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The mobile Solow Paradox? Evidence from Swedish firms

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Abstract

This thesis examines the effects of 3G and 4G technologies on firm performance and productivity in Sweden. Using a comprehensive dataset of Swedish firms and data on the availability of mobile broadband technologies, the study found that while contemporary effects of the technologies were negative, they had a positive effect on firm sales when using different orders of lags. The technologies were also found to be capital-decreasing, with HSPA being labor-augmenting and LTE being labor-augmenting at higher orders of lags. The study provides insight into the effects of mobile broadband on firm-specific productivity and carries implications for the ongoing roll-out of 5G technology.

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1 Introduction

In a famous article for the New York Times Book Review, Robert Solow (1987) remarked that, given the slowdown in the productivity of the manufacturing sector in West Germany and Japan in the late 1980s, ”you can see the computer age everywhere but the productivity statistics”. This question is especially interesting in light of what is perhaps the most important development in consumer information and communications technology (ICT) after the personal computer, namely, the appearance and widespread consumer adoption of cell phones capable of accessing the internet on the go.

The introduction of mobile-internet capable devices, especially smartphones has had a staggering impact on society thus far. Smartphones and mobile internet allow us to access information at practically any location and time, to communicate with acquaintances more easily and in more complex ways than I have before. While internet-capable mobile devices were first introduced in the early 1990s, it is only with the spread of technologies such as the Universal Mobile Telecommunications System (UMTS), the third generation of mobile telecommunications systems (3G), which in Sweden primarily employ the High Speed Package Access (HSPA) method, that mobile access to the internet has become widely used by consumers (Ezhilarasan & Dinakaran, 2017), particularly after the iPhone 3G was first sold to consumers in 2008 (Apple Inc., 2008). As for 4G[1], the Long Term Evolution (LTE) method was first employed in Sweden 2011, which significantly increased the speed of mobile broadband (MBB) in the country.

The scale and direction of the effect of these technologies on productivity is not intuitively straightforward, as one could imagine both positive and negative effects of this technology on one's capacity to work effectively, given both its well-documented effects on access to information and on focus (Goldfarb & Tucker, 2019). There are some hints to suggest that, in aggregate, the effect of access to MBB on GDP is mostly positive (Edquist et al., 2018), though the sources of this effect are somewhat murky. Can one thus see the age of the iPhone in the productivity statistics? Building on previous studies in the fields of digital economics and productivity, I will use Swedish firm-level financial statement data to investigate the link between MBB adoption and firm productivity. Thus, the main research question of this thesis is: *What effect has MBB had on productivity and firm performance in Sweden?*

[1]Early iterations of Long Term Evolution do not fulfill all of the technical criteria for the technology to be considered 4G, but given that the speeds achieved by early LTE systems are quite close, and 4G was used as a term to market the technology, I include the use of LTE as a 4G technology in all of its forms.

In order to ascertain the effects of the increased availability of MBB technologies on firm sales, I use two-way fixed effects repeated cross-section models to estimate HSPA and LTE´s direct effects on firm sales with several levels of lags. Incorporating the two technologies into a Cobb-Douglas production function, I then measure the impact of these technologies on the shares of production of inputs over time. Finally, I incorporate productivity into my analysis by adapting the methods proposed by Levinsohn and Petrin (2003) and De Loecker and Warzynski (2012) to the introduction of mobile technology, by using a two-step system Generalized Method of Moments estimator to measure each technology's direct impact on firm productivity. I find that in a simple OLS regression with fixed effects of firm sales on different orders of lags of the availability of HSPA and LTE in workplaces in a municipality yields results that increase with the order of lags. When including each technology into the firm's production function, I find that the introduction of HSPA especially increases labor's share of value added, though LTE's impact on the labor share of value added is more ambiguous, and both HSPA and LTE decrease capital's share of value added, while their direct impact on output is ambiguous. Finally, I find that both technologies' impact on productivity is positive.

Here, I contribute to the literature on the digital economics by providing evidence on the economic effects of MBB technologies. This is, to the best of my knowledge, the first study to use a nationally comprehensive database detailing the financial statements of firms to study the impact of MBB on firm performance and productivity.

2 Background- Mobile broadband in Sweden

In Sweden, one of the richest and most technologically advanced societies in Europe, with a fairly large telecommunications sector, the roll-out and adoption of this technology were particularly rapid. The first commercial 3G networks in the country were introduced in late 2006. By 2008, over 90% of the population was covered by the 3G mobile network (Ingman, 2016), and by 2012 over 60% of the population used mobile internet regularly, more so than in any country in Europe (See Figure 1 for a comparison to selected peer countries). For my purposes, it is key to note that the introduction of these services was not simultaneous throughout the country. As is shown in figures 2 and 3, both 3G and 4G were introduced to different areas of the country at different times, roughly concentrated within the areas that produce the most economic output, though not necessarily the most value added or sales per inhabitant as can be seen in figures A1 and A2 in the appendix.

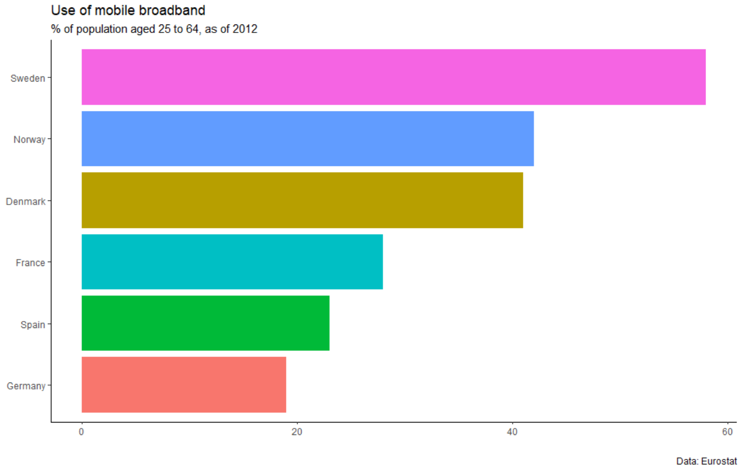

Figure 1: Mobile broadband use in selected countries

The process for allocating the rights to different radio frequencies to telecommunications companies in the country was a long, expensive and laborious process (Andersson et al., 2005). The Swedish state was interested in the rapid development and allocation of the 3G network as a part of its strategy to sustain a large telecommunications sector as a key part of its development strategy. Rather than selling the frequency rights through an auction, as most countries did, and as most economists recommended, provisions in Swedish law required the process to be conducted through a "beauty contest", whereby companies would apply to receive one of five licences, based on their ability to roll out the network rapidly, provide nation-wide coverage, and their ability to finance the initial losses resulting from the large upfront costs. While initial coverage was stronger in urban areas, it is important to note that inclusion of rural areas was an important criterion, which goes to show that the variation in the deployment of the technology is not entirely due to population density or regional output. Several firms, including the two largest incumbents, namely Telia and Telenor were denied a licence due to their lack of coverage for rural areas, though they were later able to negotiate use of the spectra acquired by other firms to retail to customers. The licences granted during this process were valid until the 31st of December 2015, covering the entire period of scope for this thesis.

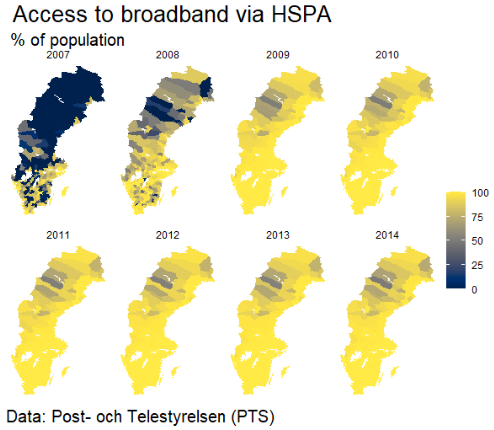

Figure 2: Spread of HSPA over time in Sweden

In contrast to the 3G frequency allocation, licences for the 4G spectra were instead allocated by auction, in line with most other European countries. The licences for the 800MHz band, where LTE operates were auctioned off in early 2011. Given that LTE is not backwards-compatible with HSPA (Rao et al., 2009), new physical infrastructure had to be installed, which is evidenced by the staggered roll-out of the technology shown in Figure 2. Still, Sweden was early in the adoption of 4G, with its 4G network being the first in the world (Vanags & Gravelis, 2015), and the most advanced in Europe in 2014. The introduction of 4G also led to a substantial reduction in the price of mobile bandwidth in the country, when compared to the times when only 3G was available, making these services more accessible to a larger share of the population.

