there is no possibility for mutually beneficial trade. On the other hand, if the pricing is not accurate enough, the price will not satisfy both parties and again there is no trade. General pricing model enables efficient trading platforms such as the one proposed in Kokkinen et al. [10]. By combining the pricing model with an efficient trading platform, transaction costs can be decreased even further,

making transactions more viable and thus increasing the total surplus. General pricing model can also significantly improve the information that is available in the markets. Valuation costs are sunk costs that disincentivize parties to even consider trading licenses. General valuation model can decrease valuation costs and even make prices available for free. Better information about prices improves market efficiency by allowing parties to compare and consider license trades. Additionally, it can reduce the adverse effects of information asymmetry, decrease uncertainty, and make the cost of ineffective regulation more transparent [41].

Germany case

In Germany, the band 3400 – 3700 MHz was auctioned for public mobile networks in 2019, whereas the band 3700 - 3800 MHz was made available for local private assignments. Access to the band requires an individual authorization from the German regulator [44]. The process allows applying for local assignments any time, in line with the demand. Eligibility is related to the land ownership or right of use. Mobile network operators having current access to licensed spectrum in 700 - 3700 MHz are only eligible for a temporary access, in case there are unused parts in the 3700-3800 MHz band. The license duration is 10 years, and the licenses are transferable. The license fee depends on the assignment bandwidth, license duration and the category of the deployment area. Deployment in inhabited and transportation areas is more expensive than a deployment in other areas. The fee is calculated as follows: $\text{Fee} = 1000 + B \cdot t \cdot 5 \cdot (6 \cdot a_1 + a_2)$, where 1000 indicates the base amount in Euros, B denotes the bandwidth in MHz (10 to 100 MHz), t is the duration of the allocation in years (e.g. 10 years), and a is the area in km^2 with a differentiation between the populated area and transportation areas (a_1) and other areas (a_2). The locations and the area of the region can be defined by the applicants. All assignments are based on 10 MHz blocks. The approach is service and technology neutral, though TDD is the only allowed duplex technology, and networks must be synchronized. Efficient use of the assignment is required, with a use-it-or-lose-it -principle. There are technical requirements to ensure that no harmful out-of-band interference is created, affecting incumbent services. In addition, operators of geographically adjacent radio networks are obliged to negotiate agreements between them. If this fails, the BNetzA may define regulatory measures to ensure efficient and interference free use of spectrum for all affected operators. This could include definition of a maximum field strength limit at the edge of the coverage area. The overall status of the band and its regulatory framework will in any case be re-viewed by

BNetzA after a year in use. By February 19, 2020, the regulator has received 29 applications and 23 of them have been processed and licensed. There are also around 50 experimental radio assignments in the band.

United Kingdom case

The UK regulator Ofcom has made spectrum locally available through Shared Access licenses in four shared access bands: 1800 MHz, 2.3 GHz, 3.8 - 4.2 GHz and 26 GHz bands. The approach is to provide spectrum for local networks in locations where it is not used by other licensed users. There are two types of licenses, low power license (per area license) and medium power license in the Ofcom statement [19]. The low power license allows the users to deploy a required number of base stations in a circular area of a 50 m radius, while the terminals are covered by the same license. For larger areas, it is possible to apply for multiple licenses to achieve the required coverage. The medium power licenses are mainly available for deployments in the rural areas. The licenses are assigned on a first-come first-served basis and the access is coordinated by Ofcom to ensure avoidance of harmful interference between the users. This approach can provide certainty for the spectrum access and QoS. The licenses are technology neutral, but Ofcom has determined technical license conditions for the bands. The license fees are cost based administrative fees, reflecting Ofcom's cost of issuing the license, charged annually on a per area based or on a per base station basis. Currently, the Ofcom deals with coordination between the licensees, but they intend to explore the potential for introducing Dynamic Spectrum Access (DSA) in the shared access bands sometimes in the future. The 2 x 3.3 MHz portion of the 1800 MHz band is best suitable for narrowband applications in the rural areas. The highest 10 MHz of the 2.3 GHz band (2390-2400 MHz) are currently used for military applications, but there is still room for local, low power deployments, initially allowed only for indoor applications. The LTE band 40 on the 2.3 GHz is already widely used for 4G deployments outside of Europe, especially in Asia, and therefore, LTE equipment is widely available. The annual license fee for the 2300 MHz and 1800 MHz shared spectrum is 80 GBP per area or per base station. The 3.8-4.2 GHz band is currently used by several incumbent services, but in addition, the band can be used for private networks as there are unused spectrum resources. The band is next to the 3.4-3.8 GHz band, which has been identified as a pioneer 5G band in Europe. Several countries plan to expand the 5G deployments also to the 3.8-4.2 GHz band. For the 3.8-4.2 GHz band, the annual fee is also 80 GBP per 10 MHz per area. The 26 GHz band (24.25-26.5 GHz) is only

available for 5G indoor low power deployments. The licenses are valid for an indefinite duration. The annual license fee is fixed 320 GBP for the 26 GHz band. Further details can be found in the Ofcom guidance document [45]. An ecosystem is building up for the band, as it has been identified for IMT by the ITU-R.

Pricing Model and Data

Approach

We use the Traficom Frequency Fee formula as our base case model. The formula uses population density as a measure for location value. In this section, we substitute the population density with other measures, namely employee density, adjusted employee density, and commercial property rental prices. The total value of the spectrum is obtained using the Traficom Frequency Fee, and it is then redistributed using other pricing methods. Thus, this paper mainly studies the relative prices yielded by different pricing methods. The absolute prices of licenses would change if other methods such as benchmarking would be used to calculate the total base value of the spectrum. The total value of licenses is the same in all models. However, the way in which this total value is distributed to different locations changes. If a combination of two methods is used, such as the max function of two pricing, the total value for the spectrum will be higher than the total base value of the spectrum. The base value reflects the spectrum value when it is used only for consumer services. It is important to note that estimating the real option value and the value from limiting competition is very context specific. It is hard to estimate these factors using a general pricing model [41]. Thus, our proposed models do not take these factors into account. Both factors only affect the price positively. Thus, the pricing derived by the proposed models might have a downward bias. In the context of local 5G licenses, the possibility to limit competition does not, most likely, increase the price significantly. The users of these licenses do not compete against each other in the same way as for example mobile network operators do. The value from limiting competition is thus smaller. Additionally, the licenses are local and thus the possibility to block competition are very limited. In many cases, the buyer of the license is the only potential user of the license in the area. However, the option value can be significant in the context of new technologies such as 5G because it increases with uncertainty. The full capability and viability of different 5G applications is still very uncertain and thus the option value of 5G licenses can be significant and should be reflected in the pricing.

