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Did electricity drive Spain's "most progressive decade"?

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Abstract

Following the growth accounting approach introduced by Oliner & Sichel (2000, 2002) to evaluate the impact of information and communications technologies on the U.S. economy in the 1990s, this paper analyses the impact of electricity on Spanish economic growth in the period 1958-1970. Spain was a follower country that exhibited the benefits of electricity nearly half a century after it had its biggest impact in the U.S. The results confirm that electricity played a significant role in Spain via the three channels identified in the literature for quantifying the contribution of a general purpose technology (GPT): capital deepening, the total factor productivity effect and the spillover effect. The overall impact is greater than that estimated for other follower countries in the 1920s. The main boost to growth came from improvements in productivity in developments in electric plants electricity and the production of electrical capital goods, not from electricity use. We also find a weaker positive effect of spillovers in electricity-using industries. The laggard effect of electrification in Spain, in spite of its early start, confirms that a GPT needs time to establish new institutional arrangements and complementary investments in order to display positive linkages deriving from the new technology.

Keywords: Technological change, Aggregate Productivity, Spain (country studies)
JEL classification: O33, O47, O52

1. Introduction

Electricity shares with steam power and information and communications technologies (ICT) the condition of general purpose technology (GPT). A GPT is defined as a "technology that initially has much scope for improvement and eventually comes to be widely used, to have many uses, and to have many Hicksian and technological complementarities" (Lipsey, 1998). The way these technologies develop and disseminate their effects over the economy will change the pace at which the growth process evolves. Pervasiveness, a potential for technological improvements and the development of complementarities that lead to increasing returns give GPT a significant role in long-term economic growth.

The spread of these technologies in the pioneering countries usually takes a long time and can take even longer in follower countries (David & Wright, 1999). If technological change is considered to be not an exogenous but an endogenous response to the economic conditions of the innovating country[1], it could be difficult for the follower countries to catch up with the technology of the leader, because it was invented to meet the specific requirements of the innovator. Today there is concern that ICT technologies are having less of an impact in Europe compared to the U.S.[2] The follower countries have to deal with institutional and economic policy changes in order to remove obstacles before they can adopt the new technologies.[3]

[1] Introduced by Gerchenkron (1962), this is a very widespread idea in economic history. Acemoglu & Zilibotti (2001) argue that technological change is guided by the needs of the innovating country.
[2] There is a relatively broad consensus that the acceleration in American productivity after 1995 was mainly driven by information technology: Oliner & Sichel (2000, 2002); Jorgenson & Stiroh (2000), Jorgenson, Ho & Stiroh (2002, 2005); Oliner, Sichel & Stiroh (2007); Brynsolfsson & Hitt (2000, 2003). For industry-level evidence supporting the role of ICT in the productivity resurgence, see Stiroh (2002). For Europe see Timmer, Ypma & van Ark (2003), and for a comparison between the U.S and other advanced countries, van Ark, Hao, Corrado & Hulten (2009).
[3] See Convay (2007) on what is important for ICT.

In the United States electricity determined the speed of the total factor productivity growth that occurred after World War I. The main driving force was the adoption of a new factory regime based on the new way of using electricity. The productivity gains associated with the introduction of electric motors in manufacturing were not limited to a reduction in energy costs. Electricity also brought significant fixed-capital savings (Devine, 1993) and managerial and organisational innovations that increased productivity in a wide array of manufacturing operations (David & Wright, 1999). The fixed transfer-line layout of assembly operations introduced by Ford and the continuous-process chemical technologies that made extensive use of electro-mechanical and electro-chemical relays for control were dependent upon the consumption of electricity for large-scale operations. The confluence between the dynamo revolution, electricity-based manufacturing process technologies and the emergence of a new organisational regime explain the speed-up of productivity growth in the U.S. (David & Wright, 1999).

However, the way electricity spread seems to have been very different in leader and follower countries. In the interwar period, the rapid spread of electricity across European countries and Japan did not necessarily translate into higher total factor productivity (TFP) or labour productivity growth[4]. Although there was no great difference between the U.S. and the U.K. in terms of science and engineering development, growth rates in the U.K. in the 1920s remained far below those in America. The U.K. lagged behind in terms of large-scale electric power generation and delivery and the extent to which the new factory regime was adopted (David & Wright,

[4] See Minami (1987) for Japan and Feinstein, Temin & Toniolo (1997) for the spread of electricity in Europe.

1999). Finland and Sweden present similar results for this decade, with a low impact of electricity on overall productivity growth.[5]

This paper analyses the particular case of Spain, a follower country that took full advantage of the use of electricity post-World War II. Although other authors have located the big impact of electrification in the 1920s, our analysis focuses on the period 1958-1970 because this represents for Spain its "most progressive era", much like the U.S. in the 1920s[6]. Along with other European countries, Spain was an early starter in the use of electricity. The first power stations were built in the last decades of the 19th century and the spread of electricity across the exiguous industrial sector was relatively rapid. Before the Civil War (1936-1939), most of the horsepower used in the manufacturing sector was generated by electricity. However, the economy was not mature enough to take full advantage of the incremental innovations that this new technology could bring in other industries. The pre-war pace of electricity expansion was not recovered until the 1950s, when the establishment of new agreements between Franco's government and the big electricity companies drove new investment plans. Hence in the 1960s Spain recorded its highest levels of output per worker and TFP growth. Trade liberalisation and greater openness to foreign capital after 1959 improved access to a wide range of technological and organisational innovations developed in the United States since the turn of the century, all highly dependent on the consumption of electricity. Chemical engineering, aeronautics, electrical machinery and equipment,

[5] For Sweden, see Edquist & Henrekson (2006), and for Norway, Javala & Pohjola (2008).
[6] According to Prados de la Escosura &and Rosés (2009), between 1952-1974 GDP grew at 6.38%, and TFP, after adjusting for inputs quality, grew at 3.83%. The average rates of GDP growth were lower in the previous period, 1850-1950 (1.3%), and in 1975-2000 (3%). For TFP the averages rates were -0.1% and 1.7% respectively.

electrical utilities, transportation, communications, and civil and structural engineering were the sectors that most benefited from this progress[7].

