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Firms and Households during the Pandemic: What do we learn from their electricity consumption?

Olympia Bover[1], Natalia Fabra[2], Sandra García-Uribe[1], Aitor Lacuesta[1], and Roberto Ramos[1]

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We analyze the impact of the COVID-19 pandemic on electricity consumption patterns in Spain. We highlight the importance of decomposing total electricity consumption into consumption by firms and by households to better understand the economic and social impacts of the crisis. While electricity demand by firms has fallen substantially, the demand by households has gone up. In particular, during the total lockdown, these effects reached -29% and +10% respectively, controlling for temperature and seasonality. While the electricity demand reductions during the second wave were milder, the demand by firms remained 5% below its normal levels. We also document a change in people's daily routines in response to the stringency of the lockdown measures, as reflected in their hourly electricity consumption patterns.

Keywords: electricity demand, economic activity, COVID, lockdowns.

[1] Bank of Spain
[2] Universidad Carlos III Madrid and CEPR

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Non-Technical Summary

Firms and Households during the Pandemic: What do we learn from their electricity consumption?

In this paper we investigate how electricity consumption patterns have changed during the COVID-19 pandemic. We focus on the Spanish economy, which has been one of the hardest hit by the COVID-19 crisis. Since electricity consumption has a strong correlation with economic growth, it has traditionally been used as an indicator of economic activity. However, as we show in this paper, changes in work and life habits triggered by the lockdown measures have implied a structural break in the relationship between electricity consumption and economic activity. In particular, we provide detailed evidence of a strong reduction in the amount of electricity consumed by firms, which was partly offset by an increase in the amount of electricity consumed by households. Therefore, to the extent that economic activity is better captured by firms' electricity consumption, using total electricity consumption would under-estimate the severity of the economic impacts of the pandemic.

We exploit one institutional feature of the Spanish electricity market in order to decompose total electricity consumption into consumption by firms and by households. In particular, different consumers, depending on their peak consumption and voltage, face different choices of types of electricity tariffs. We use publicly available information provided by the Spanish System Operator on hourly electricity consumed under the various tariffs, allowing us to estimate the consumption by firms and households. We show that quarterly GDP year on year growth rates are strongly correlated with our series for firms' consumption, particularly so during the pandemic.

We find that total electricity consumption fell substantially during the first wave of the pandemic, reaching declines of 18.2% under the total lockdown. Yet, the reduction in firms' demand was much stronger, 29.1% below its normal levels, which was partly offset by the increase in households' electricity demand, 9.6% above its normal levels. During the second wave, the reductions in electricity demand have been milder, which is explained by the less stringent lockdown measures in place. Yet, the 3% reduction in total electricity consumption masks a 4.8% decline in firms' electricity consumption, given that households' electricity consumption was still 2.4% above its normal level.

We also provide evidence of substantial changes in the hourly patterns of electricity consumption, which again differ across firms and households. In particular, we observe large declines in electricity consumption by firms during working times, which are paralleled by simultaneous increases in households' electricity consumption. We also find a morning and a late evening effect in households' demand patterns, i.e., a decline from 8am-9am and an increase from 9pm-10pm, seemingly indicating that people shifted to getting up and going to bed later than usual. Through the lens of households' electricity consumption, we can further assess how the stringency of the lockdown measures in place affected people's routines. For instance, the morning effect is no longer present when schools re-opened even if a vast majority of people were still under remote work. We also find that the pandemic affected people's holidays, as they seem to spend more time at home during the summer months than in previous years, an effect that is not explained by remote work. A similar effect can also be seen on Sundays during the total lockdown period.

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Olympia Bover,[a] Natalia Fabra,[b] Sandra García-Uribe,[a]
Aitor Lacuesta,[a] and Roberto Ramos[a]

[a]Bank of Spain
[b]Universidad Carlos III de Madrid and CEPR

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Abstract

We analyze the impact of the COVID-19 pandemic on electricity consumption patterns in Spain. We highlight the importance of decomposing total electricity consumption into consumption by firms and by households to better understand the economic and social impacts of the crisis. While electricity demand by firms has fallen substantially, the demand by households has gone up. In particular, during the total lockdown, these effects reached -29% and +10% respectively, controlling for temperature and seasonality. While the electricity demand reductions during the second wave were milder, the demand by firms remained 5% below its normal levels. We also document a change in people's daily routines in response to the stringency of the lockdown measures, as reflected in their hourly electricity consumption patterns.

Keywords: Electricity demand, economic activity, COVID, lockdowns.

JEL Codes: L94, Q43, Q54.

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1 Introduction

In this paper we investigate how electricity consumption patterns have changed during the COVID-19 pandemic. Since electricity consumption has a strong correlation with economic growth, it has traditionally been used as an indicator of economic activity (Kraft and Kraft, 1978; Henderson, Storeygard and Weil, 2012; Stern, 2018). However, as we show in this paper, changes in work and life habits triggered by the lockdown measures have implied a structural break in the relationship between electricity consumption and economic activity. In particular, we provide detailed evidence of a strong reduction in the amount of electricity consumed by firms, which was partly offset by an increase in the amount of electricity consumed by households. Therefore, to the extent that economic activity is better captured by firms' electricity consumption, using total electricity consumption would under-estimate the severity of the economic impacts of the pandemic.

We focus on the Spanish economy, which has been one of the hardest hit by the COVID-19 crisis (IMF, 2020; Banco de España, 2020).[1] Nevertheless, the changes in the electricity consumption patterns that we document should also be illustrative of the effects in other countries that have implemented similar lockdown measures, including travel restrictions, social distancing and shutdowns of non-essential businesses, schools and public offices. Indeed, the electricity demand reductions in other developed countries are similar in scale with those reported in this paper.[2]

Understanding the link between electricity consumption and economic activity has proven to be particularly relevant during the pandemic; for instance, to keep track of the state of the economy in real-time, to assess the trade-offs between health and economic issues when designing the lockdown and deescalation measures, or to assess the need to provide public support to firms and businesses to avoid closures and layoffs. However, there are good reasons to suspect that the link between electricity consumption and economic activity might now be weaker than previously thought. The link between the two had already become less strong before the pandemic - arguably, due to an improvement in energy efficiency and an increased weight of the service sector in the economy (Hirsh and Koomey, 2015; Buera and Kaboski, 2012; Metcalf, 2008) - but the pandemic might have weakened it more by changing the patterns of electricity consumption by firms and households. In the future, the likely increase in remote work (Dingel and Neiman,

[1] The IMF (2020) expects the Spanish economy to decline 12.8% in 2020, only comparable to Italy. Banco de España (2020) expects only a milder reduction, 12.6%.

[2] For instance, see Cicala (2020*a*) and Fezzi and Fanghella (2020) for Italy, Benatia (2020*b*) for France, or Leach, Rivers and Shaffer (2020) for Canada. McWilliams and Zachmann (2020) provide a tracker of electricity consumption at various countries in 2020 relative to 2019.

2020), the deployment of on-site rooftop solar installations and electric vehicles, or the improvement in energy efficiency (Davis, 2017; Stern, 2018) might further confound the link between metered electricity consumption and economic activity. These trends do not cast doubt on the usefulness of electricity data to measure economic activity, but rather call for revisiting the link between the two.

In this paper we argue that a key step to do so is to decompose electricity consumption by firms and by households. Whereas the former is mostly unambiguously correlated with economic activity, the latter might be either negatively or positively correlated with economic activity. For example, households' consumption might increase due to unemployment (at least in the short-run) or due to an increase in remote work. However, the data needed to decompose total electricity consumption across consumer types is typically not available close to real time, which is when the use of electricity data as a proxy for economic activity is more valuable relative to other indicators.

We exploit one institutional feature of the Spanish electricity market in order to decompose total electricity consumption into consumption by firms and by households. In particular, different consumers, depending on their peak consumption and voltage, face different choices of types of electricity tariffs. For instance, only households (and SMEs) have the right to be supplied at last resort rates, while only firms have the right to access the wholesale electricity market directly. In this study, we use publicly available information provided by the Spanish System Operator on hourly electricity consumed under the various tariffs, allowing us to estimate the consumption by firms and households.[3] To check the validity of our proposed decomposition, we compute the correlation of our estimated series with other data sources that should correlate positively with firms' and households' actual electricity consumption data. In particular, we show that our series for households' consumption data has a strong correlation with TV News audience and with Google's Residential Community Mobility Index, which measures the time people spend at home (Google, 2020). Moreover, we show that quarterly GDP year on year growth rates (INE, 2020) are strongly correlated with our series of firms' consumption (and not so with households' consumption), particularly so during the pandemic.

This study measures the effects of the pandemic on electricity consumption patterns. For that purpose, our empirical analysis captures the departure of (daily or hourly) electricity consumption from what one would predict using previous years' data, while controlling for temperature and seasonality. The daily analysis allows highlighting the diverging trends of firms' and households' electricity consumption during the pandemic.

[3]There is not a one-to-one mapping between users and tariffs given that a vast amount of consumers are supplied under a tariff that is available to both firms and households.

In turn, the hourly analysis allows uncovering changes in electricity consumption patterns of firms and households across the day and across the week, depending on the stringency of the lockdown measures.