Data

We use population density, employee density, and area data from Official Statistics of Finland [46]. The database includes statistics for all 3030 postcode areas and it uses 2018 postal area classification. The database includes the most recent population and employee data, from 2016 and 2015 respectively. The value added per employee by industry data used for Adjusted Employee Based pricing is from Official Statistics of Finland [47]. The commercial property rental prices are obtained from City of Helsinki [48]. The rental price data used a different area classification so the data was matched to postcode areas as closely as possible.

Base Case: Traficom Frequency Fee using population density

Traficom Frequency Fee formula is currently used in Finland to determine the annual frequency fee for all spectrum licenses in Finland. It is based on factors such as availability, usability, and number of frequencies in the license [39]. The formula fits well to the general model as seen from Table 1.

$$TraficomFrequencyFee = C_1 \cdot C_{inh} \cdot C_{6b} \cdot B_0 \cdot S \cdot P \quad (1)$$

The constant values on Table 2 are set by Traficom [39] for a 1-year public mobile network license with a bandwidth of 10 MHz and area of 1 km² in the 3.5 GHz frequency band. The values are also the same as used in [43]. The population coefficient is calculated for each postal code using the equation (2).

$$C_{inh} = \frac{POP_{PC}}{POP_{FIN}} \cdot \frac{1 \text{ km}^2}{A_{PC}} \quad (2)$$

where POP_{PC} is the population of the postal code area, POP_{FIN} the total population of Finland, 1 km the constant area of the license, and A_{PC} the area in km² of the postcode.

Location Coefficient variation: Employee Density

The Employee Density formula is the same as Traficom formula, with the exception that employee density data is used instead of population density data. The Employee Coefficient C_{emp} is obtained by dividing the number of employees working in the license area by the number of employees in Finland.

$$Employee \text{ Density Pricing} = \quad (3)$$

$$C_1 \cdot C_{emp} \cdot C_{6b} \cdot B_0 \cdot S \cdot P \quad (4)$$

$$C_{emp} = \frac{EMP_{PC}}{EMP_{FIN}} \cdot \frac{1 \text{ km}^2}{A_{PC}}, \quad (5)$$

where EMP_{PC} is the number of employees working in the postal code area, EMP_{FIN} the total number of employees in Finland, 1 km^2 the constant area of the license, and A_{PC} the area of the postcode.

Location Coefficient variation: Adjusted Employee Density

The Adjusted Employee Density formula is the same as the Employee Density formula, with the exception that employees from different industries have been given different weights. The weights are based on the industry value added per employee. The rationale behind this is that the number of employees might not be comparable between different industries. For example, some industries are more automated than others. By adding weights, locations where employees work in high value adding industries are assigned a higher location value. Each industry's employee weights (EW) are calculated by dividing the average employee value added in that industry by average employee value added in Finland (10). The weights are listed in Table 3. If there was no data on a particular industry's value added, the average for whole Finland (weight of 1) was used for that industry.

$$\text{Adjusted Employee Density Pricing} = \quad (6)$$

$$C_1 \cdot C_{\text{emp,adj}} \cdot C_{6b} \cdot B_0 \cdot S \cdot P \quad (7)$$

$$C_{\text{emp,adj}} = \frac{\sum_i EW_i \cdot EMP_{PC,i}}{EMP_{FIN}} \cdot \frac{1 \text{ km}}{A_{PC}} \quad (8)$$

$$\text{Employee Weight (EW}_i) = \quad (9)$$

$$\frac{\text{Average Employee Value Added in Industry}_i}{\text{Average Employee Value Added in Finland}} \quad (10)$$

Location Coefficient variation: Employee Density

The Rent Based pricing uses commercial office rental prices per square meter to calculate the location value. For this research, data was available for selected areas in the Helsinki region. We calculated an average price for a 1-year public mobile network license with bandwidth of 10 MHz and area of 1 km in the 3.5GHz Frequency Band in the selected areas using the Employee-Based pricing. The average price was calculated using employee-weighted average, i.e. the relative number of employees in the area was used as the weight. We then used relative rent prices as a coefficient to evaluate licenses in different areas.

$$\text{Rent Based Pricing} = \quad (11)$$

$$\text{License Value} \cdot \frac{\text{Rent}_{PC}}{\text{Rent}_{ALL}}, \quad (12)$$

where License Value is the employee-weighted average of a license in the selected areas according to the Employee-Based Pricing. Rent_{PC} is the average rent in the postcode area, and Rent_{ALL} is the employee-weighted average of rent in the selected areas. The data used is from selected areas from the Helsinki region and it uses office rental prices. Data from wider area using industrial rental prices exists but was not available for this research [49]. This more extensive data could be used to increase the accuracy of this method.

Results and Discussion

All prices in this paper have been calculated for a 1-year license with bandwidth of 10 MHz in the 3.5 GHz frequency band. In the Table 4 and Figure 1, we show descriptive statistics of prices obtained by different pricing methods for all postcode areas and selected areas in the Helsinki region. The statistics included are minimum, maximum, mean, average-weighted mean, and median price. The rent based pricing is calculated only for the selected areas in the Helsinki region. The pricing results including the rent based method are shown in Table 5 and Figure 3.