In this paper we aim to analyse the impact of the spread of electrification on Spanish growth in the period 1958-1970 using aggregate and industry-level data. Our analysis relies in part on neoclassical growth accounting, following the approach developed by Oliner & Sichel (2000, 2002) to estimate the impact of ITC on the U.S. economy and Stiroh's (2002) extension to account for the spillover effect. Jointly, both approaches consider that the productivity effects stemming from a GPT operate through three channels: the "multifactor productivity effect" coming directly from the industry or industries producing the new technology, the "capital deepening effect" and the "spillover effect", made up of all the benefits in terms of multifactor productivity that the industries enjoy due to the use of the new technology, but which remain unremunerated.

The data show that the three channels made a positive contribution to growth in GDP per capita. The highest impact came from the production of electrical capital goods and the electrical utilities via their multifactor productivity growth. The second in importance was capital deepening in electrical infrastructures and the new capital goods economy as a proportion of the economy as a whole. And finally, the weakest effect came from the speeding-up of multifactor productivity in specific industries because of investment in the new technology.

The rest of the paper is organised as follows. Section 2 describes the transformation of the Spanish economy between 1958-1970 and the changes that took place in the functioning of the electricity industry from its inception to the 1960s.

[7] Sanchis (2006) provides details on sectoral multifactor productivity growth for 25 branches in the period 1958-1975.

Section 3 presents the analytical framework, while Section 4 discusses the main results. Section 5 concludes.

2. Historical background to electrification in Spain

Electrification in Spain started around 1880, the same time as in other European countries. The process underwent a noticeable advance in the 1920s, with annual growth rates of 10.4% in electricity generation, but was partly interrupted by the Civil War and the post-war years of isolation and autarkic economic policy. It was not until the second half of the 1940s that it picked up again. Electricity production capacity multiplied by a factor of 19, reaching an average annual growth rate of 10.5% between 1945-1975, with Spain seeing the consolidation of electricity as its main source of power.

Before the Civil War the electricity industry was made up of private firms that were barely regulated by the state. At the beginning it was basically small-sized firms whose business was based on the use of coal, but with improvements in long-distance electricity delivery, the use of hydroelectricity became more important. The establishment of large generating plants in the 1910s and 1920s and the delivery of electricity over long distances altered the configuration of the market towards a more oligopolistic position. The state then began to regulate the industry. In 1919, electricity prices were fixed by the government to protect consumers against possible abusive practices by the big firms. The state also tried to regulate a central dispatching network for electricity distribution. This was the way to improve the efficiency of the electricity system as a whole and take full advantage of the large-scale production of electric power. Both the government and private producers were aware that a unified network could bring advantages by providing low-cost energy to a large number of users. Private firms would otherwise have to maintain excess capacity to deal with demand at peak times, and that greatly increased their capital costs and discouraged new investment plans. The creation of connections between the different areas and producers along with the centralised management of all the available resources would improve efficiency and reduce production costs and consumption prices.

As David (1991) states, the transformation of industrial processes by electric power technology was not simply a matter of technology, but also required political and institutional changes to enable supply-side improvements that drove the final phase of the electrification process. The integration and extension of power transmission over widespread territories was part of the electrification process and went beyond the individual interests of the various private firms (Millward, 2006). It is here that we find an important factor that contributed to the protracted delay in electrification between 1936 and the second half of the 1940s (Sudrià & Pueyo, 2007).

The government and the private firms reached no agreement on this issue until the 1940s, when frequent power cuts attracted the attention of Franco's government[8]. These electricity shortages have been attributed to the economic policy implemented by the new state.[9] The electricity companies had to carry the cost of low electricity prices, fixed by the government at pre-war levels, and the increasing cost of equipment and materials. The lack of foreign currency restricted imports of equipment and other essential materials and prevented firms from repairing or extending their facilities. Domestic intermediate inputs and equipment were not a good substitute for foreign imports because of the low efficiency and technological backwardness of the domestic

[8] The first power cuts due to supply shortages took place in 1944 and were frequent between 1944 and 1950. The worst years were 1945 and 1949, when the deficit was over 20% of demand (Sudrià, 2001).
[9] Sudrià (1990, 1994, 1997), Gómez-Mendoza, Sudrià & Pueyo (2007), Barciela, López, Melgarejo & Miranda (2001), and Pueyo (2007).

plants. There was also the Franco government's hostile attitude towards foreign investment to consider. Foreign restrictions were progressively relaxed after 1953 with the American Aid plan, and more extensively after 1959 with the Stabilisation Plan.[10] From that point economic policy changed towards a more permissive attitude in favour of trade liberalisation (González, 1979; Viñas et al., 1979) and the entry of foreign capital.

The Franco government showed no particular interest in the electricity industry until frequent power cuts posed a problem to its industrialisation plans in 1944. The government believed that electricity shortages were a sign that the private firms were unable to meet the new demand. The state therefore decided to intervene in the sector by setting up new public electricity companies and managing the regime of power cuts. Government interference in the private firms' interests paralysed investment plans and led companies to fear they would lose control of their own business. In August 1944 a new trade association, UNESA, was founded, and the state and UNESA finally agreed a deal. Private firms asked the government to respect their private interests, after which they would accept the entry of public firms into the industry and commit to managing and developing a unified electricity network. The private firms would thereby regain their trust in the government's plans and be more likely to invest. [11]

The setting-up of new electricity companies by the industrial public holding (INI) was subordinate to the interests of private initiative. The public sector built new,

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[10] One of the main items of the American Aid plan in 1953 was the import of electrical materials used to repair existing equipment and build new power stations (Calvo, 2001). An interesting case study of how foreign capital and American technology arrived at new electric power plants can be found in de la Torre & Rubio (2015).

[11] According to Sudrià & Pueyo (2007), documents relating to the founding of the INI (Instituto Nacional de Industria) reveal two positions regarding how to address the relationship between the INI and the electricity industry. One position considered that the private firms should submit to INI guidelines, whereas the other was more permissive and sought collaboration between public and private companies. Meanwhile the government did not fully define what its position would be, and the collaborative strategy seemed to lose weight. Hence the private firms distrusted the government's intentions towards the industry.

mainly thermal power stations, because in this area it would not be in competition with the private companies (Buesa, 1986)[12]. UNESA committed itself to managing the unified network following state guidelines, and in 1953 the central dispatching office, RECA, came into operation[13]. The new electricity prices (TTU) were approved in 1951 and came into effect in 1953[14]. Changes in the regulation of the electricity sector therefore led to a strong investment cycle from the mid-1940s and installed capacity increased more than tenfold between 1945 and 1970. In the period 1952-1959, investment in electric plants grew at an average annual rate of 11.7%. Electricity production grew by a factor of 19 between 1945-1970 and the industry recorded its highest figures in terms of total factor productivity, with its average annual rate of growth of 6.81% in the period 1958-1975 being well above the 4.46% average for the economy as a whole (Sanchis, 2006).

