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Evolution of mobile handset feature dependences

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Abstract

Within 20 years, the mobile handset has evolved from the basic phone merely capable of voice calling to the advanced smartphone, which combines voice communication with multiple other functionalities. Mobile handset components, or features, along with evolving communications infrastructure, enable a smartphone to run numerous mobile applications and services. Therefore, mobile operators, application developers, service providers, and regulators are increasingly interested in the information on mobile handset feature diffusion for making effective managerial and investment decisions. This paper quantitatively studies dependences between mobile handset features, which need to be analyzed for understanding and estimating future feature diffusion.

The study is based on an extensive dataset on mobile handset sales in Finland and utilizes a method of hierarchical clustering for identifying the sets of dependent features. The results show that the features became increasingly dependent in 2008-2014. Although the nature of feature dependences differs, on a general level, they arise from mobile handset design decisions made by the device producers. The factors influencing these design decisions and consequently feature dependences can be divided in four main groups: technology, demand, product strategy, standardization and regulatory factors.

Keywords: handset feature, feature dependence, feature diffusion, dissemination, handset evolution

1 Introduction

The mobile handset has changed from being an attribute of luxury to becoming an irreplaceable part of people's daily lives; from the basic phone with voice calling capability to the computer-like smartphone with a large variety of functions. Contemporary handsets are capable of running numerous mobile applications and services, which are typically based on particular hardware or software features (Riikonen, Smura, & Juntunen, 2011). For example, location-based services generally need the GPS (Global Positioning System) feature, whereas emerging augmented reality applications require a camera, Internet connectivity, and particular sensors (such as accelerometer) for the operation. This application-enabling role of mobile handset features increases the importance of estimating their future penetration, that is, studying the mobile handset feature diffusion.

In previous literature, attention has been mainly paid to the diffusion of mobile telephony and mobile devices (e.g., Botelho & Pinto, 2004; Singh, 2008) and only few works have investigated the adoption of mobile handset features (Kivi, Smura, & Töyli, 2009; Kivi, Smura, & Töyli, 2012; Riikonen, Smura, Kivi, & Töyli, 2013). Kivi et al. (2009) noted that diffusion of some features follow similar paths and therefore can be thought of as being dependent. They acknowledged the importance of studying feature dependence for the diffusion forecasting, but left further exploration of this phenomenon for the future work.

The purpose of this paper is to quantitatively analyze dependences of mobile handset features. The analysis is based on the method of hierarchical clustering, which allows a graphical representation of the dependences as well as detection of the clusters of dependent features. The defined clusters are further compared on a year-by-year basis in order to track the dynamics of feature dependences. The analysis uses the data on model-wise mobile handset sales in Finland combined with the information on the features of the sold handset models.

The study of mobile handset feature dependences is required for obtaining a holistic understanding of feature diffusion process and producing accurate diffusion forecasts. Therefore, the topic is relevant to industry stakeholders. Mobile operators are interested in forecasting of mobile handset feature diffusion in order to plan future network development; service and application providers need to know the population of compatible handsets prior to the launch of a new product or service, and policy makers are concerned with the possibility of improving market dynamics by means of promoting particular handset functionality.

The paper is structured as follows. After the introduction, background on product feature diffusion and handset evolution is presented. Then, data and methods used for the analysis are described and results of the research are demonstrated. The paper closes with a discussion on the possible reasons for feature dependences, and conclusions of the study.

2 Background

2.1 Product feature diffusion

A product feature can be defined as a distinguishing characteristic of a product that is intended to satisfy a particular customer requirement ("Product feature", 2015). A new feature can either enable a new product function (horizontal innovation) or improve an existing product characteristic (vertical

innovation) (Koski & Kretschmer, 2007). In any case, features play a critical role in product differentiation (Levitt, 1980) and introduction of successful innovations (Starr, 1992).

A complex technological product can often be considered as a feature combination that differs from one product model to another and changes over time. For example, a contemporary mobile handset includes a set of features for calling and messaging, navigation, Internet access, taking photos and listening to the music. Therefore, analysis of the future evolution of mobile handset requires considering diffusion of handset features rather than diffusion of the handset as a product category (Riikonen et al., 2013).