Comparison of Traficom, Employee Based, and Adjusted Employee Based Prices

In this section, we have selected 100 postcode areas that have the highest pricing based on the Employee Based method as these types of areas are most relevant for local 5G licenses.

The Employee Based pricing methods generate significantly higher values than the Traficom Frequency Fee for certain areas (Figure 1). This is explained by the fact that employment is concentrated more than residency. Areas such as commercial and industrial districts have a very high employee density compared to the population density of even the most populated residential areas. Conversely, as residency is more spread out, the population based prices of for example rural and residential areas are typically higher than employee based. Interestingly, there is a group of postcode areas that have no residents but a high employee density. Examples of these locations are the hospital area of Joensuu, the office park of Ilmala, Turku University of Applied Sciences, and industrial district of Martinlaakso.

Employee Density and Adjusted Employee Density based pricing methods yield very similar prices (Figure 2). However, differences occur in areas where the employees work dominantly in industries that have either relatively high or low value added per employee. Examples of locations where the Adjusted Employee Density yields higher results are postcode areas with large powerplants (Olkiluoto, Tahkoluoto), some industrial districts (Martinlaakso industrial area), and university campuses (Otaniemi).

Comparison of Prices, Including the Rent Based Method

In this section, we show the prices for selected areas in the Helsinki Region. The reason for selecting these areas was that detailed commercial rent price data was available for these areas.

Using the Rent Based pricing (Figure 3), the license prices are significantly more evenly distributed than using the other methods. Because population density and employee density can vary significantly between areas, the prices based on these methods also vary significantly and they can even be close to zero. However, office rents do not have this same characteristic and thus license prices based on rents are distributed more evenly.

Comparison of Ofcom and BNetzA pricing with employee based pricing

In Figure 4, we depicted the Ofcom area based pricing and BNetzA pricing in the Finnish postcode areas with the highest employee density. Ofcom basestation based pricing is not compared as it would only be applicable in the rural area. The whole postcode area is expected to be settlements or transportation areas using the area multiplier a_1 in the BNetzA formula. All postcode areas are fully covered by the networks. Please note that the y-axis is in logarithmic scale. The absolute price levels of BNetzA and Ofcom are comparable with each other as they are based on released regulations. The employee based pricing should only be compared to the form of BNetzA and Ofcom curves as the employee based pricing is just a proposal of the authors [50] and the absolute level of the curve should be adjusted with parameters. The graph points have been sorted by the employee number and due to that it is natural that the employee-based pricing curve is falling. The postcode areas tend to increase when moving from urban areas to rural areas. Due to that we can note that BNetzA and Ofcom curves are slightly growing.

Conclusions

As the 5G utilising technology and use cases for local licenses develop, there is a growing need to evaluate local 5G licenses. In the introduction, we presented arguments why conventional pricing methods, namely auctions and benchmarking might not work in this context. Additionally, we argued that existing population density based general pricing models might not accurately proxy the underlying drivers of location value in commercial local licenses. In this paper, we proposed two alternative proxies for location value drivers: employee density and commercial rental

prices. As seen from the results, the four pricing methods used distribute the total value of spectrum differently. The Traficom Frequency Fee is based on population density, and it is a good measure of location value for mobile broadband, where the customers are mainly private consumers. However, we can see from the results that this pricing method is not always sufficiently accurate in the context of commercial local licenses. There exist many postcode areas that have a population of zero but that have potentially high demand for local licenses. These areas include, for example, industrial districts and hospital areas. Using the Frequency Fee based pricing, the prices for licenses in these areas are very low, which does not accurately reflect reality. This problem would be even more noticeable if we were to use areas smaller than postcode areas. Relatively large areas like postcodes are applicable for pricing comparison in Finland because many welfare metrics like income and education are relatively evenly distributed in Finland compared to most other countries. The applicability of post code areas is especially noticeable for consumer demand based pricing. The difference in employee density based value distribution is quite similar in Finland and other countries. Kokkinen et al. [43] summarises this problem with a sentence: “No one lives in factories or ports.” We might add: “But many work there”. The two proposed employee density based methods are able to identify areas with low population density but high potential demand for spectrum. The methods also show that employment is more concentrated than residency. Companies tend to group up in small areas, which locally increases the demand for spectrum. This is reflected in the prices of licenses: the highest prices using employee density are significantly higher than the ones the population density based method yields. Conversely, prices for low demand areas are lower with employee density pricing. In the basic Employee Density pricing, all employees drive the spectrum value equally. However, this might not reflect the reality as different types of employees, companies, and industries have different demand and willingness to pay for spectrum. Because of this we introduced the Adjusted Employee Density pricing, where employees from different industries were weighted based on their average value added. This method distinguished for example that the employees of energy companies such as nuclear plants have a very high value added per employee and thus areas with energy plants were given a higher license price per employee. The industry categories we used were very broad. For example, all manufacturing companies were consolidated in the same category. With more detailed categories, the usability of this method would increase significantly. It could, for example, be

very useful to distinguish smart factories as their own category, as these factories typically have a very low ratio of employees to value added. Additionally, value added per employee is not the only, nor necessarily the best way to weight employees. Some industries might have a high value added but no demand for local licenses. Further research on how new 5G technologies will benefit different industries, especially in monetary terms, would improve the pricing of licenses between industries. Value of Mobile Broadband licenses is very much location dependent. If an area has no users for the service, the price of that local license is close to zero. The value of the license increases in the number of users as the potential revenues also increase. The Employee Density based pricing makes the same assumption on commercial local licenses and it might not always reflect reality. Often a factory makes similar profits no matter if it is surrounded by other businesses or not. A new factory under construction might not have many employees working at the site yet but still its willingness to pay for license can be high. In the light of these arguments, it is possible that the Employee Density based method generates too stark differences between locations. Because of this, we introduced another proxy for location value, commercial rental prices. Average rents change based on the location, but not as abruptly as employee density. Rent prices do not drop to zero even in very rural areas. As seen from the results, the rent based method yields more evenly distributed prices than the other methods. Still, it ranks different locations very similarly to the employee based method as the prices generated by these two methods have a strong correlation. Because of the limited availability of data for this research, we used only office rent prices for selected areas in the Helsinki region. There exist more extensive databases, which could be used in further research for more accurate pricing.