We find that total electricity consumption fell substantially during the first wave of the pandemic, reaching declines of 18.2% under the total lockdown. Yet, the reduction in firms' demand was much stronger, 29.1% below its normal levels, which was partly offset by the increase in households' electricity demand, 9.0% above its normal levels. During the second wave (from mid August 2020 until the end of the year), the reductions in electricity demand have been milder, which is explained by the less stringent lockdown measures in place. Yet, the 2% reduction in total electricity consumption masks a 4.0% decline in firms' electricity consumption, given that households' electricity consumption was still 2.1% above its normal level. It is unclear whether this is due to a slower rate of economic activity and/or due to an increase in remote work. Nevertheless, this asymmetry is reflective of the change in electricity consumption patterns during the pandemic.

In the Spanish case, the evidence shows a strong correlation between the growth rate of firms' electricity consumption and quarterly GDP. However, in general it is not possible to perfectly map the change in electricity consumption by firms with the decline in economic activity. The reason is that some of the economic activity that used to take place at the workplace has now shifted to the household. Hence, our proposed demand decomposition can be seen as providing bounds to the fall in economic activity: the decline in firms' demand provides an upper bound (as if no activities had shifted to the households) and the decline in total electricity consumption provides a lower bound (as if all the increase in households' demand were due to remote work). Nevertheless, it is important to point out that not all activities that can move into remote work are equally energy intensive. Furthermore, the amount of energy consumed at the workplace and at home for the same amount of work need not be the same. Hence, it is unlikely to find a one-to-one correspondence between the reduction in firms' consumption and the increase in households' consumption.

We also provide evidence of substantial changes in the hourly patterns of electricity consumption, which again differ across firms and households. In particular, we observe large declines in electricity consumption by firms during working times, which are paralleled by simultaneous increases in households' electricity consumption. During the first half of the year, we find a morning effect in households' demand patterns, i.e., a decline from 8am to 9am. This morning effect is no longer present when schools re-opened after the summer, even if a vast majority of people were still under remote work. Yet, this is

paralleled by a late evening effect, with people reducing their electricity consumption at 11pm, probably because they were going to bed earlier. This indicates that the lockdown measures may have led to longer sleeping times, in line with what is reported for other countries (Lee, Marek and Nálevka, 2020), with potential positive impacts on health outcomes and labour productivity (Marco Hafner and Stolk, 2016). We also find an increase in electricity consumption at lunch and dinner times in Spain (i.e., from 2pm to 3pm and from 8pm to 9pm), which is consistent with people cooking at home rather than eating out. Likewise, we also find that the pandemic affected people's holidays, as they seem to spend more time at home during the summer months than in previous years, an effect that is not explained by remote work. A similar effect can also be seen on Sundays during the total lockdown period.

Related Literature The impact of the pandemic on the power sector has attracted the attention of several institutions and scholars worldwide (Benatia, 2020*a*,*b*; Cheshmehzangi, 2020; Cicala, 2020*a*; Fabra, Lacuesta and Souza, 2020; Fezzi and Fanghella, 2020; Leach, Rivers and Shaffer, 2020; Ghiani et al., 2020; Ruan et al., 2020). These studies focus on measuring the declines of electricity consumption and the consequences for the performance of electricity markets in various countries. However, they all look at aggregate consumption figures without decomposing demand by firms and households.

We are aware of only two other papers focusing on the impacts of the pandemic on households' electricity consumption. Cheshmehzangi (2020) conducted a survey among 352 Chinese households to understand their energy use during the pandemic. Results suggest strong impacts on cooking and entertainment, heating/cooling and lighting, which translated into an increase in households' electricity demand. In simultaneous work with ours, Cicala (2020*b*) analyzes the distinct impacts of COVID on households' and firms' electricity consumption. Our works mainly differ in the time frame, data type and coverage.[4] He also reports an increase in households' consumption paralleled by a reduction in firms' consumption, but finds different effects on the hourly consumption patterns. The longer span of our hourly data during the pandemic allows us to assess how those patterns responded to changes in the stringency of the lockdown measures, thereby reflecting changes in people's daily routines.

The remainder of the paper is organized as follows. In Section 2 we describe our

[4]Whereas we use nation-wide publicly available hourly data from Spain for the period 2015-2020 (with a focus on 2020 to assess the impacts of the pandemic), he uses proprietary data from Texas. For households, he uses smart meter hourly data for a subset of customers from Q1 2019 to Q2 2020 (with a focus on April-May 2020 to assess the impacts of the pandemic); for firms, he uses monthly billing data dating back to 2016.

data, as well as our proposed method to decompose aggregate electricity demand into demand by firms and by households. In Section 3 we describe the lockdown measures that were put in place in Spain. In Section 4 we perform our econometric analysis, analyzing both the evolution of daily demand across time as well as the changes in hourly demand patterns by firms and by households. Last, Section 5 concludes.

2 Decomposing Total Electricity Demand

We want to explore the behaviour of Spanish households and firms during the pandemic, as reflected in their electricity consumption. However, while we have hourly electricity demand data (from 2015 until 2020), we cannot distinguish the consumption by firms from that of households. We therefore need to resort to other data sources to decompose aggregate electricity demand into the demand by firms and households. In particular, we use information on the type of tariff or market access that consumers are subject to, in order to infer whether they should be classified as either firms or households.[5]

In the Spanish electricity market, there are three options for buying power: (1) at default rates, (2) in the retail market, or (3) through direct market access. The first option is only available to households; in particular, only those households with a contracted capacity below 10kW have the choice of buying electricity at the so-called Voluntary Price for the Small Consumer,[6] which is computed as a pass-through of the hourly wholesale electricity prices. The second option, which is to buy electricity in the retail market at the prices offered by the electricity retailers, is available for both firms and households, regardless of their size. Using 2019 data, 95.2% of the buyers in the retail market are households, 4.2% are SMEs and 0.6% are large industrial consumers.[7] According to this data, in 2019 61% of all households bought electricity in the retail market. This number increased to 99% for firms. Last, while the third option is available for all consumers, only large firms decide to buy directly at the wholesale market given the large transaction costs involved.

[5]These data are provided by the Spanish System Operator, and they are publicly available through its website (Red Eléctrica de España, 2020). We use the series I3DIA02. The information is available after three days, showing the result of the P48 Schedule.

[6]More specifically, 99.9% of the users subject to the Voluntary Price for the Small Consumer are households. The remaining 0.1% are small and medium enterprises (SMEs).

[7]These data are provided on a quarterly basis by Comisión Nacional de los Mercados y la Competencia (2020). It provides the number of users of each type (either households, SMEs, or industrial buyers) and the number of users who buy electricity at either the default rates or in the retail market. The latest data available at the time of writing this paper belong to Q1-Q4 2019.

Hence, all the electricity that is bought at the default rates can be classified as demand by households, while all the electricity that is bought through direct market access can be classified as demand by firms. It thus remains to decompose the retail market demand into demand by firms and by households. For this purpose, we assume that the average consumption of households is the same regardless of whether they choose to buy electricity at the default rate or in the retail market. This assumption would not be adequate if the characteristics of those households selecting into either option differed substantially. However, the evidence indicates this is not the case. For instance, Fabra et al. (2021) show that the observable characteristics of the households in these two groups are the same on average. This is consistent with survey data showing that 77% of the Spanish households are unaware of the differences between the two options, with 64% of them declaring not to know which one they are subject to.[8]

Let us use D_j^i to denote total electricity demand of households ($i = H$) or firms ($i = F$) who buy electricity at the default rates ($j = 1$), in the retail market ($j = 2$), or through direct market access ($j = 3$). We can thus decompose the demand under each type of access $j = 1, 2, 3$ as $D_j = D_j^H + D_j^F$. Likewise, let N_j denote the number of household users under each type of access j, with $N_1, N_2 > 0$ and $N_3 = 0$. It thus follows that

$$D^H = D_1^H + D_2^H = D_1 \left(1 + N_2/N_1\right)$$

where we have used the fact that all the consumers under the default rates are households, $D_1 = D_1^H$, and the fact that households have no direct market access, $D_3^H = 0$, together with the assumption that the average consumption of households in the two first groups is the same, i.e., $D_2^H = (N_2/N_1)D_1^H$.[9]

It follows that the electricity demand of firms can be constructed as

$$D^F = D_2^F + D_3^F = D_2 - (N_2/N_1)D_1 + D_3$$

where we have used the fact that $D_3^F = D_3$.

2.1 How good is our proposed decomposition?

How good is our proposed decomposition of total demand into the demand by firms and households? In panels A and B of Figure 1, we have gathered information on electricity consumption by type of tariff, distinguishing between those tariffs that are available for

[8] See the Comisión Nacional de los Mercados y la Competencia (2019)'s household panel on electricity and gas, corresponding to Q2 2019.

[9] Using 2019 data, this ratio equals 1.61.

households (low voltage) and those that are available to firms (high voltage). These data are available on a daily basis from 2015 to the third quarter of 2019 (Red Eléctrica de España, 2020). We can see that our series capturing electricity demand by firms (panel A) and households (panel B) follow an almost one-to-one correlation with the demand at high and low voltage, respectively.