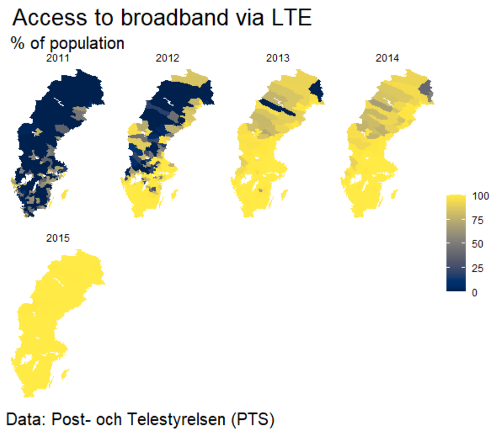

Figure 3: Spread of LTE over time in Sweden

The deployment of the 3G network essentially allowed consumers who owned a compatible device to access the internet when not connected to fixed broadband internet. It is important to note that at the point of introduction, almost all households and enterprises in Sweden already had access and were presumably connected to the internet via fixed broadband, and some could already access the internet on their mobile phone or similar devices, when connected to fixed broadband (Ingman, 2016). The change to 4G mostly increased speed and allowed consumers access to a broader range of more data-intensive media on the go, such as images or video and music streaming, and allowed for higher network security when connected to MBB (Oyman et al., 2010). This likely allowed for more consumption of social media rather than the messaging and email services to which 3G was better adapted, while the security aspects may have induced more firms to issue mobile phones to workers.

It is important to note that the adoption of smartphones and therefore MBB was not uniform amongst Swedish society (Kongaut & Bohlin, 2016). Those who live in Stockholm, are younger, have higher incomes and education are more likely to own smartphones and access the internet through them. The way consumers use these devices also changes according to income and education, notably, those with lower education tend to use smartphones more for social media usage and video streaming compared to those with higher education. As noted earlier, in 2012, long after the introduction of MBB, only 60% of the Swedish working-age population used the technology on a daily basis, as shown in Figure 1.

3 Literature review

Several years after David's publication, Brynjolfsson and Hitt (2003) used firm data to conclude that there are normal returns to computer capital on production, but that the bulk of these effects tend to appear five to seven years after the capital was first accumulated. This may account for the discrepancies in the adoption of computing and productivity that Solow hypothesized. This, however, may be a phenomenon localized to the United States. Van Ark et al. (2008) note that while productivity grew starkly in the United States in the period from 1995 to 2006, as documented by Brynjolfsson and Hitt (2003), likely due in part to the increased role of computing in Europe, the growth rate of productivity declined markedly. Van Ark et al. (2008) conclude that this might come from the slower development of a knowledge economy in Europe during this period, the lower contribution of ICT capital to growth, and small impact of technology firms in the European economy when compared to the United states. On the other hand, from the 2000s onward, Acemoglu et al. (2014) argue that since the 1990s, the accumulation of computer capital, especially in light of improvements in computing and information technology, productivity did not improve in the manufacturing sector as Brynjolfsson and Hitt (2003) had documented earlier, where, given a continuous growth in computer and IT capital stocks, one would have expected to see sustained growth in productivity.

The literature on General Purpose Technologies (GPT) provides another line of inquiry for research in this topic. Bresnahan and Trajtenberg (1995) describe GPTs as technologies "characterized by pervasiveness, inherent potential for technological improvements and 'innovational complementarities', giving rise to increasing returns to scale". While mobile phones and MBB could, given their widespread adoption be characterized as pervasive, and given the technical improvements seen in the increases in speed evidenced by the successive generations of the technology, as well as dependant technologies, their giving rise to increasing returns to scale is less evident. Nonetheless, Gruber and Koutroumpis (2011), use the theoretical framework of GPTs to argue that MBB has a positive impact on GDP growth, and that this effect is higher in countries where the technology is more pervasive, suggesting that it exhibits increasing returns to scale.

The effects of fixed broadband access on firm performance has been widely studied in developed countries, and provides a good theoretical framework of studying the effects of mobile broadband. An important paper on the rollout of broadband internet in a panel of OECD member countries (Czernich et al., 2011) found, using two-stage least squares models predicting mobile broadband diffusion and penetration based on a country's existing fixed telephone and cable television network, that increases in fixed broadband availability increase GDP growth significantly, though the effect declines over time. A study by Akerman et al. (2015) finds similar results in a paper investigating the roll-out of broadband technology in Norway, where the increased availability and adoption of fixed broadband internet increased the wages and elasticity of substitution for skilled labor performing non-routine and especially abstract tasks. This stands in contrast, however, to results from firms in Ireland and Germany (Haller & Lyons, 2015; Bertschek et al., 2013), who found no effects on firm productivity from the introduction of fixed broadband, although Haller and Lyons (2015) did find that more productive firms are more likely to adopt broadband technology.

A well-cited recent study on the broad-range effects of the arrival of high-speed internet access in Africa (Hjort & Poulsen, 2019) concluded that the availability of high-speed internet in an area increased employment, firm productivity and the wages of higher-skilled workers, though the effects of availability on demand for low-skilled labor are more uncertain. Additionally, studies in Colombia (Ospino, 2018) and Mexico (Mora-Rivera & García-Mora, 2021) found that an increased availability of broadband, especially through MBB increased labor demand, decreased the incidence of poverty and was related to higher TFP levels for firms in areas with higher broadband download speeds. Furthermore, another recent paper on the effects of MBB on consumer welfare in Nigeria (Bahia et al., 2020) found that an increase in the coverage rate of MBB technologies significantly decreased the likelihood of household consumption to fall below the poverty line, and especially decreased the likelihood of falling into extreme poverty. Moreover, the study showed that the main channel through which this occurred was that higher access to MBB internet increased the probability of individuals to be employed in salaried or wage labor rather than agricultural self employment, which suggests that one important channel through which this technology operated was through higher firm labor demand.

Regarding mobile networks specifically, the literature on their impact on productivity and growth is somewhat more sparse. Edquist et al. (2018) show that increases in MBB intensity (i.e. MBB capable subscriptions as a percentage of all mobile subscriptions), a measure approximating consumer adoption of mobile telecommunications, has a small but positive effect on productivity growth, when the variable is lagged by five years. Additionally, Edquist (2022) notes that while a contemporaneous increase in MBB speeds does not seem to have a large effect on labor productivity, the one-year lag of the variable has a modest but significant effect on aggregate labor productivity, though this result is only significant in low-income, non-OECD countries. A study with a similar approach to the one I employ, Bertschek and Niebel (2016) estimate the effects of increased mobile internet adoption by employees in a sample of manufacturing and service firms in Germany, and conclude that increased adoption of mobile broadband technologies by firm employees has a fairly large, causal impact on labor productivity. This is the only study, to my knowledge, to use firm data to study the impact of mobile broadband specifically on firm performance.

4 Data

4.1 Mobile broadband

Table 1: Percentage of workplaces with access to 3G and 4G mobile networks

	2007	2008	2009	2010	2011	2012	2013	2014	2015
HSPA	63%	87%	99%	99%	99%	99%	99%	99%	100%
LTE				0%	45%	90%	98%	99%	100%

My data on MBB availability comes from the Swedish Post and Telecommunications authority (Post- och Telestyrelsen, hereafter PTS). The PTS compiles information on the availability of broadband by method of connection at the regional and municipality levels (Ingman, 2016). The data is available upon request to PTS. The main variables I use are access to broadband via HSPA and LTE, which is the most common method of access to the internet through 3G and 4G mobile connections respectively in Sweden. These variables provide data at the municipality (kommun) and region (län) levels, as a percentage of the population or households as well as workplaces. Given that the differences between access at the household and workplace levels are low, I use data on access at the workplace henceforth. While other methods of connection to 3G and 4G networks exist, these are less common in the country and mostly appeared after the rollouts of HSPA and LTE.

As illustrated earlier, the staggered roll-out of the technologies by locality provides variation in the data, especially considering the slower roll-out of LTE in particular. Access to broadband by a given method is defined by the feasibility to obtain a subscription and access the technology from a given address. The first year of data availability is 2007, which is a year after the initial introduction of HSPA technology for consumers in the country. The numbers of adoption as a percentage of workplaces can be seen in figures 1 and 2 for each technology. As can be seen in Table 2, the deployment of the technologies was very rapid, with 63% of workplaces having access to the internet via HSPA in 2007 already, and around 45% of workplaces having access to the internet via LTE in 2011.