We compared the proposed employee number -based pricing to published BNetzA and Ofcom pricing of local licenses. BNetzA has two different area classifications and they can flexibly be combined in pricing. The maximum difference that can be achieved with them is a price difference of factor 6 between forested and urban areas. Ofcom pricing has two different pricing options: small area based pricing and basestation based pricing. Basestation pricing is only available for rural areas. By varying the antenna height and maximum transmit power, a single basestation can cover different sizes of areas. When directly applied to cover postcodes areas, neither BNetzA nor Ofcom pricing takes into account the value of spectrum based on employee density.

The pricing method should enable an allocation where the party with the highest willingness to pay

gets the license. To achieve this, a combination of different pricing methods could be used. For example, the license price could be the maximum of the population density based pricing and the employee density based pricing. If the location has a high population density compared to employee density, the most efficient allocation is most likely to use the license for mobile broadband. By using max function, the license will always be sold at the higher price, which in this case incentives mobile broadband use. Spectrum pricing should follow demand and be based on transparent methods and easily available data. The demand for consumer services such as mobile broadband follows population density but this is not necessarily true for industrial demand. We recommend the use of employee density as a measure for the industrial demand. This can be adjusted to reflect the differences between industries. Optionally, rent based pricing can also be used to price licenses. A combination of these methods, such as the max function of population density and employee density pricing, allows the consideration of both consumer and industrial demand simultaneously. This method will always price the licenses to match the highest willingness to pay

List of Abbreviations

3GPP	3rd Generation Partnership Project
5G	Fifth Generation
AIP	Administrative In-cen-tive Price
CBRS	Citizens Broadband Radio Service
DSA	Dynamic Spectrum Access
IEEE	Institute of Electrical and Electronics Engineers
LAA	License Assisted Access
LSA	Licensed Shared Access
LTE	Long Term Evolution
LTE-U	LTE-Unlicensed
MBB	Mobile Broadband
MNO	Mobile Network Operator
NR	New Radio
PMR	Private Mobile Radio
QoS	Quality-of-Service
TDD	Time Division Duplex

Declarations

Availability of data and materials

Regarding data and materials, please contact the corresponding author. All used data and materials are carefully referred in the manuscript.

Competing interests

The authors declare that they have no competing interests.

Author's contributions

Seppo Yrjölä was responsible for conducting the original valuation and pricing research with Topias Kokkinen and Heikki Kokkinen. Adrian Kliks was responsible for paper preparation, editing and for providing inputs to its sections based on initial reviews.