In panel C of Figure 1 we further explore the accuracy of the household electricity demand series by looking at the correlation with daily data television viewership. The latter is calculated with information on the number of viewers of the most watched evening news broadcast and its audience share.[10] We exclude the data points corresponding to July and August, since they fall within the peak of the holiday season. The figure shows a high correlation (0.53) between our estimated household power demand data and television viewership.

Last, in panel D of Figure 1 we explore the correlation between households' electricity demand and Google's Residential Community Mobility Index, which measures the time people spend at home with respect to a *normal* day.[11] Based on the time spent at certain places, the daily change in mobility is computed with respect to the median value of that day of week between January 3 and February 6, 2020. The figure shows a strong positive correlation (0.83) between our estimated households' electricity consumption data and the time people spend at home between March 14 (when the partial lockdown starts) and June 15 (when the new normal starts). Overall, we take the strong positive correlations between our estimated households' demand and the various measures as an indication of the validity of our decomposition.

Using our proposed decomposition, Figure 2 plots the relationship between the electricity demand by firms and households, on a daily basis before (panel A) and during (panel B) the pandemic. While the correlation between the two series before the pandemic is small (0.01), it turns negative (-0.38) during the pandemic. This suggests that the lockdown measures have moved electricity demand by firms and households in opposite directions.

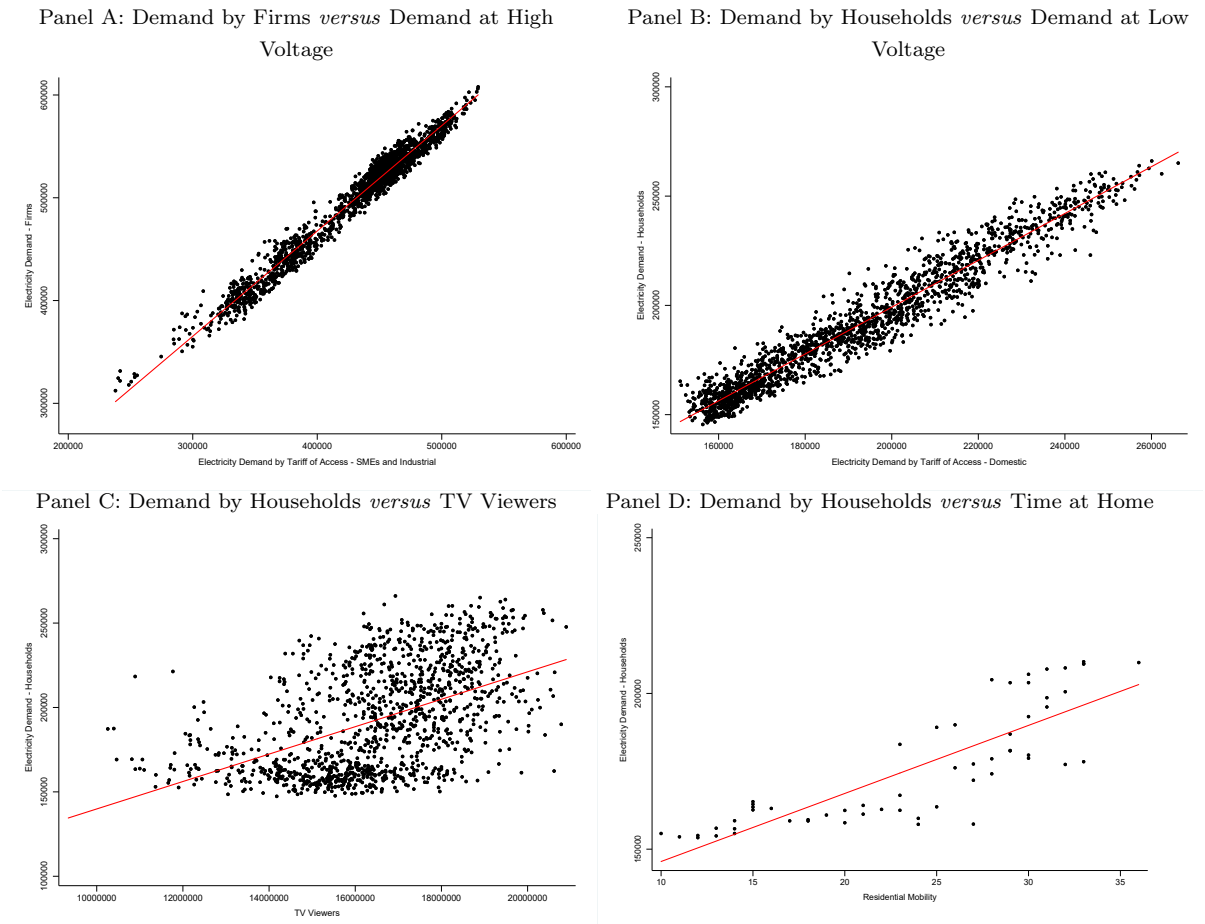
2.2 Electricity demand and GDP growth rates

This negative relationship between the two series suggests the importance of decomposing electricity consumption into the consumption by firms and households to obtain a good

[10] The data source is Vertele! (2020). These data are available on a daily basis (with gaps) since late 2010.

[11] The data source is Google (2020). They are available on a daily basis since mid-February 2020, both for European countries as well as for the US.

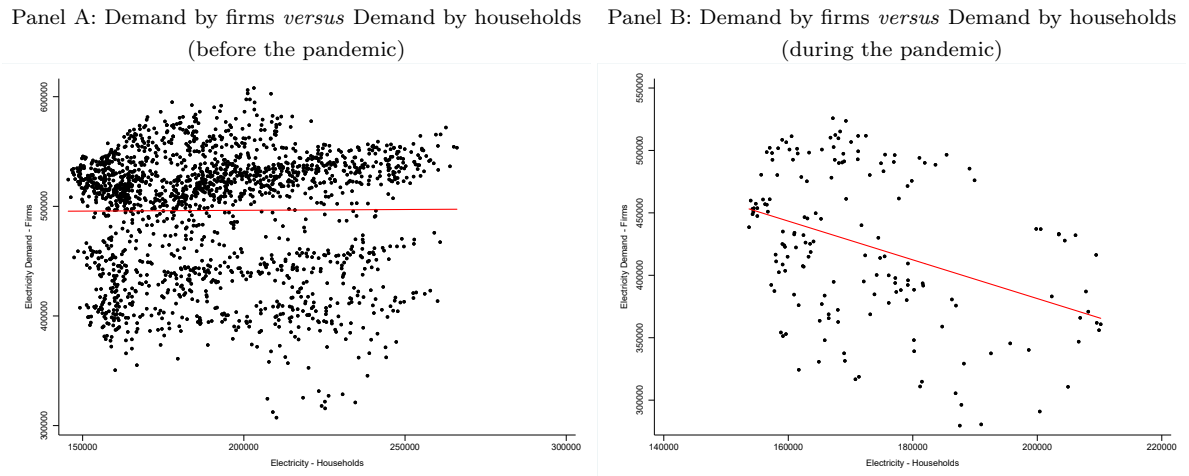
Figure 1: Accuracy of the estimated firms' and households' electricity demand series



Notes: Panels A to C provide evidence about the accuracy of our proposed decomposition of aggregate electricity demand into demand by firms and households. Panels A, B and C reflect daily data, starting on January 2015 and ending either on September 2019 (panels A and B), or on July 2020 (panel C) . Panel A shows the correlation between the electricity demand by firms and the electricity demand at high voltage. Panel B shows the correlation between the electricity demand by households and the electricity demand at low voltage, while Panel C shows the correlation with TV audience. Last, panel D illustrates the correlation with the time people spend at home. It uses weekdays (excluding holidays) from March 14 until June 15, 2020.

proxy for economic activity. Indeed, Figure 3 plots the relationship between the growth rate of the three series and GDP on a quarterly basis. Before the pandemic, the growth rates of electricity consumption by firms and households were similar, both being slightly below GDP growth. The Spanish System Operator has already documented that, since 2014, total electricity consumption has been growing at a lower pace relative to GDP (Red Eléctrica de España (2019)). They attribute this to several factors, including improvements in energy efficiency and electricity price increases. Our decomposition further reveals that, between 2016 and 2020, electricity consumption has added some noise to the evolution of total electricity consumption, as it has been more volatile than that of

Figure 2: Relationship between the estimated firms' and households' electricity demand



Notes: Panel A reflects daily data, starting on January 2015 and ending on February 14, 2020. Panel B starts on February 15 and ends on November 1; the summer period (July and August) is excluded.

firms. Nevertheless, the most striking lesson of the figure is that during the pandemic, electricity consumption by firms has fallen down at the same rate as Spanish GDP. This is in contrast to the electricity consumption by households, which has started to grow at the same time as electricity consumption by firms collapsed. As a consequence, the fall in total electricity consumption has underestimated the fall in GDP. In sum, this evidence suggests that firms' electricity consumption is a better indicator for economic activity during the pandemic, as total electricity consumption is biased by the diverging behaviour of households' consumption.