Table 1

Average electricity prices (in cents of peseta/kWh)

	Nominal (current cents)		Real (base 1953=100)	
	Domestic Users	Industrial Users	Domestic Users	Industrial Users
January 1953	39.73	39.73	100.0	100.0
August 1958	82.05	89.28	122.9	144.8
August 1969	86.54	102.47	71.4	84.5
December 1970	94.50	113.09	73.2	87.6

Source: Calculations by Sudrià & Pueyo (2007) with information on electricity prices from the BOE (*Boletin Oficial del Estado*). Nominal figures deflated by GDP deflator at factor cost calculated by Prados de la Escosura (2003), base 1952.

Spanish firms were able to purchase modern equipment from abroad that embodied the best technology. Additionally, organisational changes reduced the amount

[12] Notwithstanding, the public sector not only built thermal power stations to supply electricity to the INI's firms, it also competed with the private firms by constructing a hydroelectric plant, ENHER.

[13] Díaz Morlán (2006), pp.314-316, and Gómez Mendoza (2000), pp.69-84.

[14] Other agreements included the setting of new electricity prices (TTU, Tarifas Tope Unificadas) and granting fiscal benefits to private firms so as to promote investment. For an explanation of how the TTUs were established, see Pueyo & Sudrià (2007), chapters 3 to 7.

of power losses in the network and brought about a substantial increase in the efficiency of the electricity system as a whole. Henceforth the increase in productivity was passed on to the rest of the economy by means of a decrease in the real cost of electricity, 22% for domestic users between 1953 and 1970 and 12.4% for industrial users (Table 1).

Table 2

Electrical utilities and electrical capital deepening by industry, 1958-1970

	Growth Elec Utilities Consumption ($X_{elec.\ i}/X$)	*Growth Electrical Capital*
Energy, except electricity	-6.07	7.27
Electricity, gas and water	-11.21	9.00
Metal and non-metallic mining	-3.08	8.39
Primary transformation of metals	-2.14	8.39
Non-metallic minerals industry	-0.20	4.39
Chemical industries	-3.92	7.33
Industrial machinery and equipment	1.86	4.57
Transport equipment	2.19	14.10
Food and tobacco products	1.24	1.18
Textile mill products	3.97	0.65
Leather goods and footwear	5.90	0.65
Timber wood and furniture	0.05	2.65
Paper products, printing and publishing	-1.25	3.89
Rubber and plastics	-4.46	16.33
Miscellaneous manufacturing	-3.54	2.65
Construction	-0.66	19.62
Trade	-0.36	6.13
Hotels, restaurants and bars	-1.72	6.13
Railroad transport	-0.65	9.18
Land transport	-7.96	
Sea transport	-19.20	
Air transport	-24.60	
Communications	-4.75	15.93

Source: Sanchis (2006).

Investment in new equipment improved the way electricity was used in the different industries. Although some industries reduced consumption of electricity per unit of output, in general the most dynamic electricity-using industries intensified consumption of this input (Table 2). It is interesting to observe that the industries that increased consumption of electricity by unit of output included those with more scope for introducing the large-scale production technologies of the Second Industrial Revolution, such as automobile production, machines, even the processing of food and tobacco, and clothing and shoe manufacturing. It was from the second half of the 1950s and more especially in the 1960s that Spain began the transition to these kinds of technology. One can guess that the change towards technologies that were more intensive in the use of capital was complemented by a more intensive use of electricity. Meanwhile advances in the electrical utilities industry increasing the supply at lower cost and lower prices, removed previous obstacles to the development of these types of industry. Figures 1 and 2 compare the relative position of Spain compared to the U.S in terms of electricity production as a proportion of GDP and in terms of electricity production per capita. In 1950 Spain reached America's level of 1921 in terms of electricity per unit of GDP, while in per capita terms the American level of 1921 was reached in 1957

Figure 1

Electricity production as a proportion of GDP: Spain and the United States

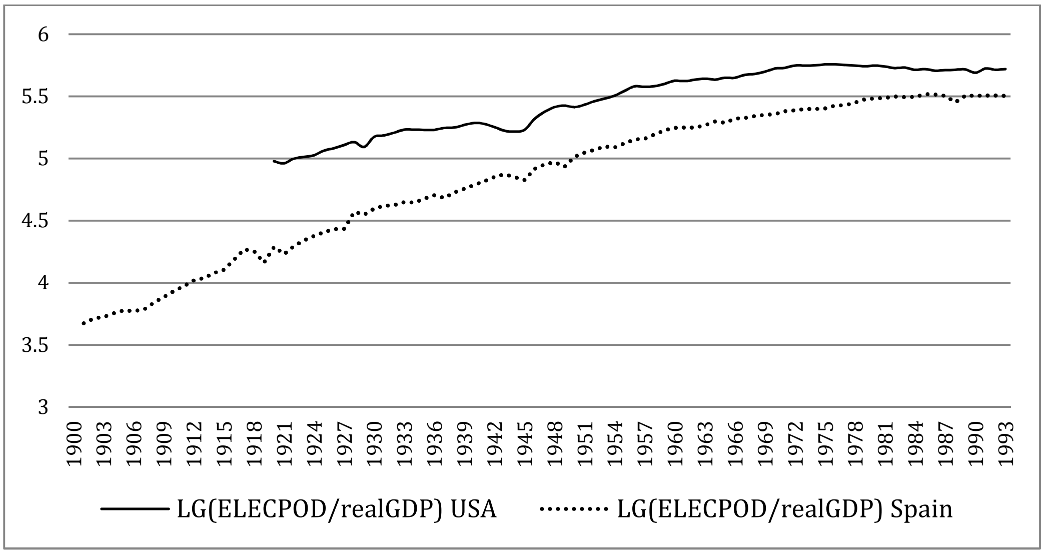
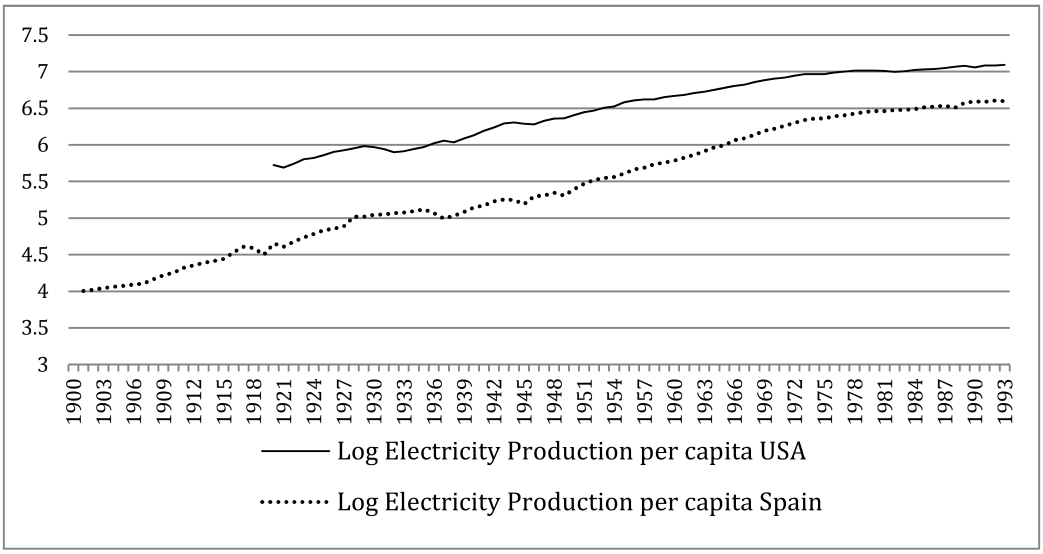