Mobile handset feature diffusion has been studied from several perspectives. Kivi et al. (2009) conducted a quantitative descriptive analysis of handset feature diffusion in Finland and concluded that the penetration rates of different features vary considerably. In a later publication, Kivi et al. (2012) developed a feature diffusion forecasting model that includes a supply-related factor referred to as feature dissemination. The dissemination has been defined as “the planned and directed effort of product suppliers and regulators to affect the diffusion of product features” (p.108). The authors modelled the dissemination of mobile handset features as their shares among handset unit sales in different time periods. Kivi et al. (2012) discovered that dissemination and, consequently, diffusion of some handset features follow similar paths that can possibly be explained by the feature bundling. Due to the bundling, the diffusion level of a mobile handset feature does not necessarily correspond to its usage. Thus, for example, while over 80% of mobile handsets in Finland in January 2012 included email, only about 35% of Finns actively used this feature (Levä, Riikonen, Töyli, & Hämmäinen, 2014).

2.2 Evolution of mobile handset

The prototype of the first handheld device named DynaTAC was presented by Motorola in 1973 (Motorola, 2015). After that, a mobile handset went through a sequence of changes that resulted in the development of truly mobile digital phones in mid-1990s. Up to early 2000s, the evolution of handsets was driven by miniaturization, enabled by the achievements in chipset, antenna, and battery technologies. At the same time, manufacturers started to pay more attention to handset design. Hence, different form factors emerged: Motorola StarTAC released in 1996 became the first clamshell mobile phone, and Nokia's 8110 introduced in 1998 was one of the first slider phones (Tynan, 2005). Later, after the launch of Symbian and Windows Mobile smartphones in the early 2000s, the focus of handset evolution started to shift gradually to the development of new product features. For instance, first WCDMA (Wideband Code Division Multiple Access) 3G (third generation) phones were sold in Finland in the end of 2003, WLAN (Wireless Local Area Network) enabled handsets in 2004, and handsets with HSDPA (High-Speed Downlink Packet Access) in 2006 (Riikonen et al., 2013).

A new direction of handset evolution was marked by the release of Apple iPhone in 2007. Apple created a new product family by utilizing an ecosystem approach implying the integration of the mobile device (iPhone) with the operating system (iOS), as well as the application and digital media stores (App Store and iTunes) (e.g., Basole & Karla, 2011). Since that time, the share of smartphones among mobile handsets has significantly increased. For example, the portion of smartphones among mobile handsets used in Finland rose from 19% in 2007 to 60% in 2014 (Vesselkov & Hämmäinen, 2015). Presently, mobile manufacturers introduce numerous new smartphone models every year (Cecere, Corrocher, & Battaglia, 2014). Because the models are aimed at different customer

segments, they differ in some characteristics. However, the handset models of a certain segment often include a standard minimum set of features (e.g., Cecere et al., 2014). This leads to the emergence of feature dependences, which are analyzed in next sections.

3 Methods

3.1 Data

The primary dataset used in the analysis is model-specific data on mobile handset sales, which was provided by GfK (Gesellschaft für Konsumforschung - Society for Consumer Research), a market research company specialized in collecting retail data on technical consumer goods. The data represent monthly sales of mobile handsets in Finland from January 2008 to October 2014 and cover up to 90% of the retail market. In order to scale the data to full market coverage, information on quarterly handset sales was first obtained from ETK - the Association of Electronics Wholesalers in Finland¹. Then the sales volumes of all handset models from GfK were multiplied by the scaling coefficient calculated based on ETK data. Furthermore, for this analysis, the data were aggregated to a yearly level.

GfK also provided feature information on most of the sold mobile handset models. In cases when the information was not available in the GfK dataset, open sources, such as GSM Arena², were used to fill the missing values. The analyzed handset features are described in the Appendix.

Most of the analyzed features are binary variables, and the features measured on a continuous scale can be coded as binary for the simplification of data handling. Continuous variables can be categorized based on the median of handset unit sales in the considered year (Table 1). This categorization method allows to account for the dynamics of the features measured on a continuous scale and ensures that the data are approximately evenly distributed in two obtained categories. Values less than the median are considered as “Low”, and values equal to or greater than the median are considered “High”. After a continuous feature has been categorized, two mutually exclusive binary variables can be created: “Feature = Low”, and “Feature = High”. However, because of the direct connection between these two variables, it is not sensible to analyze both of them. Therefore, the analysis includes only one of the two variables obtained by the categorization of a continuous feature.