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References

- 3rd Generation Partnership Project, 3GPP: TS 36.101.: User Equipment (UE) radio transmission and reception (2018)
- Zeithaml, V.A.: Consumer Perceptions of Price, Quality, and Value: A Means-End Model and Synthesis of Evidence. *Journal of Marketing* **52**(3), 2–22 (1988)
- 5GPPP: 5G Infrastructure Public Private Partnership: 5G empowering vertical industries: Roadmap paper (2016)
- Cave, M., Nicholls, R.: The use of spectrum auctions to attain multiple objectives: Policy implications. *Telecommunications Policy* **41**(5), 367–378 (2017). doi:10.1016/j.telpol.2016.12.010. Optimising Spectrum Use
- Matinmikko-Blue, M., Yrjölä, S., Seppänen, V., Ahokangas, P., Hämmäinen, H., Latva-Aho, M.: Analysis of Spectrum Valuation Elements for Local 5G Networks: Case Study of 3.5-GHz Band. *IEEE Transactions on Cognitive Communications and Networking* **5**(3), 741–753 (2019). doi:10.1109/TCCN.2019.2916309
- Matinmikko, M., Latva-aho, M., Ahokangas, P., Yrjölä, S., Koivumäki, T.: Micro Operators to Boost Local Service Delivery in 5G. *Wireless Personal Communications* **95**(1), 69–82 (2017). doi:10.1007/s11277-017-4427-5
- Matinmikko, M., Latva-aho, M., Ahokangas, P., Seppänen, V.: On regulations for 5G: Micro licensing for locally operated networks. *Telecommunications Policy* **42**(8), 622–635 (2018). doi:10.1016/j.telpol.2017.09.004. The implications of 5G networks: Paving the way for mobile innovation?
- Ferrus, R., Sallent, O.: Extending the LTELTE-A Business Case: Mission- and Business-Critical Mobile Broadband Communications. *IEEE Vehicular Technology Magazine* **9**(3), 47–55 (2014). doi:10.1109/MVT.2014.2333695
- NGMN Alliance: Description of Network Slicing Concept. (2016). NGMN Alliance
- Kokkinen, T., Kokkinen, H., Yrjölä, S.: Spectrum Broker Service for Micro-operator and CBRS Priority Access Licenses. In: Marques, P., Radwan, A., Mumtaz, S., Noguét, D., Rodriguez, J., Gundlach, M. (eds.) *Cognitive Radio Oriented Wireless Networks*, pp. 237–246. Springer, Cham (2018)
- Lemstra, W.: Leadership with 5G in Europe: Two contrasting images of the future, with policy and regulatory implications. *Telecommunications Policy* **42**(8), 587–611 (2018). doi:10.1016/j.telpol.2018.02.003. The implications of 5G networks: Paving the way for mobile innovation?
- Cramton, P., Doyle, L.: An open access wireless market. White Paper (2015)
- European Commission: Study on Spectrum Assignment in the European Union. Doc. SMART 2016/0019. (2017). European Commission
- European Commission, Radio Spectrum Policy Group (RSPG): Strategic Spectrum Roadmap Towards 5G for Europe: RSPG Second Opinion on 5G Networks. RSPG18-005. (2018). European Commission, Radio Spectrum Policy Group (RSPG)
- The Federal Network Agency Germany: 5G-Frequenzgebühren Für Lokale Anwendungen. (2019). The Federal Network Agency Germany. https://www.bundesnetzagentur.de/SharedDocs/Pressemitteilungen/DE/2019/20191031_LokalesBreitband.html
- The Swedish Post and Telecom Authority: PTS Bemötande Av Konsultationsvar På överväganden Och Förslag Inför Tilldelning Av Frekvensutrymme i 2,3 GHz- Och 3,5 GHz-banden. Dnr: 18-8496. (2019). The Swedish Post and Telecom Authority. <https://pts.se/contentassets/a61e7e47702746c38d15ffb898d52832/bemotande-av-konsultation.pdf>
- Radiocommunications Agency Netherlands: Internetverbinding Verbeteren. (2018). Radiocommunications Agency Netherlands. <https://www.agentschaptetelecom.nl/onderwerpen/internetverbinding-verbeteren>
- Arcep: Numérique des Entreprises. Guichet D'attribution des Fréquences de la Bande 2,6 GHz TDD. Connectivité des "verticaux" : Modalités D'attribution des Fréquences de la Bande 2570 - 2620 MHz. (2019). Arcep. <https://www.arcep.fr/demarches-et-services/professionnels/-numerique-des-entreprises/guichet-frequences-2-6-tdd.html>
- Ofcom, UK: Enabling Wireless Innovation Through Local Licensing. Shared Access to Spectrum Supporting Mobile Technology. (2019). Ofcom, UK. https://www.ofcom.org.uk/_data/assets/pdf_file/0033/157884/enabling-wireless-innovation-through-local-licensing.pdf
- Beltran, F.: Accelerating the Introduction of Spectrum Sharing Using Market-Based Mechanisms. *IEEE Communications Standards Magazine* **1**(3), 66–72 (2017). doi:10.1109/MCOMSTD.2017.1700012
- ECC: Report 205 Licensed Shared Access (LSA). (2014). ECC
- FCC: The Second Report and Order and Order on Reconsideration Finalizes Rules for Innovative Citizens Broadband Radio Service in the 3.5 GHz Band. FCC 16-55. (2016). FCC
- 3rd Generation Partnership Project, 3GPP: TR 36.889: Feasibility Study on Licensed-Assisted Access to Unlicensed Spectrum (2015)
- LTE-U Forum. (2016). LTE-U Forum. <http://www.lteuforum.org/index.html>
- MulteFire Alliance. (2016). MulteFire Alliance. <http://www.multefire.org/>
- Abinader, F.M., Almeida, E.P.L., Chaves, F.S., Cavalcante, A.M., Vieira, R.D., Paiva, R.C.D., Sobrinho, A.M., Choudhury, S., Tuomaala, E., Doppler, K., Sousa, V.A.: Enabling the coexistence of LTE and Wi-Fi in unlicensed bands. *IEEE Communications Magazine* **52**(11), 54–61 (2014). doi:10.1109/MCOM.2014.6957143
- 3rd Generation Partnership Project, 3GPP: TR 38.889 V0.0.1: Study on NR-based Access to Unlicensed Spectrum (2018)
- Bazelon, C., McHenry, G.: Spectrum Value. *Telecommun. Policy* **37**(9), 737–747 (2013). doi:10.1016/j.telpol.2013.06.004
- Markendahl, J., M'akitalo, O., M'olleryd, B.G., Werding, J.: Mobile Broadband Expansion Calls for More Spectrum or Base Stations - Analysis of the Value of Spectrum and the Role of Spectrum Aggregation. 21st European Regional ITS Conference, Copenhagen 2010: Telecommunications at new crossroads - Changing value configurations, user roles, and regulation 26, International Telecommunications Society (ITS) (2010). <https://ideas.repec.org/p/zbw/itse10/26.html>
- ITU Telecommunication Development Sector: Exploring the Value and Economic Valuation of Spectrum, Report, 35 P. (2012). ITU Telecommunication Development Sector
- Cramton, P.: Spectrum auction design. *Review of Industrial Organization* **42**(2), 161–190 (2013)
- Hazlett, T.W., Muñoz, R.E.: A Welfare Analysis of Spectrum Allocation Policies. *The RAND Journal of Economics* **40**(3), 424–454 (2009)
- Klemperer, P.: What really matters in auction design. *IEEE Network* **16**(1), 169–189 (2002)
- Zander, J.: Beyond the Ultra-Dense Barrier: Paradigm Shifts on the Road Beyond 1000x Wireless Capacity. *IEEE Wireless Communications* **24**(3), 96–102 (2017). doi:10.1109/MWC.2017.1500377WC
- Ahmed, A.A.W., Markendahl, J., Ghanbari, A.: Evaluation of spectrum access options for indoor mobile network deployment. In: 2013 IEEE 24th International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC Workshops), pp. 138–142 (2013). doi:10.1109/PIMRCW.2013.6707852
- Guirao, M.D.P., Wilzeck, A., Schmidt, A., Septinus, K., Thein, C.: Locally and Temporary Shared Spectrum as Opportunity for Vertical Sectors in 5G. *IEEE Network* **31**(6), 24–31 (2017). doi:10.1109/MNET.2017.1700079
- ETSI: Feasibility Study on Temporary Spectrum Access for Local