4.2 Firm data: the Serrano dataset

Table 1: Averages and totals of key summary statistics through years 2007-2015

Variable	Mean	Standard Deviation	Min.	Max.
Number of employees	16.4	140	2	20492
Sales*	47727.1	784386.7	1	127687609.3
Payroll*	8830.6	93497.2	1	19231409.5
Fixed Capital Stock*	9033.4	229276.8	2	50338931.5
	Total			
Number of firms	214084			
Number of sectors	774			
Number of Municipalities	290			

* *1000s of SEK*

Data on the financial accounts of firms in Sweden comes from the Swedish House of Finance's Serrano database (Weidenman, 2016), which contains the consolidated financial accounts of every limited liability company operating in Sweden, in thousands of Swedish crowns where the unit of measurement is in currency. This database also includes data on the firms' location, allowing me to effectively relate the firms' performance with the level of mobile internet availability in the area. This database presents major advantages over other similar sources on firm data, as its comprehensive nature ensures that the sample is representative, as opposed to others that include only data on publicly-listed firms, or include only a selection of mostly larger firms.

Eliminating holding companies and firms with no payroll, intermediate inputs and less than two employees (including mostly financial firms), my sample contains 214084 individual firms across the years 2007-2015, for which MBB availability data is available. In 2010, each firm employed on average 16.4 employees, has personnel expenses of around 8.3 million SEK, a capital stock of around 9 million SEK, and a sales volume of aroun 47.7 million SEK. It is important to note that this database lists the location of firms at their firm headquarters, meaning that many firms have several workplaces in different locations in the country, or even plants in several countries. All prices are modified by the GDP deflator from the World Bank's World Development Indicators (2021). In order to maintain the privacy of firms, I anonymize the firm data by deleting the firm's name, organization number and address, and assign new firm identities.

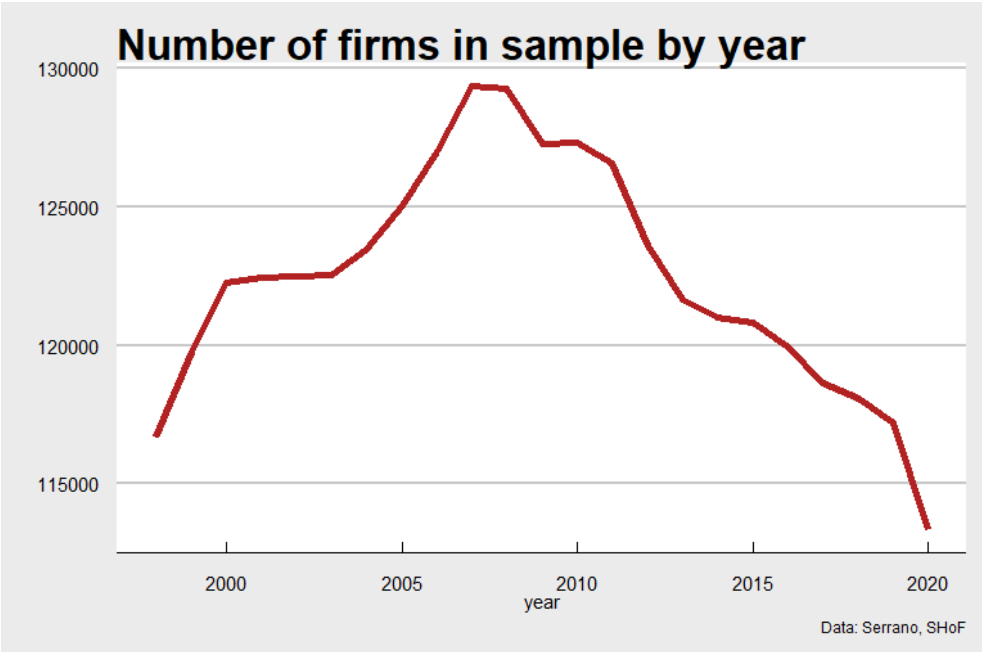

Figure 4

Additionally, the number of firms changes significantly by year, as, from 2007 to 2020, there has been, as can be seen in the figure below, a noted decrease in the number of firms in the database and in Sweden, which accounts for the declining number of observations that can be seen when I intoduce variable lags.

5 Identification Strategy

5.1 Sales

In order to establish a baseline for the effects of the introduction of 3G and 4G on firm sales, I begin by using a simple regression of firm sales on access to broadband internet by municipality, including municipality, year and industry fixed effects such that:

$$y_{it} = \alpha_0 + \%HSPA_{mt} + \%LTE_{mt} + w'_{imt}\theta + \mu_m + \tau_t + u_{imt} \qquad (1)$$

Where y_{it} is the logarithm of firm sales, μ_m and τ_t are municipality and firm fixed effects respectively, w_{imt} is a vector of industry indicators, and $\%HSPA_{mt}$ and $\%LTE_{mt}$ are the percentage of workplaces in municipality m amd time t covered by $HSPA$ and LTE respectively. Standard errors in all regressions are clustered at the municipality level.

Additionally, in order to see the effects of each technology throughout time, I use the following set of specification:

$$y_{it} = \alpha_0 + \%HSPA_{m,t-i} + \%LTE_{m,t-i} + w'_{imt}\theta + \mu_m + \tau_t + u_{imt} \tag{2}$$

These specifications allow us to see the effects of these technologies throughout time.

While these specification may begin to give us an insight on what the effects of access to the network might be, they are not sufficient to determine the effects of each variable on production, much less productivity. Rather, it is more likely that this specification might account for some mix of demand and supply effects on firm performance. In order to better disentangle these two potential sources of impact, I further incorporate local levels of HSPA and LTE accessibility into the firm's production function.

5.2 Production technology

Having established a baseline, I borrow freely from the framework provided by Akerman et al. (2015), first used to identify the firm and worker effects of the introduction of fast fixed broadband internet across municipalities in Norway. Similar to their approach, I use the modified Cobb-Douglas production function:

$$Y = e^{\alpha_0 + HSPA\alpha_1 + LTE\alpha_2} L^{\beta_{l0}} K^{\beta_{k0}} (L^{HSPA\delta_{l1} + LTE\delta_{l2}})(K^{HSPA\delta_{k1} + LTE\delta_{k2}})$$

Taking the logarithm on both sides, I obtain the following specification:

$$\begin{aligned} y_{it} = {} & \alpha_0 + \%HSPA_{mt}\alpha_1 + \%LTE_{mt}\alpha_2 + x'_{imt}\delta_0 + \\ & \%HSPA_{mt}x'_{imt}\delta_1 + \%LTE_{mt}x'_{imt}\delta_2 + w'_{imt}\theta + \mu_m + \tau_t + u_{imt} \end{aligned} \tag{3}$$

Where y_{it} is the log of firm value added, x'_{imt} is a vector of log production inputs, here labor, for which I use the personnel costs of each firm, and capital for which I use the fixed capital stock of each firm. The variables $HSPA_{mt}$ and LTE_{mt} indicate the availability of HSPA and LTE signal as a percentage of workplaces in each municipality, while the mu_m and τ_t indicate municipality and time fixed effects, and w'_{imt} is a vector of industry indicators, for which I use the Swedish SNI071 system of industry classification, which is compatible with the European NACE classification system. Akerman et al. (2015) employ a similar specification in their analysis, but extend it further to measure the effects of firm adoption of broadband internet, which I am not able to do, as I do not have access to data relating to the adoption of the technologies in question either at the firm or individual level.

In addition, I propose using the lagged values of the introduction of these technologies as such, to account for Brynjolfsson and Hitt (2003) and Edquist et al. (2018) observation that the technologies' real productive capacity arrives several years after their introduction. Due to the fact that by 2012 almost all of Sweden's population had access to HSPA and most of the country had access to LTE, and that the argument here is essentially that one these technologies' actual effects take place one or several years after their introduction, I add only the i-lagged values such that:

$$\begin{aligned} y_{it} = x'_{imt}\delta_0 + \%HSPA_{m,t-i}\alpha_1 + \%LTE_{m,t-i}\alpha_2 + \\ \%HSPA_{m,t-i}x'_{imt}\delta_1 + \%LTE_{m,t-i}x'_{imt}\delta_2 + w'_{imt}\theta + \mu_m + \tau_t + u_{imt} + \epsilon_{imt} \end{aligned} \tag{4}$$

This specification allows us to see the technologies effects on the elasticities of substitution of each input, and give us an some evidence on the effect of these technologies on demand, but tell us little as to their effects on *productivity.* In order to overcome this issue, inspired by the process described by Levinsohn and Petrin (2003) and De Loecker and Warzynski (2012), which has been used in the context of analyzing the effects of ICTs on productivity by Akerman et al. (2015) as well as Hjort and Poulsen (2019).