Figure 2

Electricity production per capita: Spain and the United States



Source: Comin & Hobijn (2009), “The CHAT Dataset”. NBER Working Papers, No. 15319.

3. Analytical framework: electricity as a general purpose technology

In this section we apply a growth accounting approach to analyse the role of electricity in the consolidation of Spanish industrialisation. The empirical literature usually considers that productivity effects operate through three channels. The first is the "multifactor productivity" effect, which comes directly from the industry or industries producing the new technology. The second is the "capital deepening effect" in the whole economy, which consists of the increase in capital intensity through investment in the capital goods that embody the new technology. In the neoclassical framework, there is no reason to expect total factor productivity (TFP) to increase in other industries outside the electrical utilities or electrical equipment-producing industries. Hence the third channel, which explores the effects on productivity growth outside the new technology-producing industries and is called the "spillover effect", should be located outside the neoclassical framework. It consists of all those non-pecuniary externalities in terms of multifactor productivity that are experienced by industries using the new technology.[15]

Neoclassical theory predicts that the use of electrical capital should not bring about TFP growth. Instead, the decline in quality-adjusted new equipment prices should lead to an increase in investment and capital deepening. This effect should be captured in the growth accounting equations through the income share of capital. This "pecuniary" externality should contribute to labour productivity growth but not to TFP growth. However, the presence of "non-pecuniary externalities" could lead to an observed correlation between the new capital and measured TFP growth (Stiroh, 2002).

[15] The spillover effect has been explored in the literature with regard to electricity: see David & Wright (1999 and 2003), Fernald & Basu (2006) and Stiroh (2002) for ICT, and Javala & Pohjola (2008) for electricity and ICT in Finland. However, there is no general consensus about how to account for this effect and the results are not conclusive with regard to its impact on overall economic growth.

3.1. Growth accounting in the neoclassical framework

In this section we examine electricity's impact as a proximate source of GDP-per-worker growth by following the methodology introduced by Oliner & Sichel (2000, 2002) to evaluate the contribution of ICT to American productivity growth in the 1990s[16]. This methodology is based on the the standard Cobb-Douglas production function:

$$\Delta A / A = \Delta Y / Y - s_k \Delta K / K - s_l \Delta L / L \qquad [1]$$

where Y, K and L represent total output, capital input and labour input, s_k and s_l are the income shares of capital and labour respectively, and A is the Solow residual, also known as "total factor productivity". Oliner & Sichel (2000, 2002) take into account developments in the new growth economics and the models that embodied the hypothesis of endogenous innovation to identify the contribution of technological change in the growth accounting framework. They develop a straightforward generalisation of Equation 1 that splits capital and the residual into different varieties. Specifically, they identified the contribution of ICT innovations to the growth of labour productivity as coming via three types of ICT capital deepening, weighted by their shares in income, and through TFP growth in ICT-producing industries, weighted by its share in gross output.

We apply this methodology to distinguish the contribution of electrification to productivity growth stemming from electrical capital deepening and technological

[16] Since then this methodology has been used by economic historians to analyse the contribution of steam power technologies to the British Industrial Revolution (Crafts, 2004a and 2004b) and to the climacteric (Crafts & Mills, 2004). For Spanish railroads see Herranz Loncan (2006).

progress in electrical equipment-producing industries and electrical utilities industries. Thus the growth accounting equation could be rewritten so as to separate the role played by electricity from overall output growth:

$$\begin{aligned}\Delta(Y/L)(Y/L) &= s_{non-elec}\Delta(K_{non-elec}/L)(K_{non-elec}/L) + s_{Kelec}\Delta(K_{elec}/L)(K_{elec}/L) \\ &+ \gamma(\Delta A/A)_{melec} + \phi(\Delta A/A)_{non-melec}\end{aligned} \quad [2]$$

In Equation 2 the specific contribution of electricity to overall labour productivity growth is measured via two components[17]: electrical capital inputs (K_{elec}) and this industry-specific productivity advance (A_{melec}). Following Crafts (2002) we distinguish between two kinds of electrical capital: the stock of electrical capital goods ($K_{elec-mach}$) and electrical utilities capital stock ($K_{elec-structures}$).

In Equation 2 the same split is made within the TFP. Again two kinds of productivity improvement linked to the electrification process are distinguished: TFP growth in the "electrical machinery and equipment" industry and the "electrical utilities industry". Industry-specific productivity growth is weighted by ϕ and γ which represent the well-known "Domar weight" usually used in the literature of growth accounting at industry level[18].