- High-quality Wireless Networks. ETSI TR 103 588, 30 P. (2018). ETSI
38. Bozsóki, I: Guidelines for the Review of Spectrum Pricing Methodologies and the Preparation of Spectrum Fees Schedules. ITU/BDT/IEE/SBD123/11/2016. (2016). Bozsóki, I
 39. Act 1028/2017. Liikenne- ja viestintäministeriön asetus hallinnollisista taajuusmaksuista ja Viestintäviraston taajuushallinnollisista suoritteista perittävästä muista maksuista. Technical report (2017). <https://www.finlex.fi/fi/laki/alkup/2017/20171028>
 40. Kokkinen, T., Kokkinen, H., Yrjölä, S.: Location Dependent Spectrum Valuation of Private LTE and 5G Networks in Europe. In: Kliks, A., Kruskiewicz, P., Bader, F., Triantafyllopoulou, D., Caicedo, C.E., Sezgin, A., Dimitriou, N., Sybis, M. (eds.) Cognitive Radio-Oriented Wireless Networks, pp. 306–319. Springer, Cham (2020)
 41. Marks, P., Pearson, K., Williamson, B., Hansell, P., Burns, J.: Estimating the commercial trading value of spectrum. Report for Ofcom, Plum Consulting (2009)
 42. Tonmukayakul, A., Weiss, M.B.H.: A study of secondary spectrum use using agent-based computational economics. NETNOMICS: Economic Research and Electronic Networking 9(2), 125–151 (2008). doi:10.1007/s11066-009-9032-7
 43. Kokkinen, H., Yrjölä, S., Engelberg, J., Kokkinen, T.: Pricing Private LTE and 5G Radio Licenses on 3.5 GHz. In: Moerman, I., Marquez-Barja, J., Shahid, A., Liu, W., Giannoulis, S., Jiao, X. (eds.) Cognitive Radio Oriented Wireless Networks, pp. 133–142. Springer, Cham (2019)
 44. BNetzA, Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen: Verwaltungsvorschrift Für Frequenzuteilungen Für Lokale Frequenznutzungen Im Frequenzbereich 3.700-3.800 MHz. (2019). BNetzA, Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen. https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Telekommunikation/Unternehmen_Institutionen/Frequenzen/OffentlicheNetze/RegionaleNetze/20191119_Verwaltungsvorschrift3.7-3.8GHz.pdf.pdf?__blob=publicationFile&v=2
 45. Ofcom, UK: Shared Access License. Guidance Document. (2019). Ofcom, UK. https://www.ofcom.org.uk/_data/assets/pdf_file/0035/157886/shared-access-licence-guidance.pdf
 46. Official Statistics of Finland: Open Data by Postal Code Area. (2018). Official Statistics of Finland. http://pxnet2.stat.fi/PXWeb/pxweb/en/Postinumeroalueittainen_avoin_tieto/
 47. Official Statistics of Finland: Structural Business and Financial Statement Statistics. (2018). Official Statistics of Finland. http://www.stat.fi/til/yrti/index_en.html
 48. City of Helsinki.: Toimitilamarkkinat Helsingissä Ja Pääkaupunkiseudulla. (2017). City of Helsinki,. https://www.hel.fi/he12/tietokeskus/julkaisut/pdf/18_01_23_Tilastoja_01_Henriksson.pdf
 49. KTI Property Information Ltd.: Market Information. Last Accessed 18/01/2018. (2018). KTI Property Information Ltd. <https://kti.fi/en/services/market-information/>
 50. Kokkinen, H.: Response to Traficom Consultation About 2.3 GHz Private LTE Licenses in Finland. Nov 12, 2019. (2019). Retrieved from: <https://www.lausuntopalvelu.fi/FI/Proposal/ParticipationNonJsShowReport?proposalId=3bf8ce50-287d-476c-a0ac-44211d32f6e0>

Figures

Figure 1 Comparison of prices yielded by the employee density and the Traficom Fee method. The 100 highest priced areas using the employee density method are included

Figure 2 Comparison of prices yielded by the employee density and the Traficom Fee method. The 100 highest priced areas using the employee density method are included

Figure 3 Comparison of prices yielded by different pricing methods, including the rent- based method. Selected areas in the Helsinki Region are included

Figure 4 BNetzA and Ofcom license prices in the Finnish postcode areas with the highest employee density.

Table 1 Fitting Traficom Frequency Fee to the General Model.

General Model	Traficom Frequency Fee
Opportunity Cost for a Given Band and Location	P Basic Fee
Amount of Spectrum Used	B_0 Relative Bandwidth
Type of Service Provided	S Basic Fee Coefficient (Type of radio equipment used) C_{6b} System Coefficient (Scaled number of transmitters used)
Frequency Band	C_1 Frequency Band Coefficient
Location	C_{inh} Population Coefficient

Table 2 Traficom Frequency Fee coefficients.

Coefficient Name	Coefficient	Value
Frequency Band Coefficient	C_1	0.4
Population Coefficient	C_{inh}	Variable
System Coefficient	C_{6b}	1
Relative Bandwidth	B_0	2000
Basic Fee Coefficient	S	0.018
Basic Fee	P	1295.5 €

Table 3 Value added weights by industry.

Finland Average	1.00
B Mining and Quarrying	1.34
C Manufacturing	1.16
D Electricity, Gas, Steam and Air Conditioning Supply	3.95
E Water Supply: Sewerage, Waste Management and Remediation Act	1.59
F Construction	0.87
G Wholesale, Retail Trade	0.85
H Transportation and Storage	0.89
I Accommodation and Food Service Activities	0.53
J Information and Communication	1.51
M Professional, Scientific and Technical Activities	0.97
N Administrative and Support Service Activities	0.61

Table 4 Comparison of prices yielded by different pricing methods. The 100 highest priced areas using the employee density method are included.

	Min (€)	Max (€)	Mean (€)	Employee-Weighted Mean (€)	Median (€)
Traficom	0.00	73.39	11.82	14.10	9.17
Employee Based	10.30	364.09	48.07	63.58	24.21
Adjusted Employee Based	10.20	366.34	48.36	64.86	24.73

Table 5 Comparison of prices yielded by different pricing methods, including the rent based method. Selected areas in the Helsinki Region are included.