5.3 Productivity

For this, I propose two models in which I estimate productivity separately. Firstly, I take the model used in the previous section, with i=1 and apply a Levinsohn-Petrin productivity process, programmed in R, using a process similar to that which Levinsohn and Petrin described in their article detailing the process they used to program it in Stata (Petrin et al., 2004), then, I take a simple Cobb-Douglas production function and apply the a similar process, adding the availability of each technology as a separate term directly in the productivity Markov process.

For both specifications, we assume that demand for intermediate inputs is a function of productivity and capital such that, for any given level of capital k_{imt}, demand for intermediate inputs is monotonous in productivity. Thus, we can invert the function for demand for intermediate inputs to uncover productivity such that:

$$a_{imt} = a_i(k_{imt}, \omega_{imt})$$
$$\omega_{imt} = \omega(a_{imt}, k_{imt})$$

Levinsohn-Petrin specification For my first specification, as in the previous models i use :

$$y_{it} = x'_{imt}\beta_0 + \%HSPA_{m,t-1}\alpha_1 + \%LTE_{m,t-1}\alpha_2 +$$
$$\%HSPA_{m,t-1}x'_{imt}\beta_1 + \%LTE_{m,t-1}x'_{imt}\beta_2 + \omega_{imt} + \chi_{imt}$$

Which can be expressed as:

$$y = l_{imt}\beta_0 + HSPA_{m,t-i}\alpha_1 + LTE_{m,t-1}\alpha_2 +$$
$$\%HSPA_{m,t-1}l_{imt}\beta_{l1} + \%LTE_{m,t-1}l_{imt}\beta_{l2} +$$
$$\%HSPA_{m,t-1}k_{imt}\beta_{k1} + \%LTE_{m,t-1}k_{imt}\beta_{k2} + \Psi(k_{imt}, \omega_{imt}) + \chi_{imt}$$

Where y_{imt} is again the log of firm sales and $\omega_{imt} = \Psi_{imt} - \beta*_{k0}$. The productivity process also subsumes the intercept and fixed effects. Our OLS estimates of $\beta_{l0}, \beta_{l1}, \beta_{l2}, \beta_{k1}, \beta_{k2}, \alpha_1$ and α_2 will be consistent, as in a similar regression in Akerman et al. (2015), but as capital will be collinear with the productivity process, our estimate of the coefficient on capital will not be consistent. To overcome the simultaneity problem, I must make further assumptions about the productivity process in order to uncover the coefficients on capital.

I assume that productivity follows a Markov process such that:

$$\omega_{imt} = \rho\omega_{im,t-1} + \xi_{imt}$$

In order to recover the coefficient for capital in the production specification, I impose the moment condition:

$$E[\xi_{imt}k_{imt}] = 0$$

I use a two-step Generalized Metod of Moments procedure, first described by Hansen (1982), in order to recover each coefficient, and bootstrap to obtain the standard errors of each coefficient, and impose the further overidentification conditions:

$$E\left[\xi_t \times \begin{bmatrix} l_{t-1} \\ m_{t-1} \end{bmatrix}\right] = 0$$

Adjusted Levinsohn-Petrin Specification Separately, I use a standard Cobb-Douglas production function such that:

$$y_{imt} = \beta_{l0} l_{imt} + \beta_{k0} k_{imt} + \omega_{imt} + \chi_{imt}$$

Which can be expressed as:

$$y_{imt} = \beta_{l0} l_{imt} + \Psi(k_{imt}, \omega_{imt}) + \chi_{imt}$$

Where, $\Psi(k_{imt}, \omega_{imt}) = \omega_i mt - \beta^*_{k0} k_{imt}$.

In contrast to the previous specification, and inspired by similar methods employed by De Loecker and Warzynski (2012) and Hjort and Poulsen (2019).

Here, my OLS estimate for β_{l0} will be consistent. I use the following process to estimate the Markov process of productivity:

$$\omega_{imt} = \rho_1 \omega_{im,t-1} + \rho_2 HSPA_{m,t-1} + \rho_3 LTE_{imt} + \xi_{imt}$$

As before, I impose the moment condition:

$$E[\xi_{imt} k_{imt}] = 0$$

As well as the moment conditions in the Markov process:

$$E\left[\xi_t \times \begin{bmatrix} \omega_{t-1} \\ HSPA_{t-1} \\ LTE_{t-1} \end{bmatrix}\right] = 0$$

and the overidentification conditions:

$$E\left[\xi_t \times \begin{bmatrix} l_{t-1} \\ m_{t-1} \end{bmatrix}\right] = 0$$

6 Empirical analysis

6.1 Sales

Figure 4

For our first specification, As shown previously for $i = \{1, 2, 3, 4, 5\}$, I run the specifications described in equations (4.1) and (4.2). The observed coefficients of each lagged value of HSPA and LTE of the previous regressions are shown in the figure above, the corresponding table is shown in figures A1 and A2 in the appendix.

As can be seen clearly on the graph, the contemporaneous effect of the introduction of 3G and 4G access on firm sales is negative, where a firm placed in a municipality with full access to HSPA or in a given year will have, all else equal, lower levels of sales than a firm having no access to the technology.

Looking at the lagged values, we see that sales tend to increase increase long after the introduction of the technologies, perhaps reflecting the effects of increased adoption of the technologies by consumers, and the continued building of an ecosystem around the technologies. One puzzling aspect of these results is the relatively larger effect of LTE. The year fixed effects should cover other growth effects. One hypothesis as to why this might be the case is that for our first value for the introduction of HSPA in 2007, most firms already had access to the technology, and so, further gains likely made for smaller effects than access in the locations that were already set up by the end of 2006. Additionally, this could reflect something similar to Brynjolfsson and Hitt (2003) results showing that investments in computer capital, especially a few years after the fact, had a modest positive effect on productivity, though this is especially true several years after the initial accumulation of capital. The demand and productivity effects of the technology are, however, more difficult to distinguish. For that, we proceed to our following set of specifications.

6.2 Production technology

Table 2

	Dependent variable:				
	ValueAdded				
	Baseline	i=0	i=1	i=3	i=5
Capital	0.068^{***}	0.086^{***}	0.082^{***}	0.072^{***}	0.074^{***}
	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)
Labor	0.917^{***}	0.902^{***}	0.898^{***}	0.912^{***}	0.899^{***}
	(0.004)	(0.005)	(0.002)	(0.003)	(0.003)
$\%\text{HSPA}_{t-i}$		-0.043	-0.046^{***}	0.030^{*}	-0.088^{***}
		(0.044)	(0.017)	(0.018)	(0.019)
$\%\text{LTE}_{t-i}$		0.027^{***}	0.036^{***}	0.003	-0.018^{***}
		(0.010)	(0.006)	(0.006)	(0.006)
$\text{Labor}\times\%HSPA_{t-i}$		0.015^{**}	0.015^{***}	0.002	0.021^{***}
		(0.007)	(0.003)	(0.003)	(0.003)
$\text{Capital}\times\%HSPA_{t-i}$		-0.015^{***}	-0.012^{***}	-0.005^{***}	-0.011^{***}
		(0.003)	(0.001)	(0.001)	(0.001)
$\text{Labor}\times\%LTE_{t-i}$		0.001	0.001	0.007^{***}	0.006^{***}
		(0.002)	(0.001)	(0.001)	(0.001)
$\text{Capital}\times\%LTE_t - i$		-0.007^{***}	-0.005^{***}	-0.005^{***}	-0.002^{***}
		(0.001)	(0.0005)	(0.0004)	(0.0005)
Fixed Effects	Yes	Yes	Yes	Yes	Yes
Observations	1,121,777	1,121,777	908,031	851,155	700,229
R^2	0.900	0.900	0.905	0.913	0.919
Adjusted R^2	0.899	0.900	0.904	0.913	0.919
Residual Std. Error	0.442 (df = 1120704)	0.442 (df = 1120698)	0.415 (df = 906955)	0.398 (df = 850081)	0.388 (df = 699166)
Note:					*p<0.1; **p<0.05; ***p<0.01

In the table above, we see my estimates for the specifications described in equations (4) and (5) above. For the sake of brevity and readability, I show the results of the regressions where $i = \{0, 1, 3, 5\}$, the results for $i = \{2, 4\}$ are shown in the appendix table A3.