Table 1. Median value of the features measured on a continuous scale

	2008	2009	2010	2011	2012	2013	2014
Weight, g.	91	88	94	100	116	121	124
Camera resolution, MP	1,9	1,9	3,1	3,1	5	5	5
Screen size, inch.	2	2	2,2	2,4	3,5	4	4
Depth, mm.	16	14,6	14,4	13,6	12,1	10,7	9,6
Screen pixel density, pixel per inch (PPI)	143	167	182	182	210	233	233

¹ <http://gotech.fi/tilastot/>

² <http://www.gsmarena.com>

3.2 Measure of dependence

In order to analyze mobile handset feature dependences, it is necessary to select an appropriate measure, which is suitable for illustrating the degree of the association between the variables. The choice of a measure depends on several factors. First of all, the object of measurement should be determined. This paper focuses on analyzing the handset feature dependence, and it is assumed that *two features are dependent if the occurrence of the first one often implies the presence of the second one and vice versa*.

Furthermore, the type of data should be considered when choosing a metric. Taking into account that all analyzed features are either originally binary, or can be converted to this type, it is sensible to consider the measures suitable for assessing dependence of the presence/absence data.

Given the object of measurement and the type of the measured data, dependence between two handset features can be thought of as their similarity in its statistical meaning. Thorough analysis of similarity measures for binary data is conducted by Warrens (2008), who compared about 30 similarity coefficients, calculated based on four dependent quantities (a , b , c , and d) from a contingency table (Table 2).

Table 2. Contingency table for two variables

Variable A	Variable B	
	Value 1 (present)	Value 0 (absent)
Value 1 (present)	a	b
Value 0 (absent)	c	d

Similarity coefficients can be divided in two broad groups based on the inclusion or exclusion of the number of negative matches d (Sokal and Sneath, 1963, Warrens, 2008). The selection between these two groups is often complicated as no rules of thumb exist to assess whether the inclusion of negative matches d is reasonable (Sneath, 1957; Dunn & Everitt, 2004). Therefore, this has to be decided individually for each separate study case. When mobile handset features are considered, in authors' opinion, a similarity coefficient should not account for the number of negative matches: if two handset features are not common or popular, it does not make them more similar or dependent.

One of the most often used similarity coefficients excluding d quantity is the Jaccard coefficient (Dunn & Everitt, 2004), which is calculated as follows:

$$S_{Jac} = \frac{a}{a+b+c} \quad (1)$$

While statistical similarity has a direct link to the feature dependence as it has been defined in this paper, some methods, such as hierarchical clustering described below, use an inverse measure called distance or dissimilarity. The dissimilarity corresponding to Jaccard coefficient is called Jaccard distance and calculated as follows:

$$d_{Jac} = 1 - S_{Jac} = \frac{b+c}{a+b+c} \quad (2)$$

Jaccard distance metric will be used as a measure of feature dependence in this paper. Its interpretation is intuitive: $d_{Jac} = 0$ shows absolutely dependent features, which are always observed

together, whereas $d_{Jac} = 1$ illustrates totally independent features, which never co-present in a handset. Jaccard distance implies that features with different levels of penetration can never be absolutely dependent, as $b + c \neq 0$. Also, the features with penetration higher than 50% cannot be totally independent, as in this case $a > 0$.

3.3 Hierarchical clustering

3.3.1 Selection of an algorithm

The matrix of pairwise dissimilarities, or distances, corresponding to the handset feature dependences can be formed using the equation (2). This distance matrix is typically visualized using a tree diagram called dendrogram. In a dendrogram, variables are joined together in a hierarchical fashion, from the most similar to the most different (Greenacre & Primicerio, 2014). This procedure is referred to as hierarchical clustering.

Hierarchical clustering can be based on agglomerative or divisive methods. The first one takes a bottom-up approach: all variables are first considered to belong to separate clusters; after that, the closest pairs of clusters are merged until all variables eventually appear in the same cluster. Divisive clustering is opposite to agglomerative and takes a top-down approach. Divisive clustering is more computationally expensive than agglomerative, thus it is not commonly used in practice (e.g., Xu & Wunsch, 2005).

Depending on the definition of the distance between two clusters, several algorithms of hierarchical agglomerative clustering (HAC) can be identified. The most widely used ones are minimum or single linkage clustering, maximum or complete linkage clustering, and mean or average linkage clustering. In the first one, the distance between clusters is taken as a distance between two closest elements, one from each cluster. The second algorithm, in contrast, defines inter-cluster distance as a distance between two cluster elements, which are furthest from each other. Finally, the third algorithm calculates the distance between clusters as an average distance from each element of the first cluster to each element of the second cluster. According to Romesburg (2004), average linkage clustering is the most frequently used HAC method, as it is an attractive compromise between maximum and minimum linkage clustering methods.

Considering the arguments mentioned above, this paper will use the method of hierarchical agglomerative average linkage clustering based on Jaccard distance as a dissimilarity metric.