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[17] Oliner & Sichel (2000) distinguish between different types of ICT capital (hardware, software and communications equipment).

[18] Domar (1961). The "Domar weight" is the rate between the total output of a particular industry and the value added of the economy as a whole. These weights do not add up to unity. For an algebraic justification of this procedure see Hulten (1978). This aggregation procedure is very common in the growth accounting literature (Jorgenson, Gollop & Fraumeni (1987), Jorgenson & Stiroh (2000)…). Domar tries to reflect the different output concepts used at aggregate and industry level. For any particular industry, gross output considerably exceeds value added, and therefore the sum of gross output across industries exceeds the sum of value added. Weighting as suggested by Domar implies that economy-wide TFP can grow faster than the sum of particular industries, as productivity gains in any particular industry are magnified as they work their way through the production process and are consumed by other industries as intermediate inputs.

$$\Delta(Y/L)/(Y/L) = s_{k\cdot non-elec}\Delta(K_{non\cdot elec}/L)/(K_{non-elec}/L) + s_{elec-struct}\Delta(K_{elec-estruc}/L)/(K_{elec-struct}/L) + s_{elec-mach}\Delta(K_{elec-mach}/L)(K_{elec-mach}/L) + \gamma(\Delta A/A)_{elec-struct} + \lambda(\Delta A/A)_{elec-mach} + \phi(\Delta A/A)_{non-elec} \qquad [3]$$

Industry-specific productivity growth has been estimated following Jorgenson *et al.* (1987), who split output growth at industry level into the sum of the contributions of intermediate, capital and labour inputs and productivity growth. The productivity measurement underlying the disaggregated approach is a homogeneous production function *(F)* for each of the *n* industrial sectors. The production function for the *i*th industry gives the quantity of output, Z_i, as a function of the primary inputs, capital services (K_i) and labour services (L_i), intermediate inputs (X_i) and the level of technology (t):

$$Z_i = f_i(K_i, L_i, X_i, t) \qquad i = 1 \ldots n \qquad [4]$$

where all inputs are measured as service flows rather than stocks. Under the assumptions of constant returns to scale and the exhaustion of the value of output by the value of inputs, the growth accounting equation for each sector is:

$$d\ln A_i = d\ln Z_i - v_{k_i} d\ln K_i - v_{l_i} dnL_i - v_{M_i} \ln X_i \qquad [5]$$

where v is the average share of the subscripted input in sector i and A_i is industry productivity. Augmentation factor A_i is conceptually analogous to the TFP concept used in aggregate accounting. The shares of intermediate inputs (v^i_X) in the value of the output take into account the variety of intermediate inputs used in the production of any particular industry *i.* The shares of the individual intermediate inputs (v^i_{Xj}) can be defined in the values of the corresponding aggregates by:

$$v^i_{Xj} = \frac{p^i_{Xj} X_{ji}}{p^i_X X_i} \qquad (i,j=1\ldots n) \qquad [6]$$

where X_{ij} is the set of n intermediate inputs from the jth sector and p^i_X denotes the prices of intermediate inputs. Under the neoclassical assumptions of competitive input markets (inputs are paid according to their marginal product) and output exhaustion (all revenues are paid to factors), the input's factor shares in equilibrium are equal to the output elasticities and, for all three inputs (K, L, X), add up to unity.

This formulation has the ability to capture the impact on output of efficiency improvements in the production of intermediate inputs and changes in the quality of factors. More efficiently produced intermediate goods would be reflected in the share of that input (v_{xj}) and hence in the productivity of the consuming industry. We have deflated output and intermediate input consumption separately in order to capture improvements in quality in the growth accounting equation. The industry-level approach to "industry productivity" also allows us to clean the residual from improvements in the quality of labour and capital. We have tried to capture changes in the quality of labour and capital following the Jorgenson *et al.* (1987) approach, taking into account the different qualities of the employment used and the user cost of capital in each industry.[19]

Technological change in the "electrical machinery and equipment industry" gives rise to a "pecuniary externality" in the form of rapidly falling new equipment prices. Cheaper new capital goods provide an incentive for firms to invest. The rental prices are dominated by rapid depreciation and capital losses that raise the user cost of the new

[19] For more details on how labour and capital inputs are measured, see Sanchis (2006).

electrical equipment relative to other assets and increase this input share in overall income. The new investment goods therefore have to generate higher marginal products in order to cover the high rental prices. This explains the rapid accumulation of new electrical capital as a profit-maximizing response to falling prices and high marginal products for new equipment (Jorgenson & Stiroh, 1999). Hence the neoclassical framework supplies a direct link between the new electrical capital and labour productivity but has no direct connection with TFP growth.

3.2. Spillover effects from the new capital goods

However, some authors observe that the arrival of a new technology can cause the rate of TFP growth in the user industries to accelerate. This could happen if the neoclassical assumptions of competitive input markets and exhaustion of output by input remuneration fail. This failure could come about due to problems of omitted variables, embodied technological change, measurement errors of the inputs or because of spillover effects. Externalities deriving from investment in new technology have to deal with the process of "learning by doing", investment-led organisational changes and induced capital accumulation in complementary goods and any positive feedbacks between these investments.

If we consider that there is a positive effect of the new electrical equipment on TFP, this will be reflected in an elasticity of this new equipment that exceeds its measured input share ($\varepsilon_{k\text{-}elec} > s_{k\text{-}elec}$). In this case measured TFP growth will be an underestimation of its true growth.[20] There is no consensus in the literature regarding how to estimate the spillover effect.[21] Here we estimate the average relationship between investment in electrical capital goods and industry productivity following Jalava & Pohjola's (2008) specification:

$$\Delta \ln A_{it} = \beta \Delta \ln K_{i,t-nonelec} + u_{it} \quad [7]$$

where a statistically significant β denotes the existence of spillover effects and the spillover contribution consists of multiplying the β coefficient by the average growth of new electrical capital goods.

In the context of electrification, there is a wide range of potential spillovers and network effects deriving from the adoption of large-scale produced electricity. The adoption of the unit drive system in factories brought direct cost savings in terms of energy consumption, labour saving and other materials. Fewer workers were needed because some tasks such as cleaning, tightening and adjusting the belts disappeared. Manufacturers considered these direct cost savings insignificant compared to the indirect benefits deriving from the adoption of the unit drive system and the transition from drive shafts to wires (Devine, 1983). One such direct benefit was the improvement in machine control achieved by eliminating slippage problems and installing variable-speed DC motors. Greater flexibility could be seen in building design and in the

[20] Unfortunately Jalava & Pohjola (2008) do not have data of this kind for electricity and estimate it only for ICT technologies in Norway for the period 1990-2004.