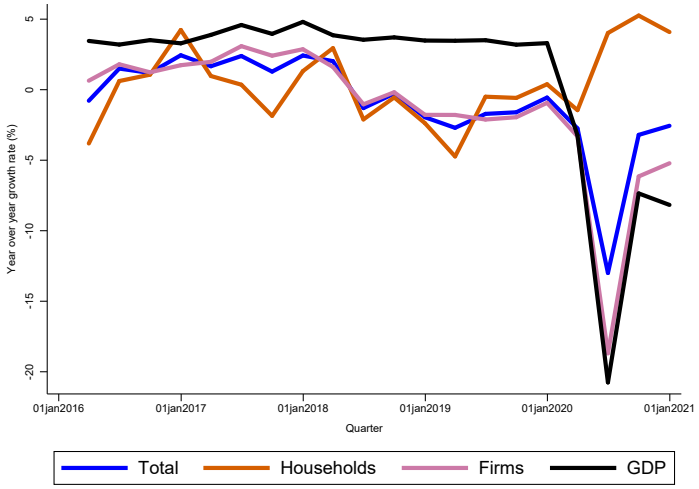
In the following sections we analyze the recent evolution of the three electricity consumption series. Before we do so, we turn to describing the various lockdown measures that have been put in place in Spain.

3 Lockdown Measures

Similarly to most countries, several lockdown measures have been put in place in Spain during the COVID19 pandemic. Table 1 lists such measures.

Starting Monday, March 9 2020, some regional governments started to close down

Figure 3: Growth rates of the estimated firms' and households' electricity demand and GDP



Notes: This figure shows quarterly year over year growth rates, starting in Q1 2016 and ending in Q4 2020. The blue, pink and orange lines represent the growth rates of total electricity consumption, electricity consumption by firms and households, respectively, in the Spanish electricity market. The black line represents Spanish GDP growth.

kindergartens, schools and universities.[12] These measures were first supposed to last for 15 days. However, on Saturday March 14, the Spanish government approved the state of alarm in order to centralize all decisions regarding the sanitarian crisis. It also decided to close down most retail shops, hotels, and restaurants, as well all to cancel all sport events and recreational activities. Groceries and health centers were the only establishments allowed to stay open.[13] Moreover, strict mobility restrictions were imposed, only allowing people to go to work and to buy first necessity products. On Monday March 29, those restrictions were strengthened, leading to a total lockdown of businesses other than those considered to be of first necessity,[14] or those that could rely on remote work. The total lockdown lasted until the end of Easter, on April 10.

During the following month, the economy remained under a similar lockdown as the

[12]On March 9 2020 the Basque government closed all schools in La Bastida and some in the city of Vitoria. On the 10th, these measures were extended to all schools in Vitoria. The regional government of Madrid and La Rioja approved on March 9 the closing of all schools in their regions to be effective on Wednesday March 11. On Thursday 12 it was approved in Cataluña, Canarias, Castilla La-Mancha, Asturias and the rest of País Vasco, to be effective on Friday 13, while the rest of regions closed schools on Monday 16.

[13]Article 10 in RDL 463/2020 listed the exceptions to this rule: food; beverages; first necessity products; pharmaceuticals; medical, optical and orthopedic products; hygiene products; hairdressers; press; automotive fuel; tobacco; technological and telecommunications equipment; pet food; establishments related to e-commerce or distribution by phone or mail; dry cleaners and laundries.

[14]The annex of RDL 10/2020 defined the meaning of 'first necessity'.

one that was initially imposed on March 14. From then onward, the government put in place deescalation measures, organized in three phases, until reaching the so-called *new normal* on June 21. It was then when Madrid, Cataluña and Castilla León reached the last phase. The different phases differed in the degrees of stringency regarding mobility and businesses operations. On a regional basis, the decision to move from one phase to the next was based on the number of cases detected and the occupancy of the ICUs.

During the new normal, only mild restrictions were imposed. Establishments were required to guarantee the minimum interpersonal distance of 1.5 meters, and the use of masks became compulsory. On August 14, the risk of a second wave led the national and regional governments to agree on additional restrictions for bars, restaurants and recreational activities.[15] On the other hand, schools and universities re-opened under some restrictions. On October 25, after an increase in the number of cases, a second state of alarm was declared. Domiciliary confinement was imposed between 10pm and 7am, which obliged to readjust the closing time of shops, bars and restaurants. Mobility across regions was banned and regions were allowed to impose additional restrictions between districts or municipalities, depending on the incidence of the pandemic as well as on the capacity of their hospital facilities. The state of alarm lasted until May 9, 2021.

4 Predictive Impact of the Pandemic on Electricity Consumption

To provide a formal analysis of the evolution of daily electricity consumption after March 2020, our sample spans from January 1 2015 until December 31 2020. Using information up to December 31 2019, we first estimate the following equation in order to control for low frequency demand shifters, temperature and holiday differences:

$$\ln(q_{dt}) = \rho + \beta\tau_t + \beta_2\tau_t^2 + \gamma_t + \epsilon_{dt} \tag{1}$$

where $_{dt}$ is daily electricity consumption, γ_t includes time fixed effects (year and month of the year) and holiday indicators,[16] and τ_t is the average (weighted by electricity demand at the province level) of the maximum temperature within a day. We then average out all

[15] In particular, regions agreed the closure of discos and dance halls. The closing time of terraces and restaurants was set at 1am, without being able to admit new clients after midnight.

[16] Holiday indicators are constructed in such a way that we include a 1 when there is a national holiday and for the Christmas period beginning on the 24th of December and finishing on the 31st of December. Regional holidays are weighted by the regional electricity consumption, as kindly provided to us by Red Eléctrica de España (REE).

Dates	Lockdowns	Legal documentation
March 11-13, Wednesday-Friday	Schools closed (starting in Madrid and La Rioja)	Regional legal texts
March 15 , Sunday	Partial lockdown (retail, hostel, restaurant, recreation)	RD 463/2020
March 29, Sunday	Total lockdown (non essential, non-work from home)	RDL 10/2020
April 10, Friday	Partial lockdown (retail, hostel, restaurant, recreation)	RDL 10/2020 (art. 2)
May 11, Monday	Beginning deescalation (Phase I applied to Canarias, Baleares, Galicia, Asturias, Cantabria, País Vasco, La Rioja, Navarra, Aragón, Extremadura y Murcia, Andalucía except for Granada and Málaga, and Castilla la Mancha only in Cuenca and Guadalajara)	SND/399/2020
May 18, Monday	Ongoing deescalation (Phase I applied to all regions but Madrid, metropolitan area of Barcelona, and some regions in Castilla y León and Phase II applied to some islands - El Hierro, La Gomera, La Graciosa, Formentera)	SND/414/2020
May 25, Monday	Ongoing deescalation (Phase II applied to those in phase I the 11 of May and phase I rest)	SND/458/2020
June 1, Monday	Ongoing deescalation (Phase II applied to all regions but Madrid, and some regions in Cataluna, Castilla y León, Phase III applied to some islands - El Hierro, La Gomera, La Graciosa, Formentera)	RDL 21/2020
June 8, Monday	Ongoing deescalation (Phase III applied to all regions but Madrid, and some regions in Catalunya, Castilla y León, Castilla la Mancha and Comunidad Valenciana)	
June 15, Monday	Ongoing deescalation (new normal in Galicia, phase III applied to all regions but Madrid, metropolitan area of Barcelona, Lleida and some regions in Castilla y León)	
June 21, Thursday	New normal	SND/458/2020
August 14, Friday	Second wave	Central government and regions agreement
October 25, Sunday	Partial lockdown (nights, movements across regions)	RDL 926/2020 and renewal RDL 956/2020

Table 1: Different lockdown measures in Spain

the residuals happening in a particular day of the week during the pre-lockdown period, i.e., $\tilde{\epsilon}_d$, for d running from Monday through Sunday before January 1, 2020. Finally, for days belonging to the lockdown period, we compare out of sample estimated residuals in each particular day of the week with those of the same day of the week during the pre-lockdown period. For example, for Wednesday April 1, we plot the difference between $\hat{\epsilon}_{dt}$ for dt= Wednesday April 1, minus $\tilde{\epsilon}_d$ for dt=Wednesday prelockdown. Quantitatively, if this difference equals -10 on Wednesday April 1, it means that electricity consumption was 10% lower as compared to a typical pre-pandemic Wednesday, controlling for temperature, year, month and holiday differences.