	Min (€)	Max (€)	Mean (€)	Employee-Weighted Mean (€)	Median (€)
Traficom	2.71	73.39	16.77	18.00	11.18
Employee Based	3.87	228.05	54.50	90.57	25.75
Adj. Employee Based	3.86	221.47	56.33	94.66	24.54
Rent Based	56.84	126.34	81.14	90.57	76.43

Figures

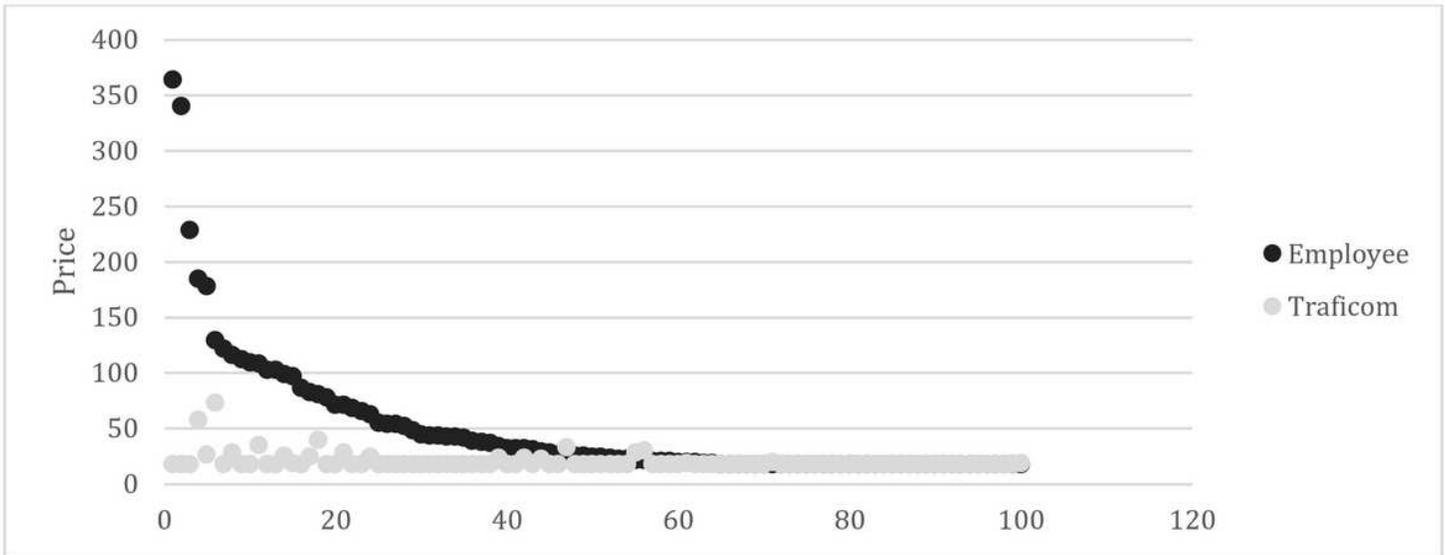


Figure 1

Comparison of prices yielded by the employee density and the Traficom Fee method. The 100 highest priced areas using the employee density method are included

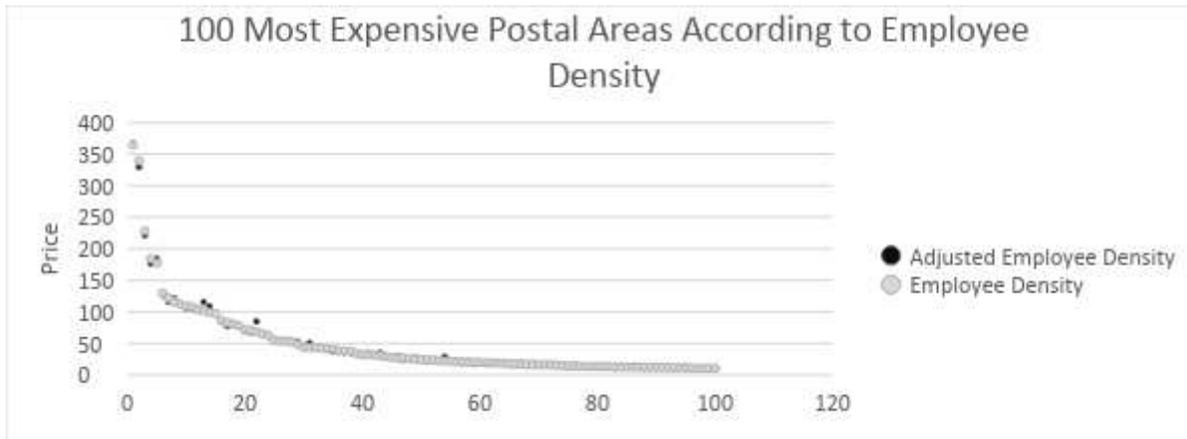


Figure 2

Comparison of prices yielded by the employee density and the Traficom Fee method. The 100 highest priced areas using the employee density method are included