[21] Early attempts to measure the spillover effect were carried out by David (1991) and David & Wright (1999, 2003). They estimated the correlation between the percentage point per annum acceleration in the adjusted TFP residual and the proportionate increase of secondary electric motor capacity. Stiroh (2002) proposes a panel data econometric estimation of the relationship between the increase in ICT capital and the acceleration in measured TFP growth calculated under the neoclassical framework and finds that there is no correlation for the period analysed. Basu & Fernald (2006) estimate the delayed effect of investment in ICT and find that industry TFP accelerations in the 2000s are positively correlated with ICT capital growth in the 1990s. More recently, Jalava & Pojohla (2008) use a panel data estimation approach to calculate the spillover effect for any particular industry. They find that spillovers from ICT capital played an important role in Finland in the 1990s but not in the case of electricity in the 1920s.

arrangement of machines throughout the factory. This led to space saving and increased efficiency, and also improved the working environment by providing better lighting, ventilation and cleanliness. But perhaps one of the biggest benefits was the flexibility and autonomy in operating the machines. Electric motors could be accurately matched to the specific requirements of individual machines in terms of time and intensity. This made plant expansion less hurried because production could continue even during the construction of new buildings. All these changes in engineering, factory architecture and motor-truck transportation were collateral with changes in power technologies and the organisation of work in factories and new personnel management. These kinds of change follow the logic of technical or organisational complementarities and can be identified as spillovers generated in the process of applying the unit drive system (David & Wright, 1999). Thus changes in TFP growth across manufacturing sectors correlated strongly with changes in electric motors.

4. Empirical results

Table 3 presents industry productivity growth (*tfp*) for several industries, obtained following Jorgenson et al.'s (1987) analytical framework.[22] The group of leading industries includes "the machinery and equipment industry", "electricity, gas and water", "transport equipment", "the rubber and plastics industry" and communications.

We can therefore consider that technological change in Spain in the 1960s was linked to the use of electrical machinery and appliances, to the motor vehicle, chemical industries and new communications (telephone and television) and thus to the same

[22] Sanchis (2006) exploits sectoral growth accounting methodology in a similar way to Jorgenson, Gollop & Fraumeni (1987) in order to measure the contribution of intermediate inputs, capital, labour and multifactor productivity to the increase in total output for 25 branches of production.

industries that led the upsurge in productivity growth in the U.S. in the 1920s (Field, 2003 and 2004). The industries with the largest increase in productivity were responsible for half the total productivity growth while representing around only 20% of the total value added, excluding the agricultural sector. Despite the highly concentrated nature of the transformation, it can still be seen that 77% of total value added and 100% of all manufacturing shows positive productivity growth. While the accelerated TFP reflects technological progress in specific industries, TFP gains are widely spread throughout the economy. This opens up the possibility that electricity-related spillovers or network effects among the electricity-using industries are contributing to economy-wide TFP growth.

What is striking about this period of technological progress is its broad base, both inside and outside manufacturing. If anything characterises the advances in all these sectors, it is their interrelation, as shown by Field (2003, 2004) for the 1920s and 1930s in the U.S. There is no shortage of examples, such as the interconnection between large-scale car manufacturing, road building, the new layout and asphalting of cities and the development of cheaper and cheaper rubber and oil-refining industries. The widespread use of assembly lines using electricity in factories due to the expansion of "machinery and equipment industries" is at the same time related to large-scale electricity generation and supply and new corporate organisation techniques.

Table 3

Total factor productivity growth rates, 1958-1975

	1958-1962		1962-1970		1970-1975	
	tfp	%VA	*tfp*	%VA	*tfp*	%VA
Energy, except electricity	4.54	0.02	7.98	0.01	-0.74	0.01
Electricity, gas and water	8.30	0.04	9.78	0.03	0.86	0.03
Metal and non-metallic mining	3.03	0.01	5.92	0.01	4.95	0.01
Primary transformation of metals	1.59	0.03	1.96	0.02	2.81	0.03
Non-metallic minerals industry	8.55	0.03	6.35	0.02	0.91	0.02
Chemical industries	8.49	0.04	4.09	0.03	1.64	0.03
Industrial machinery and equipment	9.22	0.08	5.74	0.05	3.01	0.07
Transport equipment	4.06	0.05	1.86	0.03	7.99	0.04
Food and tobacco products	-0.76	0.06	2.02	0.05	0.46	0.05
Textile mill products	1.58	0.03	2.32	0.04	2.70	0.02
Leather godos and footwear	4.15	0.04	4.51	0.03	0.90	0.04
Lumber, wood and furniture	-0.07	0.02	6.44	0.02	2.78	0.02
Paper products, printing and publishing	5.01	0.03	5.78	0.02	3.08	0.02
Rubber and plastic	8.40	0.02	7.36	0.01	4.03	0.01
Miscellaneous manufacturing	6.77	0.02	1.21	0.01	12.67	0.01
Construction	-1.08	0.11	-2.34	0.07	-0.87	0.09
Trade	0.95	0.19	-2.70	0.14	0.18	0.16
Hotels, restaurants and bars	4.24	0.07	-1.46	0.05	-0.33	0.06
Railroad transport	-5.15	0.01	-1.79	0.01	1.96	0.01
Land transport	-0.68	0.07	5.30	0.05	3.16	0.06
Sea transport	-1.84	0.01	3.36	0.01	4.14	0.01
Air transport	-3.82	0.01	10.43	0.00	8.87	0.01
Communications	7.65	0.02	0.57	0.01	12.38	0.01
Financial institutions	-0.84	0.02	4.82	0.04	-0.50	0.02

Sources: Industry TFP has been calculated following the growth accounting framework developed by Jorgenson, Gollop & Fraumeni (1987). Capital and labour are adjusted by quality. Input-output tables from 1958, 1962, 1970 and 1975 for total output, intermediate inputs and input shares in total output; Fundación BBVA for labour and capital input; INE for weights in the capital and labour input categories to account for quality changes. For more details on data construction see the appendix in Sanchis (2006).