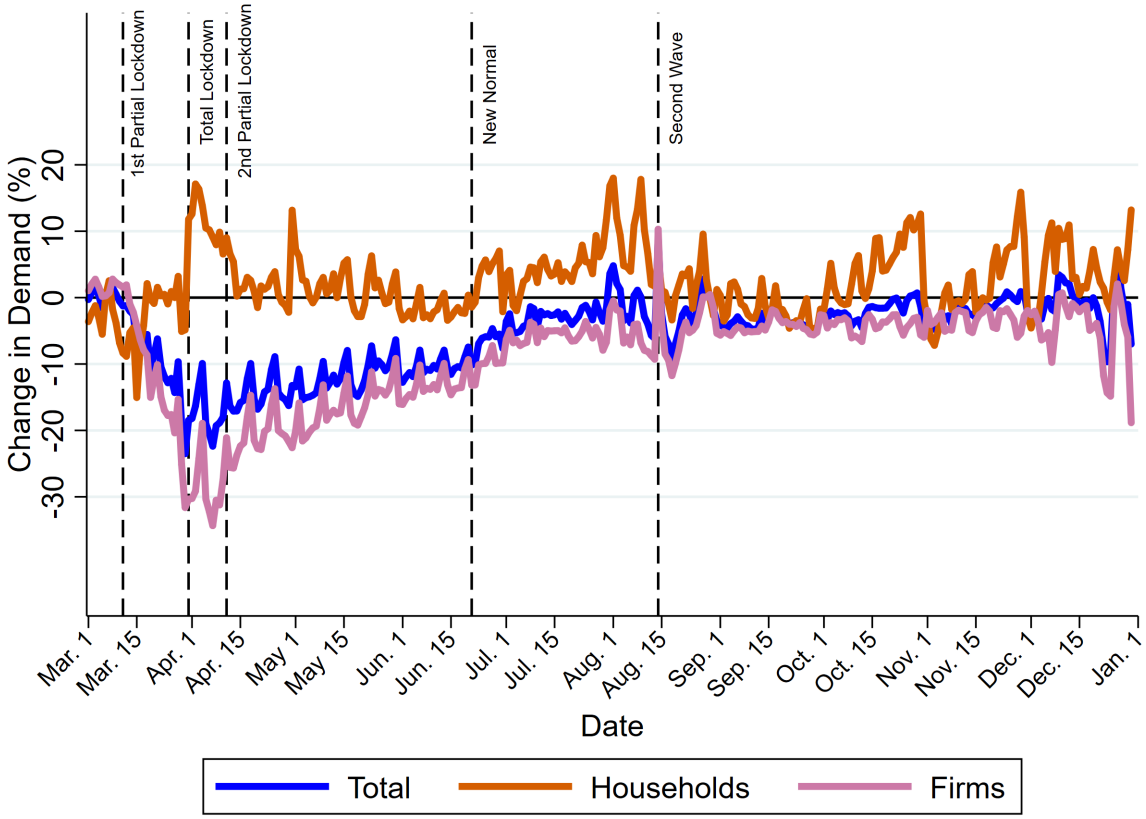
Figure 4 plots the estimated percentage change in electricity consumption (total, by firms or by households), and Table 2 summarizes the results.

4.1 Total electricity consumption

The stringency of the various lockdown measures had a strong effect on total electricity consumption (depicted in blue in the figure, and displayed on the first column of the table). Before March 10, electricity consumption was slightly higher than what the model would have predicted, although differences are not statistically significant. On average, during the first ten days of March, electricity consumption was 0.41% higher than the corresponding prediction. After March 10, when the first lockdown measures were introduced, electricity consumption started to decline. The partial lockdown that started on March 11 strengthened the declining trend down to a 7.27% reduction on average. By Monday March 30, electricity consumption had fallen sharply - by as much as 18.96% - and remained around that level until the end of the total lockdown on April 10. The average fall during the total lockdown (between March 29 and April 10) was 18.15%.

After that date, electricity consumption started to recover, but the recovery was more gradual than the fall initially observed in March. On average, electricity consumption during the first week of May showed a 14.04% decline as compared to the pre-crisis levels. This slow recovery towards the pre-crisis consumption levels was the norm along the deescalation. During the first two weeks of June, electricity consumption was 10.69% lower than before the crisis. Once the new normal came into play, electricity consumption rapidly went back close to its predicted level. Despite the new restrictions that were introduced on August 14, electricity consumption remained close to the predicted level during the second wave. Indeed, during this period, electricity consumption decreased by 2.26% on average.

Figure 4: The impact of the various lockdown measures on electricity consumption



Notes: This figure shows the estimated percentage change in total electricity consumption as compared to what the model would have predicted with 2015-2019 data. The effect on total electricity consumption appears in blue, on households' consumption in orange, and on firms' consumption in pink.

4.2 Electricity consumption by firms and households

Due to the economic crisis and the lockdown, several firms have gone bankrupt and others have temporarily ceased their activity, leading to permanent or temporary worker lay-offs. This should have reduced the electricity demand by firms while increasing the electricity demand by households. Therefore, because of this countervailing effect, using aggregate electricity consumption as a proxy for economic activity might under-estimate the true economic impact of the pandemic. Yet, other firms that have remained active have shifted their workers to remote work, which is expected to show up as an increase electricity demand by households. Hence, the true economic impact probably lies somewhere in between the impact on the electricity demand by firms and by households, but certainly below the reduction in aggregate electricity demand.

For this reason, in this section we decompose the effects of the lockdown measures on electricity demand by firms and households, separately. Results are shown in Figure 4

	Total	Firms	Households
Pre-Lockdown			
(March 1 - March 10)	0.50	1.29	-1.69
	(0.85)	(0.96)	(1.46)
1st Partial Lockdown			
(March 11 - March 28)	-7.27***	-9.17***	-3.00***
	(0.63)	(0.71)	(1.08)
Total Lockdown			
(March 29 - April 10)	-18.15***	-28.82***	9.05***
	(0.81)	(0.91)	(1.39)
2nd Partial Lockdown			
(April 11 - June 20)	-12.26***	-16.86***	0.81***
	(0.32)	(0.36)	(0.55)
New Normal			
(June 21 - August 13)	-3.19***	-6.41***	5.37***
	(0.37)	(0.41)	(0.63)
Second Wave			
(August 14 - December 31)	-2.27***	-4.11***	2.06***
	(0.23)	(0.26)	(0.40)
Observations	2,185	2,185	2,185

Table 2: The impact of the various lockdown measures on electricity consumption

Notes: This table shows the estimated percentage change in total electricity consumption as compared to what the model would have predicted with 2015-2019 data. The coefficients and standard errors are obtained by regressing the daily differences on indicators for each lockdown period.Significance at 10%, 5%, and 1% is indicated by *, **, and ***, respectively.

(in pink and orange, respectively) and Table 2 (second and third columns of the table). According to the estimated effects, the level of electricity consumption by households remained close to the predictions of the model during March. Indeed, during the first partial lockdown, households even dropped their electricity consumption by 3.00% relative to what one would expect at the counterfactual. However, during the total lockdown period, people had to stay at home, which translated into a sharp increase in households electricity consumption, i.e., 9.04% above the counterfactual. During the deescalation, households' electricity consumption remained slightly above the counterfactual (again, approximately 0.81% over the pre-crisis levels). It is interesting to see that after Monday June 22 and up to Friday August 14, households' electricity consumption jumped again.

Indeed, during the first half of August, on average, it remained around 10% above the pre-crisis levels. This is consistent with people spending more time at home during the summertime as compared to previous years. Afterwards, households' consumption stabilized at around the pre-crisis level up until October 15, and it then started to increase again during the second wave, reaching a 4% raise on average above the pre-crisis level despite big fluctuations during this period.

Electricity demand by firms is almost a mirror image of that of households. According to the estimates, during the first half of March, the demand by firms behaved similarly to what one would expect with 2015-2019 data. During the partial lockdown that started on March 11, it initiated a decreasing trend. This effect was slightly higher than that on total electricity consumption, given the mild drop in households' consumption. The total lockdown made things worse, leading to a fall in the electricity demand by firms of 31.66% by March 31. This low level was maintained up to April 10. The week after the total lockdown, the electricity demand by firms started to gradually recover, yet reaching a level that was 23.94% below the pre-crisis level. It remained low until the start of the deescalation on May 11. From that moment onward, there was a partial recovery of firms' electricity demand, which nevertheless remained below its normal level. For instance, on June 21, it was 9.33% lower than expected. The new normal pushed firms' electricity demand to a level -6.49% on average, and by the end of August it fluctuated between 0 and -5% below its normal level. Electricity demand by firms remained around -5% up to December, when it recovered the pre-crisis level. However, Christmas holidays led to a sharp decline in electricity demand. Indeed, the average consumption by firms was 20% below its pre-crisis level between the 24th and the 31st of December.

We conclude this section by providing further evidence on the drivers of increased households' electricity consumption up to Q3 2020. In particular, we have obtained TV audience data at three different times corresponding to the daily News (8-9am, 3-4pm and 9-10pm), during weekdays.[17] We identify the normal audience at each day and time using a similar model as the one we used for electricity demand, see equation (1). In particular, the model incorporates year, month, and day dummies, as well as temperature and holidays. Figure 5 plots the estimated percentage change in TV audience with respect to the normal audience. As it is clear from the figure, more households turned on the TV during the first days of confinement at news broadcasts. From that moment

[17]The data source ObjetivoTV (2020). Our dataset contains daily information on the number (and share) of TV viewers watching a particular TV program at a particular time. We consider the news programs of a channel (leader in that type of program) in the usual three tranches during the day. We divide the number of people watching those programs by the corresponding share to obtain the total number of people watching TV at a particular time of the day.

onward, audiences in the afternoon and evening remained abnormally high, although they converged towards their normal level by the end of June[18]. This is in line with our estimates of households' electricity demand, as both pieces of evidence are consistent with people spending more time at home due to the lockdown measures. On the contrary, TV audiences during the morning were abnormally low during the lockdown. In turn, this is consistent with people getting up later as kids did not have to go to school and adults could work remotely, thus replacing commuting times with extra sleep.[19] During the summer, the audience raised again in the afternoon and evening, and it dropped again after September. During the second wage the audience in the afternoon and evening was still 10% above its normal level. On the contrary, in September, when schools re-opened, the morning audiences jumped back to normal. These findings suggest that a finer analysis of the changes in electricity demand at an hourly level would also reflect changes in peoples' habits during the pandemic. We turn to this issue next.