3.3.2 Selection of a cutoff point

The evolution of mobile handset feature dependences can be tracked by comparing the dendrograms corresponding to different years of measurement. A side-by-side comparison of the dendrograms is one of the easiest and most intuitive ways of tracking the evolution of the clusters of dependent features. In order to formalize this comparison, the clusters should be defined by cutting the dendrogram at a particular level of distance. A cutoff point is typically selected where the difference between two subsequent nodes in the tree is maximal (Todorovski, Cestnik, & Kline, 2002). However, sometimes there are several equally good cutting points or there is a need in illustrating different alternative sets of clusters. In these cases, authors consider several cutoff levels (e.g. Urbani, 1976; Ahn, Bagrow, & Lehmann, 2010).

In order to investigate different levels of feature dependence, this paper will examine clusters formed at two cutoff points: $d_{CO} = 0,1$ ($d_{Jac} \leq 0,1$) and $d_{CO} = 0,25$ ($d_{Jac} \leq 0,25$). The clusters obtained at the level $d_{CO} = 0,1$ can be thought of as representing strong feature dependences, whereas the clusters at the level $d_{CO} = 0,25$ illustrate moderate strength of dependence.

4 Results

Figure 1 shows the dendrograms of Jaccard distance-based average linkage clustering of feature dissemination in Finland. Due to space limitations, the dendrograms are presented for selected years (2010, 2012, and 2014). The figure indicates that feature dependences are dynamic and change over time. For example, whereas in 2010 GPS and WLAN were independent, in 2012 they became strongly connected with each other. However, after the features start to be strongly dependent, they typically remain in this state. For example, Bluetooth, Camera, GPRS, and EDGE have maintained their strong dependence since 2009. In general, mobile handset features have become increasingly dependent over time. Thus, Figure 1 shows that the features formed the clusters on average on a lower level of Jaccard distance in 2014 in comparison with 2012 and 2010.

Table 3 summarizes the clusters of dependent features defined for each year of measurement at two cutoff points: $d_{CO} = 0,1$ (strong dependences) and $d_{CO} = 0,25$ (moderate dependences). The size of the largest feature cluster in different years can be viewed as another evidence of the increasing level of feature dependence. Thus, in 2008 a maximum of five features were moderately dependent with each other, whereas in 2014 the largest cluster included 18 features ($d_{CO} = 0,25$). This is mainly due to increasing feature penetration and introduction of new features. Thus, Multitouch, LTE, NFC, and multi-core CPU did not exist in mobile handsets in 2008.

The evolution of mobile handset feature dependences can be roughly divided into three time intervals: 2008-2009, 2010-2011, and 2012-2014. In the first period, smartphone penetration was rather low (about 25%), and there was no dependence between Smartphone OS and any other features. This indicates the absence of the features specifically inherent to smartphones. Furthermore, this period can be characterized by a low number of strong feature dependences and a relatively high number of moderately dependent feature sets. These dependences may illustrate a differentiating role of the feature bundles: in 2008-2009 customers could choose between handsets with some of the features, but rarely all of them were included. The emergence of some pairwise dependences in 2008-2009 can be explained by the feature complementarity. For example, WCDMA and secondary camera are complements since the frontal camera was initially intended to be used for video calling, which was enabled by the third generation connectivity (that is, by WCDMA). Likewise, HSDPA and GPS are complements, because fast Internet connection (HSDPA) is required for loading the maps for navigation (GPS). Similarly, USB port and memory card slot may be thought of as complements, which likely present in multimedia-capable phones that require memory card for storing heavy music and video files, as well as USB port for transferring these files from a computer to the handset.

Another characteristic of the period 2008-2009 is the formation of a set of ‘basic’ features, consisting of GPRS, EDGE, Bluetooth, and Camera. While before 2008 these features were rarely included in handset models as a bundle, in 2009 it seems to have become technically and economically feasible to supply these “basic” features together.