In Spain the big push for industrialisation from the mid-1950s went hand in hand with these developments and the construction of an integrated network to supply electricity all over the country. The lower real prices of electricity enabled production and productivity in the electricity-using industries to be increased. Working conditions improved not only in the big plants but in small factories and craft mills too. Factory design and organisation was transformed, with more efficient machines being used and plant expansion being made easier. As a result the electricity-using industries were able to benefit from the high rates of multifactor productivity growth. In addition to this, the American Aid plan in 1953 and the Stabilisation Plan in 1959 encouraged trade liberalisation and openness to foreign capital. Among the sectors that most benefited were the electrical utilities and the machinery and equipment industries. This signalled the arrival of more technologically advanced equipment, engineers and foreign capital to invest in the new power plants and capital goods-producing industries.[23]

Table 4 summarises the results of implementing the growth accounting framework as represented in Equation 3. The contribution of electricity to overall economic growth is broken down into the three effects: electric-specific productivity growth (section 1), capital deepening (section 2) and spillover effects for particular industries (section 3). The average rate of total factor productivity growth for the period 1958-1975 is 6.81% for the "electrical utilities industry" and 5.86% for the "electrical machinery and equipment industry". The Domar weights are 0.04 and 0.1 respectively. Multiplying both components we find that the contribution in terms of TFP is 0.27 for the "electrical utilities industry" and 0.58 for the "electrical machinery and equipment industry", which gives us a total "electricity productivity effect" of 0.85. This means that both industries together make a contribution of 18% to aggregate TFP growth (4.62).

[23] See Calvo (2001, 2007, 2008) for the link between the American Aid plan and imports of electrical equipment and electrical intermediate inputs. See Puig & Alvaro (2004), Puig *et al.* (2008), Puig & Castro (2009) for a business perspective of the way American aid was introduced in Spain and its contribution to facilitating the entry of new technologies linked to electricity and developing complementary investments in the form of new management and factory organisation. Puig & Fernandez (2003) describe the relationship between American aid and the upgrading of entrepreneurs and managers to adapt to the new ways of business organisation. See Cebrián (2005) and Cebrián & López (2004) for the international transfer of technology in the 1960s and the arrival of new organisational and management techniques. See de la Torre & Rubio (2015) for specific examples related to the entry of foreign capital to invest in the new electricity power stations.

Table 4

Contributions to GDP per capita in the business sector, 1958-1975 (% per year)

	1958-1974	
1.1. Productivity contribution of electrical machinery industry	0.58	
Productivity growth in electrical machinery	5.86	
Output share (Domar contribution)	0.1	
1.2. Productivity contribution of electrical utilities industry	0.27	
Productivity growth in electrical utilities	6.81	
Output share (Domar contribution)	0.04	
1. Total global TFP effect (1.1+1.2)	*(0.85)*	67%
2.1. Capital deepening from electrical machinery and equipment	0.15	
Capital stock growth per capita in machinery and equipment	7.67	
Income share	0.02	
2.2. Capital deepening from electricity production and distribution	0.12	
Capital stock growth per capita in electrical utilities	7.94	
Income share	0.015	
2. Total capital deepening effect (2.1+2.2)	(*0.27)*	21%
3. Spillover effect from electricity	*(0.14)*	11%
Spillover from electric capital	0.14	
Overall electricity contribution to GDPpc (1+2+3)	1.26	
GDP per capita	5.81	
% Electricity over GDPpc		21.67%

SOURCE: Own

"Capital deepening from electrical machinery and equipment" (row 2.1) refers to the increase in this kind of capital for the economy as a whole. Most sectors of the economy invested in new electrical capital goods. According to the industrial survey *Estadísticas de la Producción Industrial* published by the Servicio Sindical de Estadística, around 90-95% of all equipment in the period 1958-1975 was driven by electricity. The capital stock estimations made by Prados de la Escosura & Rosés (2010) give an average annual growth of total equipment of 7.67% between 1958 and 1975.[24] The income share of "electrical machinery and equipment" capital stock is then calculated as follows. First, we take the "total capital income share" from Prados de la Escosura & Rosés (2006), who correct by the compensation to employees and obtain an average share in income of 0.22 for the period 1958-1975. Second, we multiply this figure by the "share of machinery and equipment" in total capital, which ranges from 9.07% in 1958 to 11.32% in 1975 according to the Prados de la Escosura & Rosés (2010) figures. Third, we multiply by the 95% of electricity-driven machines. Finally, the estimated income share of "electrical machinery and equipment" stands at 0.02, which gives a contribution to overall GDP per capita growth of "electrical machinery and equipment" capital stock of 0.153 (see row 2.1).

The "income share of electrical structures" is calculated as follows. The capital stock in infrastructures devoted to the production and distribution of electricity has been measured via the increase in the capacity installed in electricity power stations. According to figures published by the Ministry of Industry and UNESA, installed capacity increased at 9% per annum in the period 1958-1975, which in per capita terms represents a growth rate of 7.94%. The capital income share of the "electrical utilities industry" was 0.032 of the total capital share according to input-output tables. We have multiplied this by the share of infrastructure in this sector's capital according to the Ministry of Industry and Trade figures for technical production coefficients for manufacturing[25]. The final contribution of the increase in the stock of capital invested in

[24] This is not the most accurate way to measure the volume of electrical machinery and equipment capital because, unlike Oliner & Sichel (2002), we do not have hedonic prices to deflate ICT investment, and so we cannot take into account the improvements in quality that this kind of machinery could incorporate. We should consider it as a lower bound approximation to the increase in the stock of electrical machinery and equipment.

[25] A survey by the Ministry of Industry (1980), "Los coeficientes técnicos de capital-producto y capital-empleo en diferentes sectores de la economía española", shows the shares of the different capital components in different industries.

power generating infrastructures is 0.12, which rises to 0.15 due to the increase in electrical machinery stock, giving a "total capital-deepening effect" of 0.27.