In this specification, we see how the introduction of the two technologies affects production. In order to have a comparison point, I also run a simple regression with the Cobb-Douglas production function $y_{itm} = \alpha_0 + k_{itm} + l_{itm} + \mu_m + \tau_t + w_i' + \epsilon_{itm}$

Similarly to the results obtained by Akerman et al. (2015) and Bertschek and Niebel (2016), the increased availability of both HSPA and LTE increases value added per unit spent on payroll, while decreasing the share of capital in production, though in smaller proportion. This can be interpreted as an increase in the labor elasticity of substitution of capital, or as an increase in labor productivity. For $i = 0$, $i = 1$ and $i = 5$, the effect of the increase in the availability of HSPA on labor's share of value added predominates upon that of LTE, while for capital, HSPA is more capital-decreasing than that of LTE for $i = 0$, $i = 1$ and $i = 5$. Additionally, the coefficients on the introduction of LTE in the lag orders $i = 1$, $i = 2$, $i = 4$ and $i = 5$ are consistent with Edquist's (2022) result that increased average broadband speeds increase labor productivity.

In regard to the autonomous effects of each technology, for every level of lags except for $i = 3$, the autonomous effect of LTE is larger than that of HSPA, which is consistent, with our estimates in the previous sections. For $i = 0$, $i = 1$ and $i = 5$, the autonomous effect of HSPA on firm value added is negative, which suggests that the positive effect of especially HSPA technology comes primarily from supply rather than demand, while the reverse is true for LTE, except at the level of 5 lags.

6.3 Productivity

Table 5

	Dependent variable:				
	ValueAdded				
	(1)	(2)	(3)	(4)	(5)
Labor	0.915***	0.898***	0.812***	0.832***	0.832***
	(0.004)	(0.002)	(0.004)	(0.006)	(0.006)
Capital	0.066***	0.082***	0.057***	0.046***	0.049***
	(0.002)	(0.001)	(0.0003)	(0.001)	(0.001)
Labor×$\%HSPA_{t-1}$		0.015***	0.019***		
		(0.003)	(0.006)		
Labor×$\%LTE_{t-1}$		0.001	−0.003***		
		(0.001)	(0.001)		
Capital×$\%HSPA_{t-1}$		−0.012***	−0.013***		
		(0.001)	(0.002)		
Capital×$\%LTE_{t-1}$		−0.005***	−0.004***		
		(0.0005)	(0.001)		
$\%\text{HSPA}_{t-1}$		−0.046***	−0.068		
		(0.017)	(0.042)		
$\%\text{LTE}_{t-1}$		0.036***	0.067***		
		(0.006)	(0.009)		
			Productivity (ω_t)		
ω_{t-1}			1.004***	1.01***	0.98***
			(0.0002)	(0.0003)	(0.00005)
HSPA_{t-1}					0.032***
					(0.0003)
LTE_{t-1}					0.0099***
					(0.0001)
Fixed Effects	Yes	Yes	Yes	Yes	Yes
Productivity Process	No	No	Yes	Yes	
Observations	1,081,097	908,031	874,213	1,081,097	1,081,097
R^2	0.892	0.905	0.904	0.899	0.899
Adjusted R^2	0.892	0.904	0.904	0.899	0.899
Residual Std. Error	0.437 (df = 1080025)	0.415 (df = 906955)	0.395 (df = 873131)	0.422 (df = 1080020)	0.422 (df = 1080020)
Note:					*p<0.1; **p<0.05; ***p<0.01

In the table above, I show the results of the specifications proposed in section 5.3. For comparison, I add two Cobb-Doulgas specification as in the last section, covering the years 2008-2016 and 2007-2015 respectively where I use OLS estimation and where I use a simple Levinsohn-Petrin model to compute firm autonomous productivity, as well as the 1-lagged model in the previous section. Due to the necessities of this model, I omit all firms that don't report intermediate input expenses, though this only represents a small portion of all firms.

In my first Levinsohn-Petrin specification, there are significant changes from the baseline OLS models. Firstly, we see that the autonomous effect of LTE in the specification is much larger than that of the OLS model, while its effects on the output shares of each input are smaller. The effect on the labor share of LTE reverses direction and becomes significant, while the effects on the shares of capital remain similar to those in the OLS specification. The effect of HSPA on labor remains significant and similar to that of the OLS results. The unmodified coefficient on capital, obtained with GMM is, however, worryingly small, which puts the results of this specification in doubt, though the OLS coefficient obtained is more in line with the baseline specifications.

For our second specification, I use a simple Cobb-Douglas production function and add an adjusted Levinsohn-Petrin production function where I add terms for HSPA and LTE directly in the production Markov process, to investigate the effect of each technology on total factor productivity directly. In this specification, one can observe that both technologies have a significant effect on productivity, where gaining full coverage of HSPA in a given municipality increases autonomous productivity by approximately 3%, and LTE increases productivity by approximately 1%. The coefficients for both labor and capital are both smaller than in the baseline Cobb-Douglas specification, which is somewhat similar to what can be observed in Akerman et al. (2015), though the fact that the coefficient on capital is disproportionately smaller than that of the baseline specification is somewhat worrying.

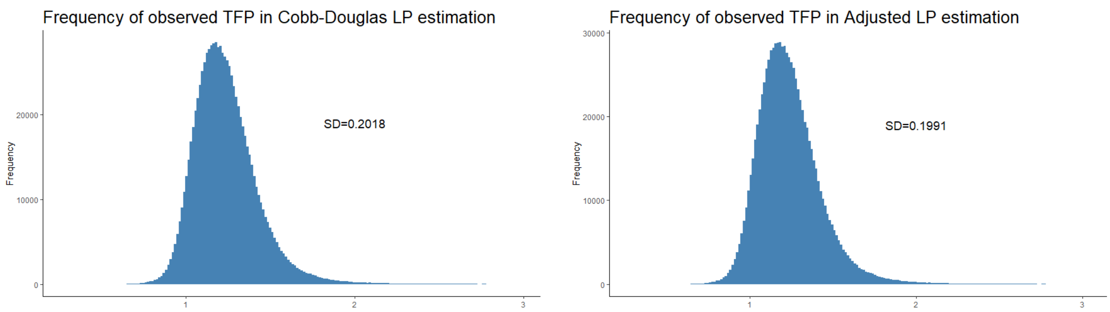

Figure 5

In Figure 5, I plot the densities of observed productivity in the models denoted in columns 4 and 5 of the table. Here, one can observe that the standard deviation of observed TFP has declines slightly when we add the terms for the introduction of HSPA and LTE in the productivity Markov process, resolving some of the observed dispersion of my measure of productivity, meaning that these variables hold some explanatory power in the framework proposed by Syverson (2011) and Hsieh and Klenow (2009).

7 Robustness checks

In order to verify the robustness of my results, and address key issues within the structure of the data, tied to possible localized and sectoral effects, I run the same specifications as before, while removing certain firms or localities that could potentially distort certain effects of these technologies.

One important objection to these results might result from two features of the data. Firstly, my results rely on the connection between a firm's location, and the availability of mobile broadband in that particular location. However, several of the firms in this database have several locations, some of which might not be in the municipality where the firm's headquarter is measured. To verify the validity of my results, I run the regressions of the specifications (2) and (4) presented in section 6.1 and 6.2 using only firms with one workplace.

The results of these regressions can be found in tables A4 and A5 in the appendix. As can be seen there, the results do not change much, with most of the magnitudes, directions and standard errors measured previously remaining consistent with what was found in the main results.

Other objections might result from sectoral differences in contributions to the results. It would be possible that the information technology and telecommunications sectors play an outsized role in the results, especially given the fact that this sector is fairly important in the Swedish economy. In order to verify our results, I remove the telecommunications sector and run my first two set of results.

The results of this check can be found in tables A6 and A7 in the appendix. Here, we see that the results are again similar to those found in the main results, though the increases in value added per unit of payroll costs and capital do indeed appear more muted, as well as the autonomous effects.

Finally, in order to correct some of the issues relating to the initial distribution of HSPA in Sweden and the, I again run the specifications from sections 4.1 and 4.2, excluding municipalities in Stockholm county in order to exclude some of the municipalities with the highest level of access to HSPA in 2007, and who were early to recieving LTE. The results of this exercise can be found in tables A8 and A9.