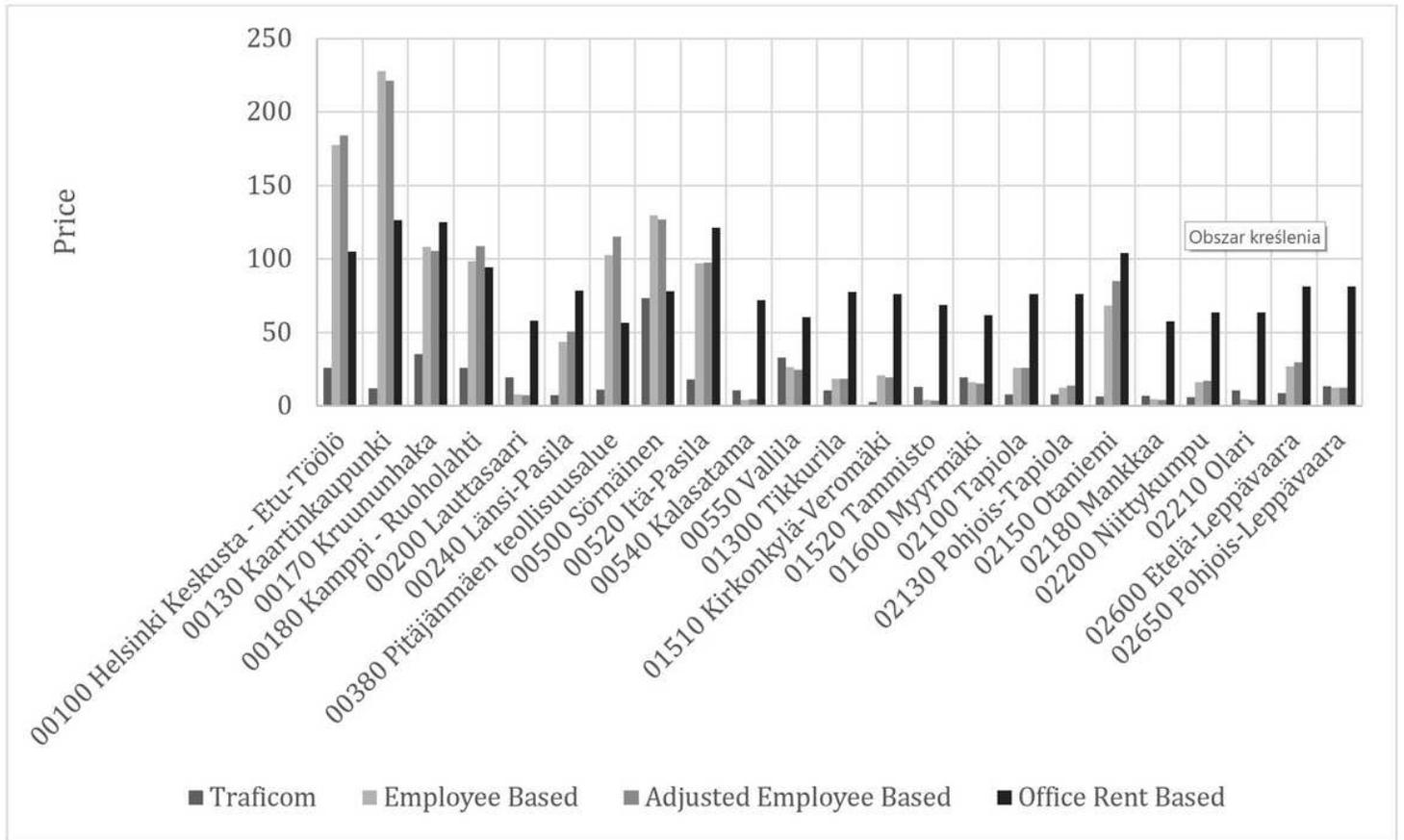


Figure 3

Comparison of prices yielded by different pricing methods, including the rent-based method. Selected areas in the Helsinki Region are included

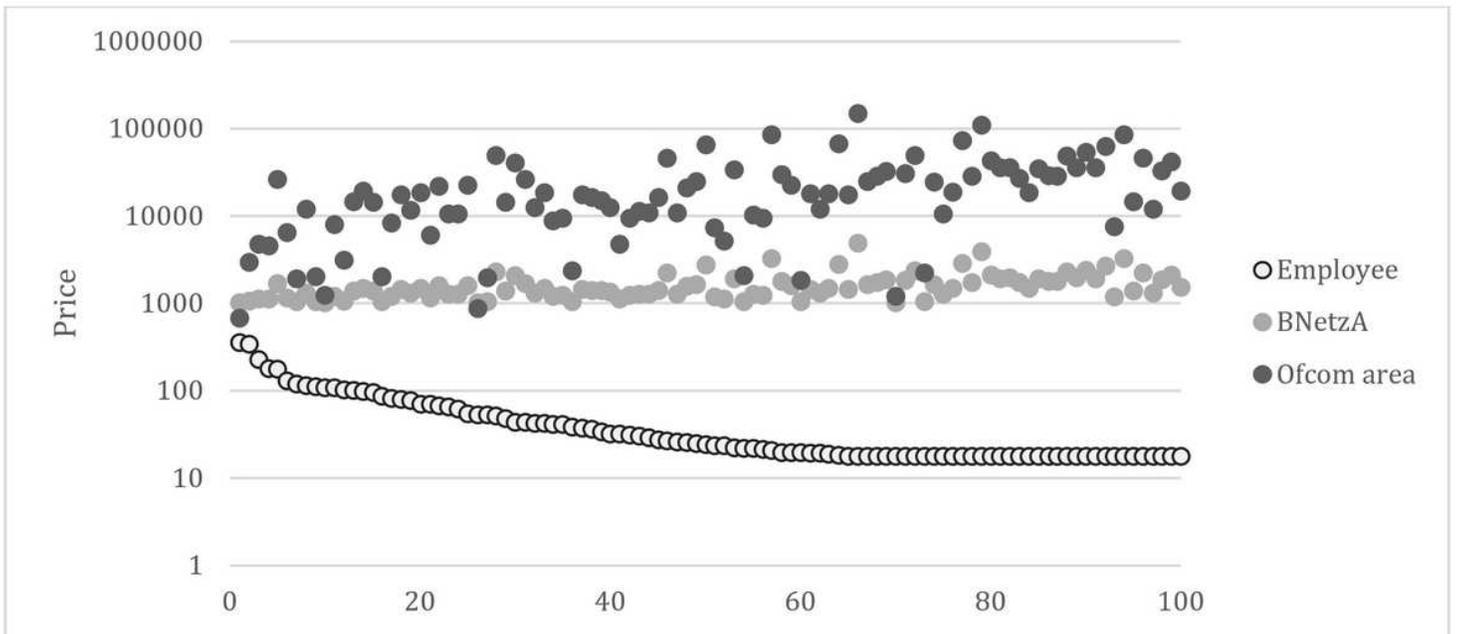


Figure 4

BNetzA and Ofcom license prices in the Finnish postcode areas with the highest employee density.