Table 3. Clusters of dependent handset features (based on handset unit sales)

	Strong dependences ($d_{CO} = 0,1$)	Moderate dependences ($d_{CO} = 0,25$)
2008	1) Bluetooth, Camera	2) Cluster 1 + GPRS, EDGE, FM radio 3) Secondary camera, Flash 4) USB, Memory card slot 5) PPI = High, 16 Million Colors.
2009	1) Bluetooth, Camera, GPRS, EDGE 2) USB, Memory card slot	3) Cluster 1 + FM radio 4) Camera = High, Screen size = High 5) GPS, HSDPA 6) Secondary camera, WCDMA 7) Flash, 16 Million Colors.
2010	1) Bluetooth, Camera, GPRS, EDGE, FM radio 2) USB, Memory card slot	3) Cluster 1 + Cluster 2 4) Smartphone OS, GPS, HSDPA 5) Flash, 16 Million Colors.
2011	1) Bluetooth, Camera, GPRS, EDGE, USB 2) Touch Screen, Screen size = High	3) Cluster 1 + FM radio, Memory card slot, Form factor = Bar 4) Cluster 2 + WLAN 5) Smartphone OS, GPS, HSDPA, 16 Million Colors.
2012	1) Bluetooth, Camera, GPRS, EDGE, USB 2) Smartphone OS, GPS, WLAN 3) WCDMA, HSDPA	4) Cluster 1 + Form factor = Bar, FM radio 5) Cluster 2 + Cluster 3, Touch Screen, Multitouch, PPI = High, Screen size = High, Flash, 16 Million Colors, Autofocus.
2013	1) Bluetooth, Camera, GPRS, EDGE, USB, Form factor = Bar 2) Smartphone OS, GPS, WLAN, Touch Screen, Multitouch 3) WCDMA, HSDPA 4) 16 Million Colors, Autofocus	5) Cluster 1 + Cluster 2 + Cluster 3 + Cluster 4. 6) Secondary camera, Flash, Multi-Core CPU
2014	1) Bluetooth, Camera, GPRS, EDGE, USB, Form factor = Bar, WCDMA, HSDPA 2) Smartphone OS, GPS, WLAN, Touch Screen, Multitouch, 16 Million Colors, Autofocus, Multi-Core CPU 3) Secondary camera, Flash	4) Cluster 1 + Cluster 2 + Cluster 3 5) Camera = High, PPI = High.