In the simple sales model, the effects seem to be similar though somewhat more muted than those in our main results.

In the production technology model, we see somewhat more interesting results. For the order of lags $i = 3$, HSPA appears to be labor decreasing rather than augmenting, though the autonomous coefficient on HSPA is positive and large. For other orders of lags, the results are quite similar to those obtained previously, though, again, slightly more muted.

Thus, my specifications seem to be robust to these changes in the sample.

8 Discussion

To summarize my results, I find that the introduction of both HSPA and LTE has a positive impact on firm sales, but only when the variables are lagged at least once. Additionally, when introduced into a Cobb-Douglas production function, HSPA is labor-augmenting, and capital-decreasing, while LTE is almost certainly capital-decreasing, though it only becomes labor-augmenting after the introduction of at least two lags. These findings are robust to the several changes in the sample that could plausibly change the results. When one adds a Levinsohn-Petrin productivity process, only HSPA is labor-augmenting, while both technologies are capital decreasing, though the autonomous effect of LTE is positive while that of HSPA is negative. Additionally, when I create an adjusted Levinsohn-Petrin process, I find that both LTE and HSPA have a positive effect on firm-specific productivity, though the effect of HSPA is larger than that of LTE.

8.1 Interpretation

The first important question that might come to mind is, quite simply, where the effect comes from, that is, why mobile broadband would have any effect on production, as mobile phones and remote connection to the internet is likely not a significant input of production, given that most production tends to be conducted in places that have access to fixed broadband. On its own, mobile broadband signal does nothing, except disrupt cable television signal in certain cases. In order for consumers or firms to make any use of the technology, they must use a mobile phone or similar technology. As was evidenced earlier, while the working-age population in Sweden was quick to adopt the technology, adoption was not universal, even six years after it was initially deployed. In order for the technology to prove useful, an ecosystem of use cases, such as the development of smartphone apps, mobile-adapted websites and the spread of online messaging services needed to develop. This is quite similar to the point made by David (1990), that adaptation to a particular technology within a production process is costly and takes time. The importance of the technologies would only be realized several years after their introduction. This may account for the fact that the magnitude of the effects of the technology tend to become larger as the order of lags increases, as this may represent the importance of integration of the technology into firms' decision making, marketing and administrative practices. One puzzling result is the finding of negative effects when we regress net sales on the contemporaneous values of HSPA and LTE access. While this is rather confusing at first glance, as we see in the subsequent section, it seems likely that this is a result of factors relating to demand rather than firm performance *per se*, although the exact mechanism behind these results is still out of reach.

Another interesting result is the fact that both HSPA and LTE are labor-augmenting. One plausible hypothesis might be that, given that smartphones are known to cause distraction and spending too much time on social media and other activities that are not work-related, one might expect that labor productivity specifically would decrease as the technology gains more widespread adoption. While this may be the case, as Akerman et al. (2015) reasoned for fixed broadband, the technology especially increased the productivity of workers performing abstract non-routine tasks, while decreasing that of those performing routine or repetitive tasks. This may well also be the case with mobile broadband, though, as I cannot observe adoption of the technology by workers, I cannot necesarily verify this effect. Bertschek and Niebel (2016) find similar results to those that I do, while having more detailed data on adoption rates within the firm, with mobile broadband use having a significant positive effect on labor productivity.

In regards to the models using a Levinsohn-Petrin productivity process, there are few studies that incorporate this sort of analysis into their examination of the effects of broadband internet. Akerman et al. (2015) use a framework similar to that described in the first specification in section 5.3, while Hjort and Poulsen (2019) use specifications similar to both of those presented in section 5.3. In my first Levinsohn-Petrin specification, I showed that at the level of one lag, my results presented in section 6.2 do not change drastically when using a Levinsohn-Petrin specification including a firm-specific productivity process, although we do see that access to LTE becomes labor-decreasing, though the effect is quite small. Additionally in the second such specification, I showed that access to both HSPA and LTE are positively related to firm-specific productivity, and that, as introducing these variables into the specification slightly reduces the dispersion of measured firm-specific productivity, this interpretation of the results is plausible.

8.2 Limitations

There are several important limitations to the results presented above, due to the features of my data, as well as from limitations in my analysis.

Firstly, one important issue here is that of the effect of the availability of the technology, in contrast to the adoption of the technology by the population. Here, I rely on the assumption that adoption follows somewhat linearly from availability in a given municipality, and that in municipalities that gain access to the technology first, consumers are more likely to begin using 3G and 4G technologies before those in municipalities where the technology becomes accessible later. While I believe this assumption to be reasonable, given that I have no localized data on smartphone use, or use of any of these technologies, I cannot assert this to be the case. Moreover, it is noted (Lee et al., 2011), at least at the country level, that the number of subscriptions in a country is positively related with population density, which may threaten my identification, as it is also areas with higher population density that were able to obtain mobile broadband first, which is why the presence of municipality fixed effects is so important.

Furthermore, there is the issue of the availability of data, specifically with regards to the introduction of HSPA. The earliest available date for the availability of HSPA technology at the local level in my dataset dates from year-end 2007, while the first commercial networks of the technology were made available from November 2006, presumably covering areas at least around Stockholm and other major cities, but due to the fact that PTS did not record availability levels at that point, I am left to study the effects of the introduction of that technology from the year after it was introduced, meaning that careful interpretation of the effects I record from the availability of HSPA is required, as most of the increase in availability of the technology after 2007 happened in rural and minor urban areas especially in the North of the country. Despite this issue, the fact that there is considerable variation in the availability of coverage in 2007 and that municipality and year fixed effects are included in the regressions give me some confidence that the effect is at least partially identified.

Additionally, there is the issue of accounting for firm sales and profits earned abroad. Sweden is home to many multinational companies that have subsidiaries abroad and that export to other markets, which might affect where sales and profits are recorded, and might thus affect my results by overstating the production of certain firms relative to the level of employment and capital recorded. While restricting our sample to firms that only have one workplace might help mitigate the doubt that this effect might pose, I cannot confidently assert that this issue is avoided in that way.

Moreover, there is the issue of potential overinstrumentation in the GMM estimation. In my GMM estimations, I find particularly high Hansen J-statistics, which means that my system estimator is certainly (p-value approximates 0), overidentified (Roodman, 2009). This means that the calculated standard errors for the estimates obtained using GMM are almost certainly far too small, and the number of estimators too large. Here, I have chosen to present these results in either case, as there is theoretical justification for the overidentifying estimates I have chosen, and due to the fact that in their abscence, results were either theoretically non-sensical or very sensitive to small changes to the initial guesses of β_{k0} and $\rho_{(1)}$.

Finally, another important factor in the analysis that the data available to me does not distinguish between skilled and unskilled labor. This factor is key to the analysis proposed by several studies (Akerman et al., 2015; Hjort & Poulsen, 2019; Bahia et al., 2020), who note that an increase in the availability or adoption of fixed and mobile broadband primarily increase the productivity of skilled workers performing abstract, nonroutine tasks rather than that of unskilled workers performing routine repetitive tasks. This is a source of potential bias that I cannot entirely avoid, but given that this thesis is more concerned with the effects of these technologies on the firm than on workers, pooling both types of labor is likely valid, at least to an extent.

8.3 Further research and policy implications

Several avenues for further research present arise from the results found in this work. These may relate to the effects of increases in broadband speed, such as the ongoing transition to 5G technologies that represent a large increase in download speeds and decrease in latency when compared to 4G (Cave, 2018). The possible effects of this new technology might be similar to those experienced during the transition from 3G to 4G, which led to small gains in labour productivity and firm-specific productivity. Cave specifically notes the potential uses in the automotive industry, but worries that the introduction of 5G could increase the concentration of the telecommunications industry and have adverse effects on price. This study is important, as it provides evidence on the effects of an increase in broadband speed, though it is unclear whether the results shown here will be similar to those resulting from the introduction of 5G mobile internet.

Additionally, more work could be done to use detailed firm or plant-level data, particularly in countries such as India or Mexico, in order to better identify the effects of access to and adoption of these technologies on key firm or plant-level indicators. It is important to note that for many lower income countries, MBB is a more common way to access the internet than fixed broadband connections (Mora-Rivera & García-Mora, 2021; Ospino, 2018; Rodríguez-Castelán et al., 2021) for most of the population. It would thus be important to analyze the effects of access to different technologies on firm or plant productivity, how this differs between countries and how future investments into telecommunications technology might best be conducted and regulated, especially in the context of developing countries.