4.3 Analysis of hourly data

In this section we analyze the hourly demand response to the various lockdown measures. To this end, we exploit differences in hourly electricity consumption across the day during the lockdown period as compared to the average electricity consumption of the same average day of the week in the pre-lockdown period. We use a similar model than the one used in the previous sections but making extensive use of hourly data:

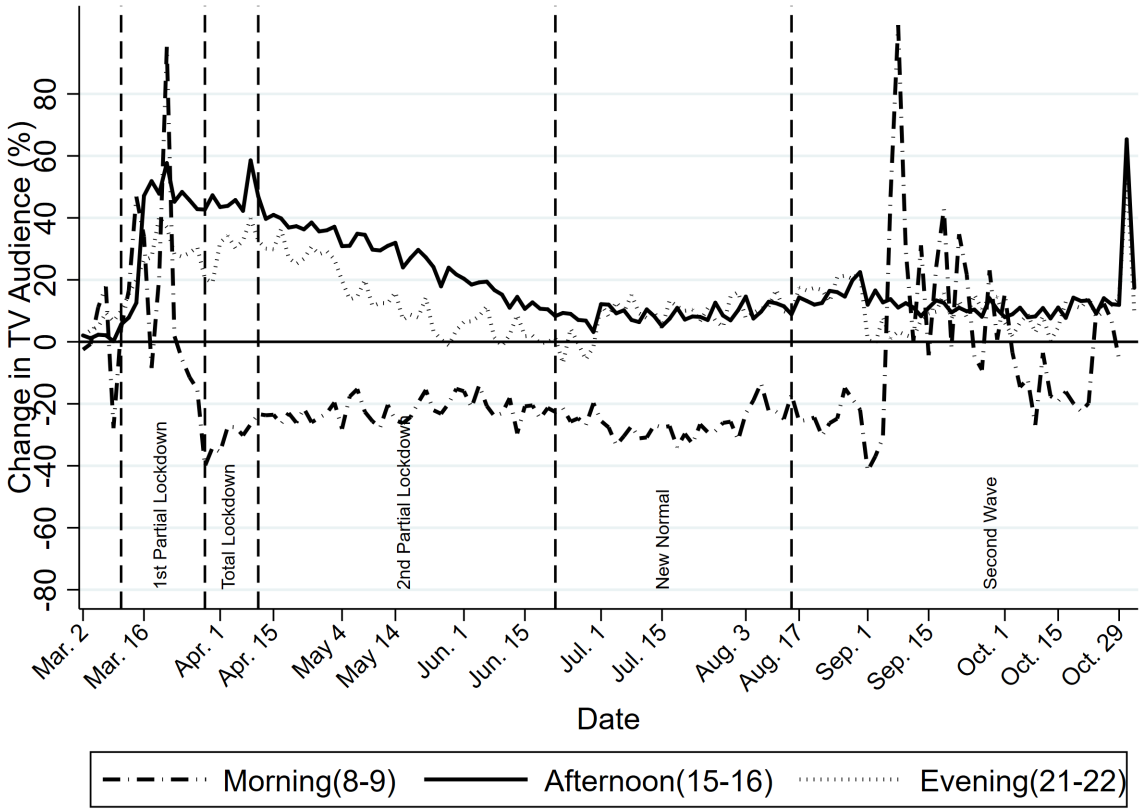
$$\ln(q_{hdt}) = \rho + \beta\tau_t + \beta_2\tau_t^2 + \gamma_t + \epsilon_{hdt} \tag{2}$$

where similarly to (1), $_{hdt}$ is hourly electricity consumption, γ_t includes time fixed effects (year and month of the year) and holiday indicators, and τ_t is a weighted average of the maximum temperature within a day in each province. We then average out all the residuals happening every single hour h in each particular day d of the week during the pre-lockdown period, i.e., $\tilde{\epsilon}_{hdt}$, for d running from Monday through Sunday before March 10. For the averaging, we consider two subsets within the year: winter days (from the last Sunday in October to the last Sunday in March the following year) or summer days (from the last Sunday in March to the last Sunday in October each year). Finally, for days belonging to the lockdown period we compare the residuals in each particular hour with the average of the residuals for that same hour and day of week during the

[18]Nevertheless, we recognize that there are other reasons why TV audiences might be higher between April and June. For instance, people might be particularly eager to be informed about the sanitarian developments.

[19]The analysis of hourly patterns presented in the next section is consistent with this finding.

Figure 5: The impact of the various lockdown measures on TV audience



Notes: This figure shows the estimated percentage change in total audience as compared to what the model would have predicted with 2016-2019 data. The effect on morning news (8-9am) appears in a dash-dot black line, on afternoon news (3-4pm) appears in a solid black, and on evening news (9-10pm) appears in a dotted black line.

pre-lockdown period. For example, for each hour h during Wednesday April 1, we plot the difference between $\hat{\epsilon}_{hdt}$ for dt= Wednesday April 1, minus $\tilde{\epsilon}_{hdt}$ for dt=Wednesday for that same hour h. Quantitatively, finding a coefficient -10 between 8am and 9am during Wednesday April 1 would mean that electricity consumption was 10% lower as compared to that same hour during a typical pre-pandemic Wednesday, controlling for temperature, year, month and holiday differences.

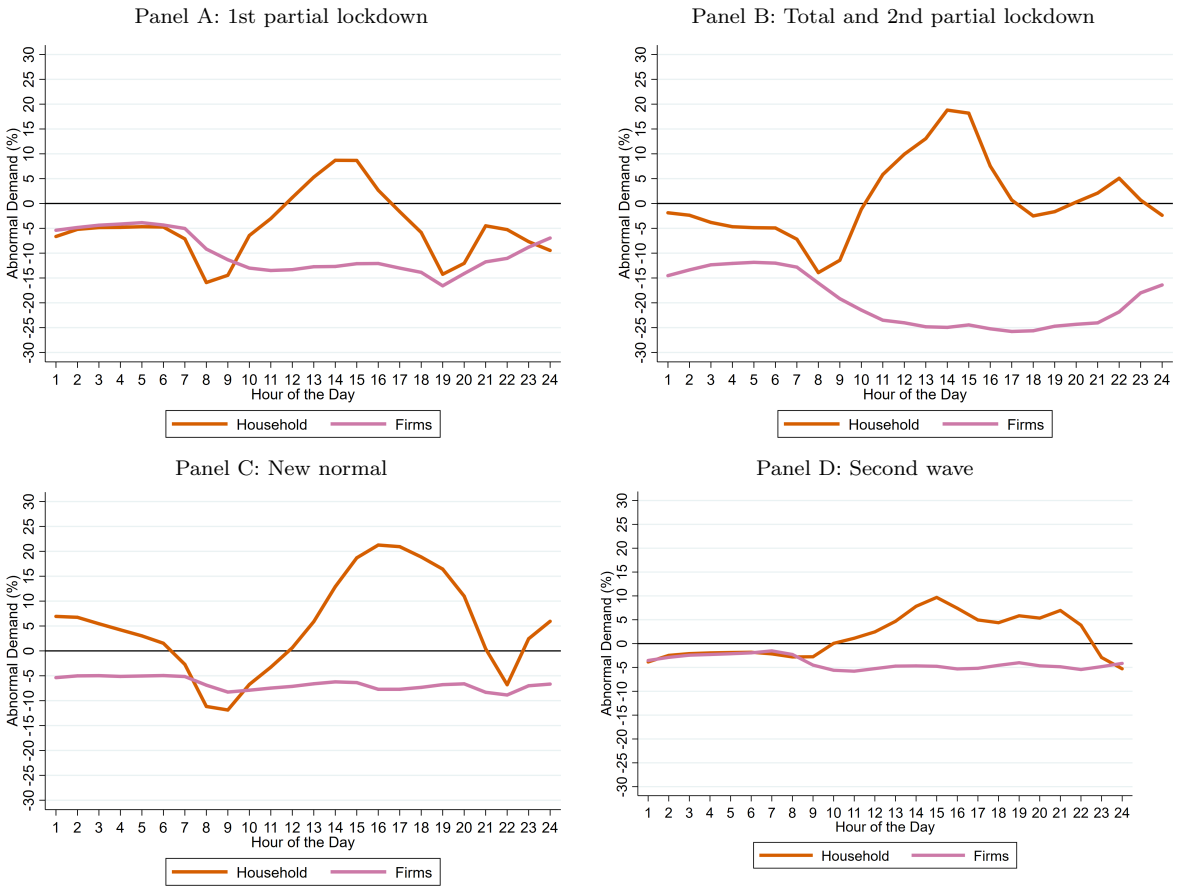
Figure 6 shows the evolution of those residuals along the day for firms and households. Days are grouped in four types of periods that differ on the stringency of the lockdown measures in place (weekends and holidays are excluded). Table 3 summarizes the results by reporting the changes in electricity demand during representative hours.[20]

Consistently with our previous analysis, electricity demand by households went up, while electricity demand by firms went down, particularly so during the total lockdown period. Therefore, changes in total demand (as shown in Figure 9 in the Appendix) hide the opposite movements in the two series. The effects are not uniform across all hours of the day, or across time, as the stringency of the lockdown measures changed.