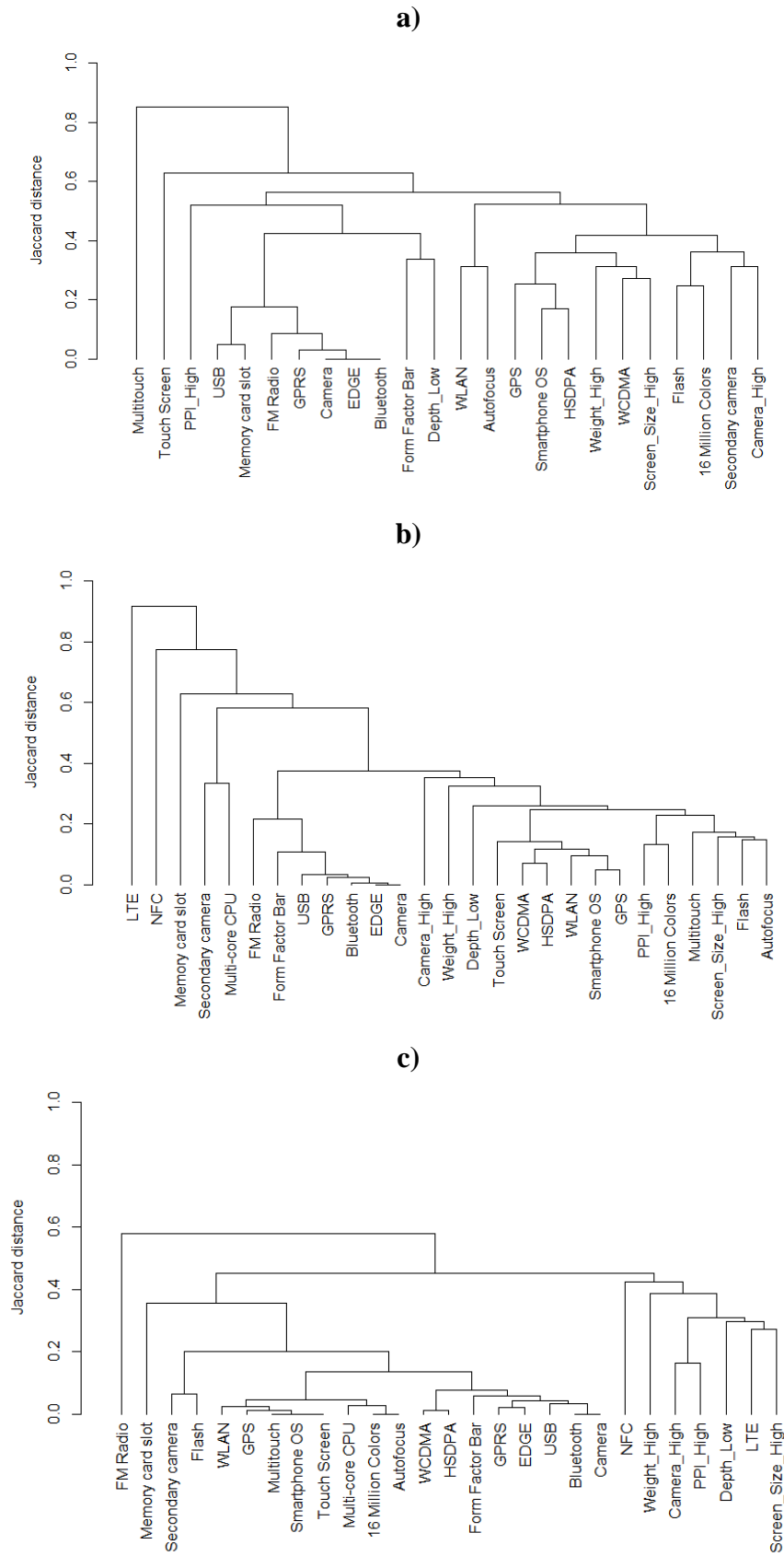


Figure 1. Dendrograms of Jaccard distance-based average linkage clustering of feature dissemination in Finland in: a) 2010; b) 2012; c) 2014.

The second period of the evolution of feature dependences (2010-2011) can be characterized by the formation of a new set of moderately dependent features, consisting of Smartphone OS, HSDPA, GPS, and display with 16 million colors. A possible explanation for this dependence is growing penetration of early smartphones, which typically included all of these features. Moreover, in 2011 touch screen and high display size became strongly dependent features. This is logical, since touch screen provides good user experience only when the display size of a handset is large.

The evolution of mobile handset feature dependences during the third period, 2012-2014, was driven by the diffusion of Android, iOS, and Windows Phone smartphones, along with the decreased sales of feature phones. In 2012, Smartphone OS, GPS, and WLAN formed a strongly dependent feature set, which was complemented with the touch screen and multitouch features in 2013. The feature set further expanded in 2014 and included display with 16 million colors, autofocus, and multi-core CPU. This feature bundle is inherent to the smartphones and could be found in 75,6% of total handset unit sales in Finland in 2014. Furthermore, in 2014, 18 out of the considered 27 features formed a moderately dependent feature bundle. This demonstrates that many previously advanced features have become commodities and that the basis of differentiation between handset models switched from the presence of particular hardware features (HSDPA, WLAN, GPS and some others, as it was in 2008-2009) to some other factors, such as quality and size of a handset display. Thus, the connection between LTE, high PPI, high display size, and low handset depth in 2014 ($d_{jac} = 0,31$) can be thought of as a feature set inherent to contemporary high-end handsets. This means that manufacturers started to differentiate their products by introducing vertical innovations, rather than horizontal innovations. Moreover, smartphone's operating system became an important handset differentiation factor.

Another change in feature relations in 2012-2014 was a decrease in the dependence of FM Radio and memory card slot with other features. This is likely because of the launch of several popular smartphone models, which did not include FM Radio and abandoned external memory cards in favor of the increased internal memory and cloud storage services.

Overall, it is likely that the trend of strengthening feature dependences will continue in future, as currently advanced features become available in cheaper handsets. For example, LTE is no longer specifically inherent to high-end phones and it can be found, for example, in Nokia Lumia 635, which is sold in Finland for less than 100 euro (as of May 2015). Furthermore, it seems that the development of vertical innovations has slowed recently. Thus, the median camera resolution has not changed for three years, and median screen size along with pixel density – for two years. It is likely that the handset evolution will continue with further increase of processing power, standby time, as well as software diversity and functionality.

5 Discussion

Better understanding of mobile handset feature dissemination that has been gained in the previous section has potential implications for improving the feature diffusion forecasting model developed by Kivi et al. (2012). Thus, the knowledge on feature dependence can enable conditional forecasting, i.e., predicting the diffusion of a feature given the information on another dependent feature. Moreover, the observations on feature dependences can facilitate the modelling of different scenarios of feature diffusion, that is, “what-if” type of analysis. Obviously, the inclusion of additional

complexity (such as feature dependence information) to the forecasting model should be justified by the significance of an improvement expected due to the model change. Therefore, it is likely that consideration of the feature dependences is more relevant to the diffusion estimation of new rather than old saturated features. Thus, this section attempts to generalize the investigated historical feature dependences in order to provide a basis for improving the diffusion forecasting of new features.