9 Conclusion

In this thesis, I first described the process for the allocation of rights for provision of 3G and 4G technologies in Sweden. I further explain the intentions of policymakers in their implementation, in partnership with operators, of the roll-out of HSPA and LTE technologies, and the subsequent spread of the technology in the country. The reason that the Swedish government allocated licences in the way it did was its ambition to bolster the digital economy and firm productivity, though, of course, at the time there was little evidence that the introduction of the technology would do so. Later evidence, such as that provided by Edquist et al. (2018) and Edquist (2022), suggests that in aggregate, increased availability of MBB has a positive effect on GDP and that an increase in the average speed of MBB has a positive effect on labor productivity. Additionally Bertschek and Niebel (2016) suggest that higher adoption of MBB by employees increases labor productivity.

Throughout this thesis, I use a comprehensive database of Swedish firm data, and connect it to a panel of data on the availability of MBB through two key technologies. I then use this dataset to analyze the effects that these technologies have on several key metrics of firm performance. First, I use a fixed effects OLS model to analyze the effect of these technologies on firm sales. I find that while the contemporary effects of availability of these technologies are negative, using diferent orders of lags of these variables yields a positive effect of these technologies on firm sales, though the precise channel through which this occurs is unclear. Next, I incorporate the level of availability of these technologies into a production function, and estimate the effects of these technologies, and the interaction of these variables with inputs of production on firm value added. I find that both technologies are capital-decreasing, that HSPA is labor-augmenting, and that LTE is labor-augmenting at higher orders of lags. Finally, I employ the Levinsohn-Petrin process, and I find that both HSPA and LTE are positively related to my estimated values of firm-specific productivity.

My results are in line with previous literature on the effects of mobile internet, and internet access more broadly on firm productivity. Though no concrete policy recommendations ensue from the study presented previously, this study does provide some clarity on the effects of an increase in mobile broadband speed, which carries some implications for the ongoing roll-out of 5G.

This thesis is, to the best of my knowledge, the first study to use a nationally comprehensive dataset of firms to investigate the effect of mobile broadband on several metrics relating to firm performance and firm productivity.

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A Tables- Sales Models

Table A1

	Dependent variable:		
	Sales		
i =	0	1	2
$HSPA_{t-i}$	−0.100***	0.015	0.048**
	(0.025)	(0.011)	(0.021)
LTE_{t-i}	−0.013**	0.235***	0.369***
	(0.006)	(0.009)	(0.018)
Fixed Effects	Yes	Yes	Yes
Observations	1,121,777	908,031	934,873
R^2	0.223	0.233	0.240
Adjusted R^2	0.222	0.232	0.239
Residual Std. Error	1.313 (df = 1120704)	1.268 (df = 906961)	1.268 (df = 933803)
Note:			*p<0.1; **p<0.05; ***p<0.01

Table A2

	Dependent variable:		
	Sales		
i =	3	4	5
$HSPA_{t-i}$	0.074***	0.106***	0.161***
	(0.021)	(0.021)	(0.019)
LTE_{t-i}	0.451***	0.521***	0.582***
	(0.017)	(0.020)	(0.021)
Fixed Effects	Yes	Yes	Yes
Observations	851,161	773,611	700,229
R^2	0.246	0.251	0.255
Adjusted R^2	0.245	0.250	0.254
Residual Std. Error	1.273 (df = 850093)	1.279 (df = 772548)	1.286 (df = 699172)
Note:			*p<0.1; **p<0.05; ***p<0.01

B Production technology-Supplementary table

Table A3

	Dependent variable:	
	Value Added	
i =	2	4
Labor	0.904***	0.905***
	(0.003)	(0.003)
Capital	0.075***	0.073***
	(0.001)	(0.001)
Labor×$\%HSPA_{t-i}$	0.009***	0.011***
	(0.003)	(0.003)
Labor×$\%LTE_{t-i}$	0.005***	0.007***
	(0.001)	(0.001)
Capital×$\%HSPA_{t-i}$	−0.006***	−0.008***
	(0.001)	(0.001)
Capital×$\%LTE_{t-i}$	−0.005***	−0.004***
	(0.0004)	(0.0005)
$\%HSPA_{t-i}$	−0.017	−0.029
	(0.018)	(0.018)
$\%LTE_{t-i}$	0.012*	−0.009
	(0.006)	(0.006)
Fixed Effects	Yes	Yes
Observations	934,873	773,611
R^2	0.908	0.917
Adjusted R^2	0.908	0.916
Residual Std. Error	0.408 (df = 933797)	0.393 (df = 772542)
Note:		*p<0.1; **p<0.05; ***p<0.01

C Maps- Descriptive Statistics

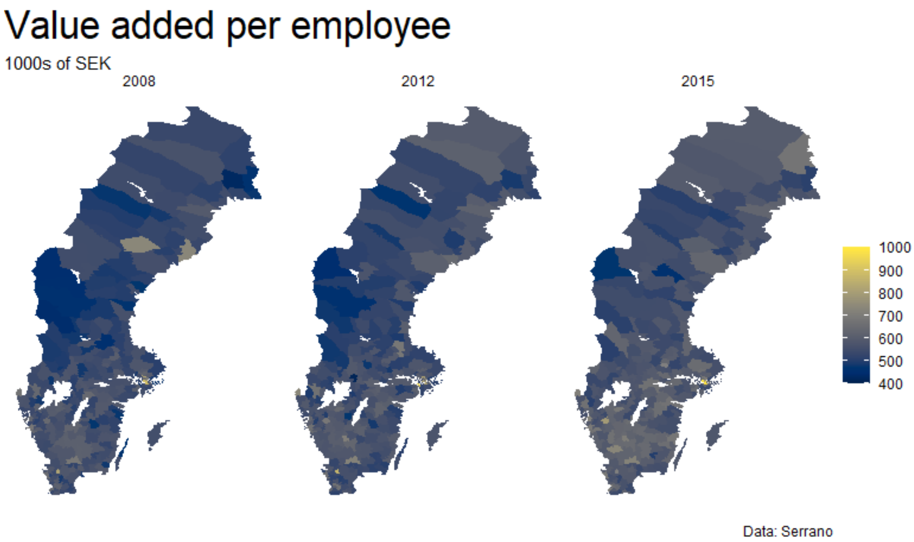

Figure A1

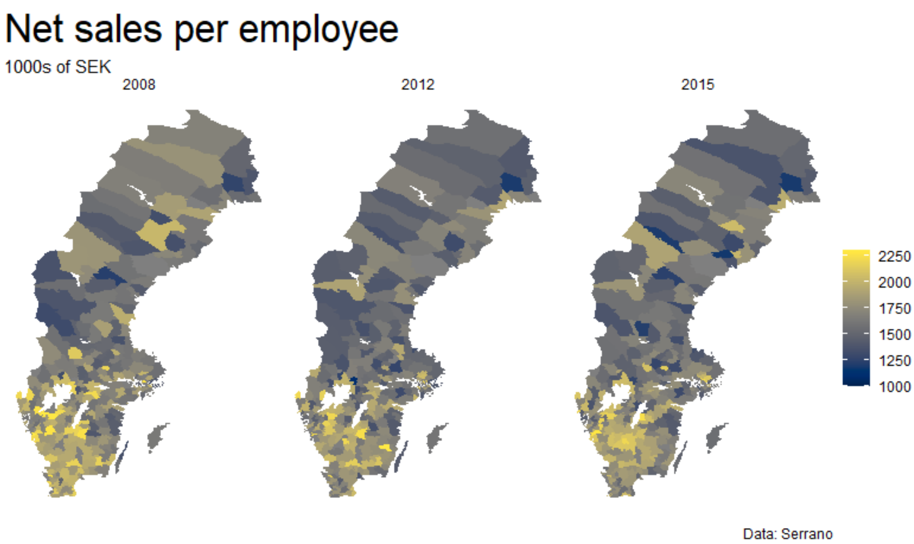

Figure A2

D Tables- Robustness Checks

D.1 Excluding firms with more than one workplace

Table A4

	Dependent variable:					
	Sales					
i =	0	1	2	3	4	5
$\%HSPA_{t-i}$	−0.091***	0.008	0.036*	0.071***	0.079***	0.126***
	(0.021)	(0.010)	(0.019)	(0.023)	(0.021)	(0.018)
$\%LTE_{t-i}$	−0.014***	0.202***	0.305***	0.452***	0.427***	0.479***
	(0.005)	(0.008)	(0.014)	(0.017)	(0.013)	(0.013)
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,057,446	849,974	871,791	838,858	714,317	643,077
R^2	0.214	0.221	0.226	0.247	0.235	0.237
Adjusted R^2	0.213	0.221	0.225	0.246	0.233	0.236
Residual Std. Error	1.191 (df = 1056375)	1.159 (df = 848907)	1.158 (df = 870723)	1.274 (df = 837791)	1.160 (df = 713256)	1.162 (df = 642024)
Note:						*p<0.1; **p<0.05; ***p<0.01