Indeed, the effects on households' electricity demand patterns reflect changes in their habits during the pandemic. One can observe that the increase in households' electricity demand is more pronounced during working hours, which is also when the strongest reduction in firms' electricity demand takes place. The reduction in demand at around 8-9am is consistent with people getting up later (as also suggested by the TV audience data). The most striking difference between the two series is observed during the total lockdown period at 2pm (Panel B), when households increase their electricity demand by 18% while firms reduce theirs by almost 25%. This is consistent with the sharp increase in remote work, which partly went down during the second wave. Finally, similar patterns can be seen around 8-10pm. During the total lockdown (Panel B) as well as during the second wave (Panel D), one can observe an increase in electricity demand, which disappears during the new normal (Panel C). This is consistent with people eating out only during the summer months, when the confinement measures were relaxed.

[20]The choice of hours also coincides with the timing of TV news, allowing us to check whether the changes in households' demand and TV viewership are consistent with each other.

Figure 6: Changes in firms' and households' hourly electricity consumption relative to 2015-2019



Notes: These figures show the estimated percentage change in hourly electricity consumption by firms and households as compared to what the model would have predicted with 2015-2019 data. Only weekdays and non-holidays are considered.

	8am		2 pm		8 pm	
	Households	Firms	Households	Firms	Households	Firms
1st Partial Lockdown						
(March 11 - March 28)	-15.57***	-12.22***	8.89	-12.68***	-4.85*	-11.88***
	(2.22)	(1.24)	(1.95)	(1.11)	(2.68)	(1.11)
Total and 2nd Partial Lockdowns						
(March 29 - June 20)	-11.73***	-19.47***	18.27***	-24.70***	2.11*	-24.11***
	(1.06)	(0.59)	(0.93)	(0.53)	(1.28)	(0.53)
New Normal						
(June 21 - August 13)	-12.24***	-8.53***	18.67***	-6.57***	0.33	-8.36***
	(1.26)	(0.71)	(1.11)	(0.63)	(1.53)	(0.64)
Second Wave						
(August 14 - December 31)	-3.44	-4.95***	9.84***	-5.01***	6.79***	-4.83***
	(0.81)	(0.45)	(0.71)	(0.40)	(0.97)	(0.41)

Table 3: Abnormal energy demand for selected hours of the day

Notes: This table shows the estimated percentage change in hourly electricity consumption compared to what the model would have predicted with 2015-2019 data. The coefficients and standard errors are obtained by regressing the hourly differences on indicators for each lockdown period. Significance at 10%, 5%, and 1% is indicated by *, **, and ***, respectively.

Changes in the hourly consumption patterns of households can be further analyzed through the lens of Figures 7 and 8, which report the evolution of abnormal electricity consumption over time at four representative hours (8am, 12pm, 8pm and 11pm), both for weekdays as well as for Sundays. In Figure 7, Panel A shows that electricity consumption went down at 8am after March 10, a period when schools were closed, and it remained below normal values up to mid September. Interestingly, the reopening of schools and universities led to an increase in electricity demand at 8am. These changes are not observed during Sundays (Panel B), which indicates that they are linked to work-related changes in people's habits.

Panel C and D show that electricity demand by households increased substantially at 2pm relative to normal times throughout the year, both for weekdays and even more so during Sundays. This can be attributed to the lockdown restrictions (particularly so on Sundays, when people could no longer go out for lunch as they used to), and the greater incidence of remote work. Such an increase in electricity consumption at 2pm becomes milder by the end of the third quarter during weekdays, probably due to the diminishing incidence of remote work, as reflected in the Spanish Labour Force Survey (EPA). In Q2 2020, 16% of the population was working from home for more than half of their working hours, compared to 4.5% in 2019. However, this rate declined to 11% at the end of the year. Banco de España (2021) suggests that the relative small size of Spanish cities, the small firm size, the high ratio of temporary employment, and the small amount of intangible investment could have limited the growth of remote work in Spain.

Figure 8 analyzes the evening hours. As shown in Panels A and B, electricity demand at 8pm remained fairly unchanged around normal levels, except for the total lockdown period and for the second wave (after October).[21] While this demand increase can be explained by the confinement measures during the total lockdown period, during the second wave it can only be explained by people's voluntary decision to stay at home.

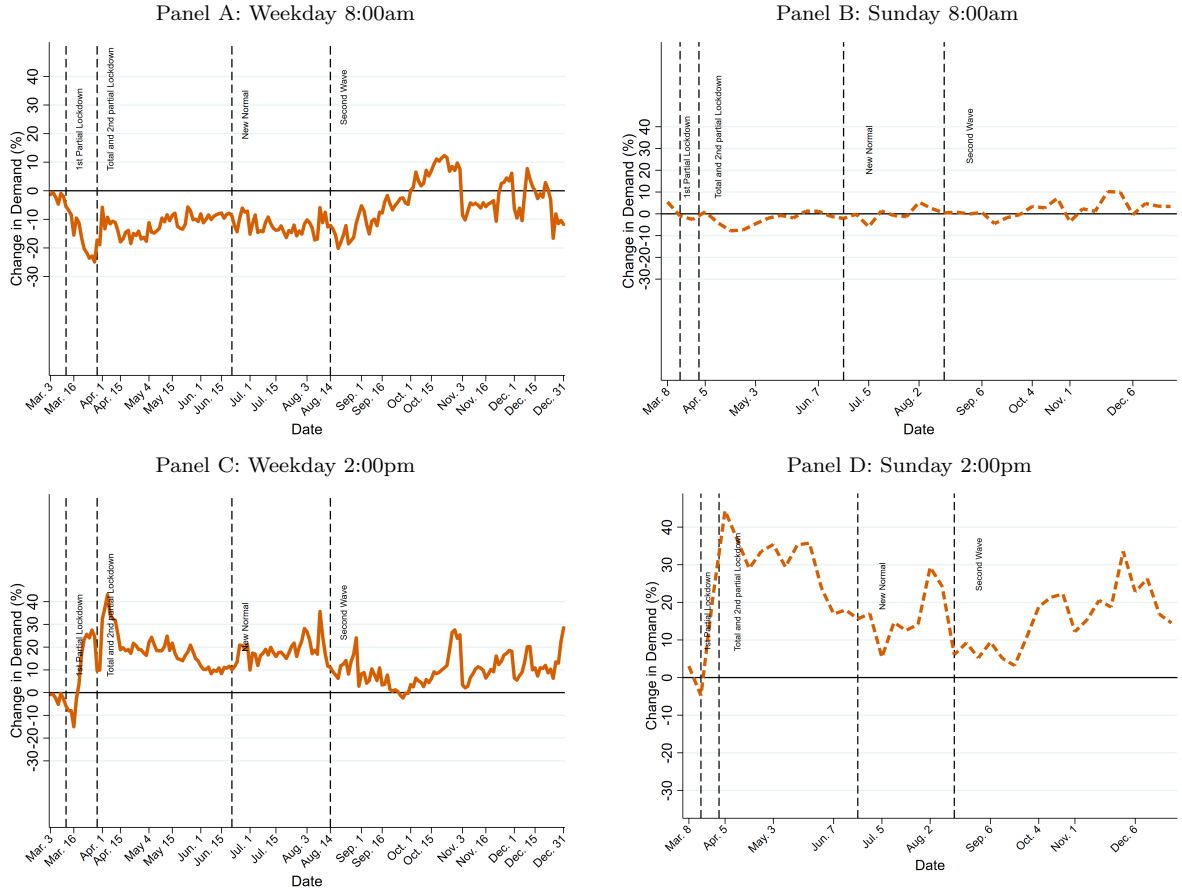
One potential question is whether this affected sleeping times. Panel C and D analyze the evolution of electricity demand at 11pm as a way of testing this hypothesis.[22] Interestingly, the figures show positive abnormal electricity levels during the total lockdown and during the summer. This is consistent with a delay in the time to go to bed during those periods. On the contrary, there are no positive abnormal electricity levels during the second wave (if anything, one can see slight declines in households' electricity demand at 11pm). These patterns point at an interesting conclusion: during the second wave, the lockdown measures in Spain may have induced longer sleeping times. Several

[21] A similar pattern is obtained for 9pm.

[22] A similar pattern is obtained at midnight.