Mobile handset feature dissemination, as defined in Section 2.1, is a process primarily controlled by handset producers; therefore, general understanding of feature dissemination can be obtained from studying mobile handset design decisions. These decisions are influenced by factors, which can be divided in four main groups: demand, technology, product strategy, standardization and regulatory factors.

Demand factors primarily include requirements of customers and end-users, as well as trends and fashion. Because of national differences in demand, the sales of the same handset model can differ from country to country. Therefore, the features dependent in Finland are not necessary dependent in other countries. For example, whereas a large display size of smartphones is favored by many customers in some Asian markets (Yu, 2014), it is less critical for European customers.

Demand factors furthermore include requirements of mobile software developers that can also be considered as customers of handset manufacturers. The influence of mobile application developers on handset design is implicit and can be observed through the feedback loop of an indirect network effect. When a new feature is introduced, application developers start to search the ways of using it in mobile apps, and if this usage is possible and sensible, feature-based applications start to emerge. Furthermore, as the number of popular feature-enabled applications grows, demand on handsets equipped with this feature also increases, and handset manufacturers start to include the feature in other handset models.

Technology factors comprise technology availability, maturity, and complementarity. The feature cannot be included in a handset and reach a high penetration level if the corresponding technology is unavailable or immature. Moreover, most of the mobile handset features require the presence of particular hardware components, development of which has to be started well before the features are launched. One of the trends in the evolution of mobile circuits is integration of several previously separated components into a single die. Chipset integration allows reducing the size of components and improving their performance and energy efficiency. This has a direct connection to the dependence of mobile handset features: once components are implemented on a single die, they start to co-present in most of the handsets³. This can be a possible reason for the observed dependence of GPRS and EDGE.

Moreover, the availability of complements is critical for including a feature in mobile handsets. For example, GPS requires fast Internet connection for loading the maps; therefore, it only succeeded after HSDPA became available. Touch screen is only usable when the display size is large; therefore, these features are typically supplied in a bundle. When technologies are complementary, their dissemination is usually dependent.

³ However, integration of the features into a single chipset does not always guarantee that all the included features will be enabled in the handset

Product strategy factors include expected profit, product positioning in the market, and differentiation from other products. Features included in a handset model directly depend on the customer segment for which the handset model has been designed. Thus, taking into account that GPRS is supplied in low-end handsets, this feature is unlikely to be dependent with LTE or NFC, which are currently included only in high and mid-end handsets. Moreover, it should be considered that product management teams in handset manufacturing companies have to reach the compromise between the features which are included in the handset and its cost, so that the manufacturers can achieve the planned margins given the estimated retail price of the handset. This has direct implications for the estimation of feature dissemination: the feature will be included in many handset models when its inclusion becomes cheap enough.

Finally, standardization and regulatory factors consider interoperability specifications and requirements for the inclusion of features. Many feature technologies have to be standardized before their introduction into mobile handsets, in order to ensure compatibility between the handsets. Definition of the dissemination highlights its dependence on regulatory factors, stating that adjusting feature dissemination is a way that regulators can use to affect feature diffusion. For example, in 2006 the Finnish regulatory body discontinued the mandatory unbundling of 3G mobile devices and services, which resulted in a significant increase of the 3G (WCDMA) diffusion (Tallberg, Hämmäinen, Töyli, Kamppari, & Kivi, 2007). Another example is the Enhanced 911 directive issued by Federal Communications Commission (FCC) in the USA, which require mobile operators to define the position of 911 callers with accuracy that can be provided in practice only by the GPS feature. It should be noted that due to the feature dependences, by adjusting the diffusion of one feature, regulators can indirectly influence the diffusion of other dependent features.

6 Conclusions

This study quantitatively analyzed mobile handset feature dependences using a method of hierarchical clustering applied to the model-wise data on mobile handset unit sales in Finland in 2008-2014. The results show that feature dependences are highly dynamic and change every year. The evolution of dependences can be divided into three time intervals: 2008-2009, 2010-2011, and 2012-2014. The first period can be primarily characterized by the formation of the only set of strongly dependent features, which can be referred to as “basic”, consisting of GPRS, EDGE, Bluetooth, Camera. The second time period, 2010-2011, is driven by the diffusion of early smartphones and can be described by the emergence of a new set of dependent features, including Smartphone OS, HSDPA, GPS, and 16 million colors display. Finally, the last period, 2012-2014, can be characterized by the takeoff of “new” smartphones (Android, iOS, and Windows Phone) and consequent strengthened dependence of the most of the considered features.