Table A5

	Dependent variable:				
	ValueAdded				
i=	Baseline	0	1	3	5
Capital	0.069***	0.087***	0.083***	0.072***	0.075***
	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)
Labor	0.910***	0.892***	0.895***	0.911***	0.894***
	(0.005)	(0.004)	(0.003)	(0.003)	(0.003)
$\%HSPA_{t-i}$		−0.062	−0.044**	0.029	−0.100***
		(0.044)	(0.019)	(0.018)	(0.021)
$\%LTE_{t-i}$		0.029***	0.040***	0.001	−0.039***
		(0.011)	(0.007)	(0.006)	(0.007)
Labor$\times\%HSPA_{t-i}$		0.018***	0.015***	0.002	0.023***
		(0.007)	(0.003)	(0.003)	(0.003)
Capital$\times\%HSPA_{t-i}$		−0.015***	−0.013***	−0.005***	−0.012***
		(0.003)	(0.001)	(0.001)	(0.002)
Labor$\times\%LTE_{t-i}$		0.001	0.0003	0.007***	0.009***
		(0.002)	(0.001)	(0.001)	(0.001)
Capital$\times\%LTE_{t-i}$		−0.007***	−0.005***	−0.005***	−0.002***
		(0.001)	(0.0005)	(0.0005)	(0.001)
Fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	1,057,446	1,057,446	849,974	838,851	643,077
R^2	0.876	0.876	0.884	0.914	0.898
Adjusted R^2	0.876	0.876	0.884	0.914	0.898
Residual Std. Error	0.441 (df = 1056375)	0.441 (df = 1056369)	0.413 (df = 848901)	0.397 (df = 837778)	0.387 (df = 642018)
Note:					*p<0.1; **p<0.05; ***p<0.01

D.2 Excluding firms in telecommunications sector

Table A6

	Dependent variable:					
	Sales					
i =	0	1	2	3	4	5
$\%HSPA_{t-i}$	-0.093^{***}	0.017	0.052^{***}	0.078^{***}	0.108^{***}	0.162^{***}
	(0.023)	(0.011)	(0.020)	(0.021)	(0.021)	(0.019)
$\%LTE_{t-i}$	-0.013^{**}	0.230^{***}	0.363^{***}	0.445^{***}	0.513^{***}	0.573^{***}
	(0.006)	(0.009)	(0.016)	(0.016)	(0.018)	(0.019)
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,087,720	880,880	906,744	826,338	751,817	681,186
R^2	0.228	0.237	0.244	0.250	0.255	0.258
Adjusted R^2	0.227	0.236	0.243	0.249	0.253	0.257
Residual Std. Error	1.304 (df = 1086659)	1.260 (df = 879822)	1.259 (df = 905686)	1.264 (df = 825282)	1.270 (df = 750766)	1.277 (df = 680141)
Note:						*p<0.1; **p<0.05; ***p<0.01

Table A7

	Dependent variable:				
	ValueAdded				
i=	Baseline	0	1	3	5
Capital	0.068^{***}	0.086^{***}	0.075^{***}	0.072^{***}	0.075^{***}
	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)
Labor	0.916^{***}	0.902^{***}	0.903^{***}	0.911^{***}	0.898^{***}
	(0.004)	(0.005)	(0.003)	(0.003)	(0.003)
$\%HSPA_{t-i}$		-0.035	-0.014	0.032^{*}	-0.093^{***}
		(0.043)	(0.018)	(0.018)	(0.019)
$\%LTE_{t-i}$		0.027^{***}	0.011^{*}	0.002	-0.019^{***}
		(0.008)	(0.006)	(0.006)	(0.007)
Labor$\times\%HSPA_{t-i}$		0.014^{**}	0.008^{***}	0.002	0.022^{***}
		(0.007)	(0.003)	(0.003)	(0.003)
Capital$\times\%HSPA_{t-i}$		-0.015^{***}	-0.006^{***}	-0.005^{***}	-0.011^{***}
		(0.003)	(0.001)	(0.001)	(0.001)
Labor$\times\%LTE_{t-i}$		0.001	0.006^{***}	0.007^{***}	0.007^{***}
		(0.002)	(0.001)	(0.001)	(0.001)
Capital$\times\%LTE_{t-i}$		-0.007^{***}	-0.006^{***}	-0.005^{***}	-0.002^{***}
		(0.001)	(0.0005)	(0.0005)	(0.0005)
Fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	1,087,720	1,087,720	906,744	826,332	681,186
R^2	0.899	0.899	0.907	0.912	0.918
Adjusted R^2	0.899	0.899	0.907	0.912	0.918
Residual Std. Error	0.441 (df = 1086659)	0.441 (df = 1086653)	0.406 (df = 905680)	0.397 (df = 825270)	0.387 (df = 680135)
Note:					*p<0.1; **p<0.05; ***p<0.01

D.3 Excluding firms in Stockholm county

Table A8

	Dependent variable:					
	Sales					
i =	0	1	2	3	4	5
$\%HSPA_{t-i}$	-0.070^{***}	0.032^{***}	0.073^{***}	0.100^{***}	0.129^{***}	0.178^{***}
	(0.018)	(0.012)	(0.019)	(0.020)	(0.021)	(0.021)
$\%LTE_{t-i}$	-0.014^{*}	0.210^{***}	0.331^{***}	0.413^{***}	0.476^{***}	0.535^{***}
	(0.007)	(0.010)	(0.018)	(0.017)	(0.017)	(0.018)
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	837,425	679,630	701,481	641,014	584,995	531,882
R^2	0.233	0.242	0.246	0.251	0.254	0.257
Adjusted R^2	0.232	0.241	0.245	0.249	0.253	0.256
Residual Std. Error	1.266 (df = 836384)	1.218 (df = 678595)	1.217 (df = 700443)	1.221 (df = 639980)	1.227 (df = 583966)	1.232 (df = 530862)
Note:						*p<0.1; **p<0.05; ***p<0.01

Table A9

	Dependent variable:				
	ValueAdded				
i=	Baseline	0	1	3	5
Capital	0.069^{***}	0.086^{***}	0.075^{***}	0.072^{***}	0.074^{***}
	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)
Labor	0.913^{***}	0.902^{***}	0.907^{***}	0.915^{***}	0.900^{***}
	(0.002)	(0.005)	(0.002)	(0.002)	(0.002)
$\%HSPA_{t-i}$		-0.012	0.044^{**}	0.086^{***}	-0.062^{***}
		(0.031)	(0.017)	(0.018)	(0.019)
$\%LTE_{t-i}$		0.039^{***}	-0.008	-0.018^{**}	-0.034^{***}
		(0.010)	(0.007)	(0.007)	(0.007)
Labor$\times\%HSPA_{t-i}$		0.012^{**}	0.0002	-0.007^{***}	0.016^{***}
		(0.005)	(0.003)	(0.003)	(0.003)
Capital$\times\%HSPA_{t-i}$		-0.015^{***}	-0.005^{***}	-0.003^{**}	-0.010^{***}
		(0.002)	(0.001)	(0.001)	(0.001)
Labor$\times\%LTE_{t-i}$		-0.002	0.007^{***}	0.009^{***}	0.008^{***}
		(0.002)	(0.001)	(0.001)	(0.001)
Capital$\times\%LTE_{t-i}$		-0.006^{***}	-0.005^{***}	-0.006^{***}	-0.002^{***}
		(0.001)	(0.0005)	(0.001)	(0.001)
Fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	837,425	837,425	701,481	641,008	531,882
R^2	0.901	0.901	0.908	0.913	0.919
Adjusted R^2	0.901	0.901	0.908	0.912	0.919
Residual Std. Error	0.421 (df = 836384)	0.421 (df = 836378)	0.389 (df = 700437)	0.380 (df = 639968)	0.370 (df = 530856)
Note:					*p<0.1; **p<0.05; ***p<0.01