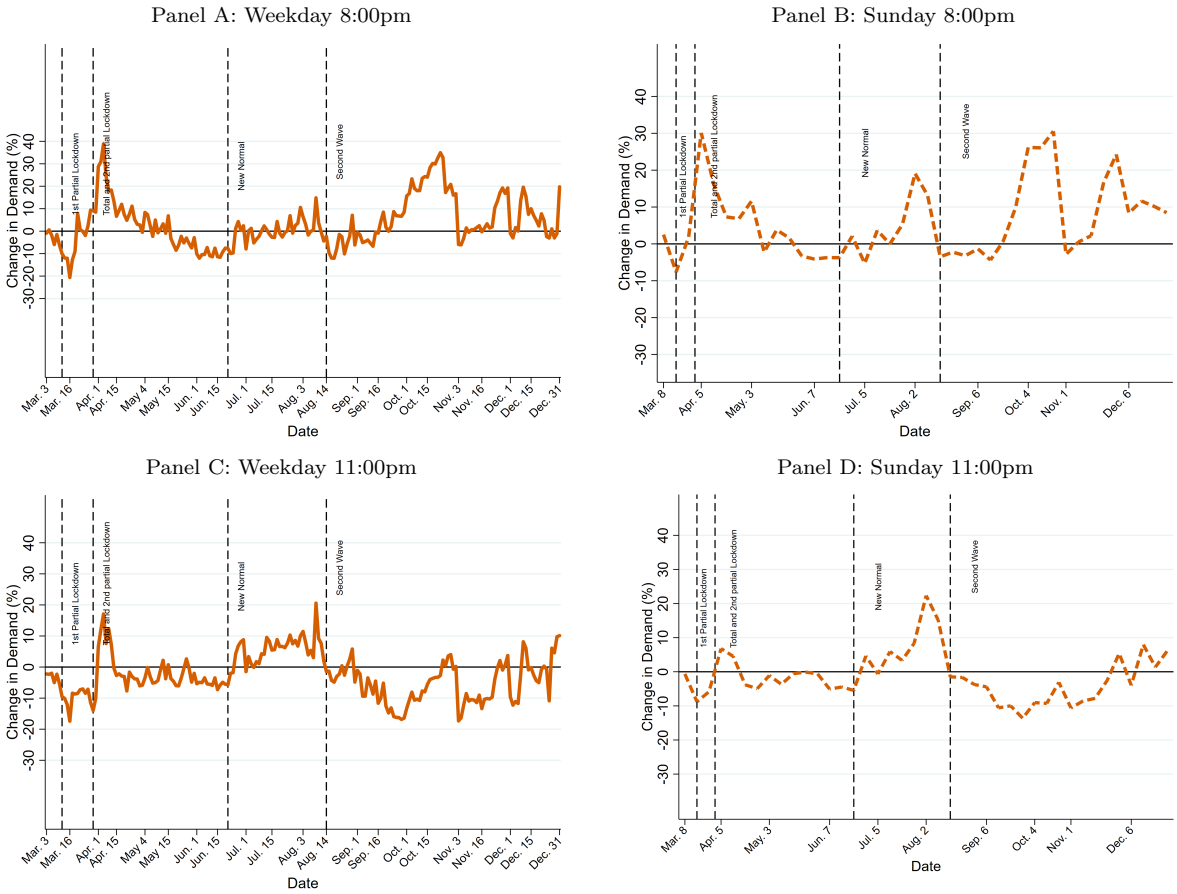
studies (Marco Hafner and Stolk, 2016) have documented the positive impacts of sleep on health outcomes, productivity and skill accumulation. Hence, our finding suggests that this change in people's habits may have at least partly mitigated the large economic and health costs caused by the pandemic. This finding is consistent with Lee, Marek and Nálevka (2020), who report that, during the COVID-19 pandemic, residents in the US and 16 European countries slept longer than usual. In particular, they find that people slept between 11 and 19 minutes more on weekday nights.

Figure 7: Abnormal energy demand by households over time for 8am and 2pm



Notes: These figures show the estimated percentage change in hourly electricity consumption by households as compared to what the model would have predicted with 2015-2019 data. Only non-holidays are considered.

Figure 8: Abnormal energy demand by households over time for 8pm and 11pm



Notes: These figures show the estimated percentage change in hourly electricity consumption by households as compared to what the model would have predicted with 2015-2019 data. Only non-holidays are considered.

5 Conclusions

In this paper we have analyzed the impact of the COVID-19 lockdown measures on Spanish electricity consumption. We have highlighted the importance of decomposing total electricity consumption into consumption by firms and households, to better understand the economic and social impacts of the crisis. While electricity demand by firms has fallen substantially, the demand by households has gone up, with both effects being stronger under more stringent lockdown measures. These countervailing effects have implications for indicators of economic activity that rely on total electricity consumption as an input. The full economic impacts of the pandemic might be masked by those indicators - see for instance, Lewis, Mertens and Stock (2020).

Understanding the relationship between electricity consumption and economic activity will become increasingly complex, as the drivers of electricity consumption are likely to evolve over time. On the one hand, the energy transition will heavily rely on electrification as a means to reduce emissions in many polluting sectors (notably, transport and residential heating and cooling), and *ceteris paribus* this will lead to greater electricity needs. On the other hand, this will be partly offset by improvements in energy efficiency. The long term trend of electricity demand will likely depend more on the interplay between these two countervailing factors than on the state of the economy.

The strength of these drivers will also differ between firms and households, depending on their scope to electrify their energy needs and improve their energy efficiency. Electric vehicles are a category of important growth, which will likely affect electricity demand by households relatively more than that of firms. A confounding effect will be the deployment of rooftop solar photovoltaics, which are also expected to grow rapidly over the coming years both at industrial sites as well as at homes. Electricity consumption is measured net of any onsite generation, so the increase in rooftop solar generation will confound the true electricity consumption.

These issues do not imply that electricity consumption will no longer be informative of economic activity. Rather, they point at current and future challenges to understand the changing link between the two. By decomposing the change in electricity demand during the pandemic, this paper illustrates how such challenges can be, at least partly, overcome.

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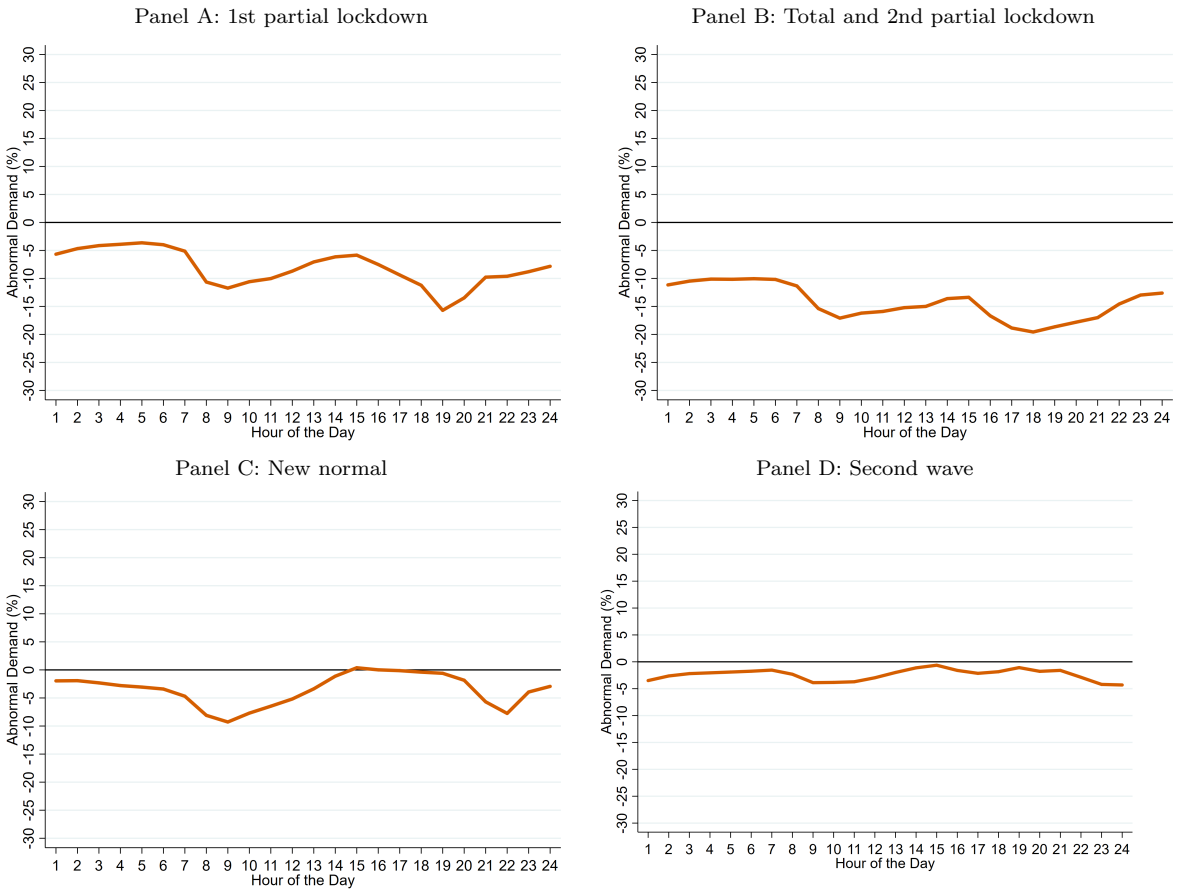
Appendix: Additional Figures

For completeness, we report here the evolution of residuals along the day for total electricity consumption. Days are grouped in four types of periods that differ on the stringency of the lockdown measures in place (weekends and holidays are excluded).

Figure 9: Changes in total hourly electricity consumption relative to 2015-2019



Notes: These figures show the estimated percentage change in hourly electricity consumption adding up firms and households as compared to what the model would have predicted with 2015-2019 data. Only weekdays and non-holidays are considered.