The increasing dependence of handset features results from the decreasing cost of feature components and consequent growing number of handset models equipped with the features. Thus, whereas WLAN and GPS features presented only in a small number of expensive handset models in 2008, currently they can be found in most of the average-price handsets. Moreover, whereas previously handset differentiation was primarily based on the introduction of new features (horizontal innovation, e.g., introduction of Multitouch and LTE), currently high-end handset models can be distinguished from

other handsets by the enhanced quality of older features (vertical innovation, e.g., increased resolution of camera and screen pixel density).

The dissemination of mobile handset features is primarily driven by supply rather than demand; therefore, dependences in the dissemination arise because of mobile handset design decisions taken by handset manufacturers. However, the manufacturers are limited in their decisions by a number of factors. For example, a new handset feature cannot be launched unless the corresponding hardware component is ready (technology factor). Furthermore, handset will not include a feature if its cost is too expensive for the target customer segment (product strategy factor).

The investigated feature dependences and their evolution, as well as discussion on the possible reasons for these dependences, can have important implications for improving handset feature dissemination and diffusion forecasts. However, the implementation of these improvements and forecasting are left for the future work. Moreover, due to the limitations of data, this study does not consider some important features, including processing power related features, such as clock speed of the smartphone processor (CPU frequency), or presence of some sensors, such as accelerometer or gesture and proximity sensors. Therefore, future research could address dependences of these additional features. It could also be valuable to consider the features on different levels of technological maturity (e.g., WLAN 802.11g and 802.11ac can be considered separately, not as a single WLAN feature).

Appendix

Table A1. Description of mobile handset features

Feature	Description
16 Million Colors	The number of colors shown in the display is about 16 million (24-bit color, $2^{24} = 16777216$ color variations).
Autofocus	System, which is able to establish correct focus of a camera automatically.
Bluetooth	Short-range wireless communication technology, operating in the unlicensed radio frequency bands.
Camera	A digital camera capable of capturing photographs and possibly video.
Camera_High	The resolution of digital camera, in megapixels, is equal to or greater than the median resolution of handset units sold in the considered year (see Table 1).
Depth_Low	The depth of a mobile handset, in millimeters, is lower than the median depth of handset units sold in the considered year (see Table 1).
EDGE (Enhanced Data rates for GSM Evolution)	Technology for data transmission, sometimes referred to as 2,75G.
Flash	Build-in flash in digital cameras, intended for capturing photographs in dark conditions.
FM Radio	Receiver for FM radio broadcasts.
Form Factor Bar	Handset design, can also be referred to as “block”.
GPRS (General Packet Radio Service)	Technology for data transmission in 2G/3G mobile communication systems.
GPS (Global Positioning System)	Satellite-based positioning and navigation.
HSDPA (High-Speed Downlink Packet Access)	Technology for data transmission, sometimes referred to as 3,5G.
LTE (Long-Term Evolution)	Technology for data transmission, commonly referred to as 4G.
Memory card slot	Slot for a memory card, enabling expansion of the memory capacity.
Multi-core CPU (Central Processing Unit)	The number of CPU cores built in the device is more than one.
Multitouch	Touch screen display that can recognize more than one point of contact simultaneously.
NFC (Near Field Communication)	Short-range wireless communication technology enabling exchange of data between devices.

PPI_High (Pixel per inch)	Pixel density of a handset display, in PPI, is equal to or greater than the median pixel density of handset units sold in the considered year (see Table 1).
Screen_Size_High	Diagonal of handset display, in inches, is equal to or greater than the median display diagonal of handset units sold in the considered year (see Table 1).
Secondary camera	Frontal digital camera for video communication.
Smartphone OS (Operating System)	Operating system of a smartphone, which enables the installation and running of third party applications.
Touch Screen	Virtual touch screen keyboard. Also includes hybrid keyboards (e.g., touch + QWERTY).
USB (Universal Serial Bus)	Port for connecting a handset to the USB port of PC. Also includes mini-, micro-USB and proprietary connectors.
WCDMA (Wideband Code Division Multiple Access)	Radio interface of 3G mobile communication networks.
Weight_High	Weight of a handset, in grams, is equal to or greater than the median weight of handset units sold in the considered year (see Table 1).
WLAN (Wireless Local Area Network)	Short range wireless network operating in the unlicensed radio frequency bands, also called Wi-Fi.

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