The last item is the "spillover effect from electrical machinery and equipment". To calculate this effect we estimated an ordinary least square regression between industry productivity growth and the average changes in electrical machinery stock for a set of manufacturing industries and a number of service branches following Equation 7. The estimated β coefficient is 0.55 for 1964-1970. This estimated effect is quite poor since it gives an R-square of 0.2. The spillover from electrical capital is calculated by multiplying 0.55 by the average growth in electrical capital for each industry. Finally the sum of all these components is aggregated using the industry's Domar weight in total value added. The final "spillover" deriving from the incorporation of new electrical equipment is 0.14. Several authors suggest that this effect should be estimated using the lagged impact of the investment in new technology over actual GDP in order to leave room for the investment in complementary inputs to operate[26]. However, we have no annual estimates of *tfp* growth enabling us to introduce lags into our estimation.

To sum up, electricity's overall contribution to GDP per capita growth was 1.46% per year between 1958 and 1970, of which 0.85 points came from specific *tfp* growth in the industries producing the new technology, 0.27 from capital and 0.14 represents the "spillover effect". The shares of each effect in electricity's overall contribution are 67% for *tfp* in the new technology industries, 21% from capital deepening and 11% from "capital spillovers".

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[26] Brynjolfsson & Hitt (2000) find that the contribution of ICT to labour productivity growth is accompanied by large and time-consuming investments in complementary inputs, such as orgnisational capital. Consequently its contribution to overall growth equals its share in output in the short-run but greatly exceeds it in longer periods. Basu & Fernald (2006) estimated the delayed effect of investment in ICT and find that industry TFP accelerations in the 2000s are positively correlated with ICT capital growth in the 1990s. Jalava & Pojohla (2008) find that spillovers from ICT capital played an important role in Finland in the 1990s. However, there are no published estimates of this effect for electricity in other countries.

As regards the relative importance of the three sources to overall GDP per capita growth, we find similar results to those obtained for ITC in Finland, where *tfp* growth in the new technology-producing industries is around 60% of the overall contribution. Stiroh (2002) also finds that capital deepening and *tfp* growth had the biggest impact on overall labour productivity growth. However, Oulton (2012) finds that the main boost to growth comes from ICT use and not from ICT production, and concludes that a country with no ICT production can benefit from the new technology through trade. In our case the predominant effect is the multifactor productivity growth in the electricity-producing industries (utilities and electrical machinery and equipment). The modernisation of the domestic machinery and equipment industry made it easier for a wide array of local firms to access new electrical equipment. Cheaper capital goods and utilities invigorated investment. This implies that the benefits of electrical capital investment were consistent with the costs (caused by the rapid decline relative to capital goods prices) and accrued to those firms that either produced electrical goods or restructured their operations to implement the new technology. The second contribution comes from the rapid *tfp* growth in the electrical utilities industry. This reinforces the idea that the articulation of the central dispatching network was crucial in reducing the real cost of production and boosting electricity consumption across sectors, and thus the implementation of the new managerial and organisational regime based on the emergence of electricity-based manufacturing process technologies.

Since other authors have not estimated the contribution of the electricity spillover effects, it is difficult to set a reliable comparison. However, the “spillover effect from ICT capital” has been estimated for several countries. We found that the relative importance of this effect is lower than that obtained by most of the above-cited authors for ICT in the 1990s and 2000s.

5. Conclusions

One specific question is posed in this paper: to what extent did electrification contribute to economic growth in Spain's "most progressive era"? Like the 1920s in the U.S., the 1950s and 1960s represent for Spain the moment to seize the opportunity to incorporate and develop the technologies of the Second Industrial Revolution. It therefore makes sense to calculate the contribution of electrification to Spanish economic growth some decades after the introduction of this new source of energy and some decades later than usually estimated for the U.S and other European countries.

As elsewhere in Europe, the introduction of electricity into Spain took place relatively early, in the final decades of the 19th century. Its spread across the exiguous industrial sector was relatively rapid. By the start of the Civil War, most of the horsepower used in the exiguous manufacturing sector was generated by electricity. The expansion of electricity was interrupted by the war and the economic policy of the early years of Franco's dictatorship. New agreements between Franco's government and large private firms in the 1950s created the conditions to encourage investment in new plants and organise a centralised dispatching network. The expansion of electricity production made it possible to cope with increasing demand from the expanding industrial sector. In the 1960s a change towards a more outward-looking orientation of foreign trade policy and the inflow of foreign capital led to an expansion of the machinery and equipment industry that was highly dependent on the arrival of capital, technology and expertise from abroad.[27]

We have estimated that the general contribution of electricity to GDP per capita growth was in the order of 22%. The breakdown of this figure into contributions from three different sources - multifactor productivity growth in the new technology

[27] Cubel & Sanchis (2007); Cubel *et al.* (2012).

producing-industries, capital deepening and spillover effects from the use of electricity - draws a similar picture to that obtained by other authors for the impact of ICT over the last two decades. Multifactor productivity growth within the "electrical utilities" and the "electrical machinery and equipment" industries made the biggest contribution to overall GDP per capita growth. At least 67% of the overall contribution of electricity came from these sources.

As the recently-created technology-producing industries became more efficient, new technology could spread its productivity gains throughout the economy. Between 1958 and 1970, the relative price of machinery and equipment with regard to the GDP deflator decreased by 45%.[28] As a result, investment in new capital goods boomed in those decades, rising from a rate of 2.3% of GDP in 1958 to 5.7% in 1970. At least 95% of this investment was in electrical capital goods. Hence we find that 21% of electricity's contribution to GDP per capita growth came from capital deepening in specific capital goods and infrastructures related to electricity.

Finally, one of the main contributions of this research is the calculation of some kind of spillover effect related to the use of this technology. Total factor productivity growth at industry level has been calculated following a double deflation method for output and intermediate inputs and after accounting for industry-specific improvements in labour quality and capital. We therefore believe that the positive relationship that we find between specific-industry TFP growth and investment in electrical capital goods is due to spillovers or positive externalities deriving from the use of this new technology. The spillover effect arising from capital deepening in electrical capital goods was in the order of 11%, although computations in connection with this effect are still quite rough.

[28] It is interesting to highlight that Spain could be a special case of some kind because much of the decrease could be explained by openness to international trade (Cubel & Sanchis, 2007). This meant abandoning rationed markets and opening the door to new competitors. Certainly openness brought the opportunity to access capital goods on the cutting edge of technology and at the same time encouraged investment in the domestic capital industries to cope with the arrival of new competitors.

It has been shown that electricity's contribution to GDP per capita growth in Spain in the period 1958-1970 was twice the size of electricity's contribution in Finland in the period 1920-1938, with Finland until now being the only country with reliable estimations for electricity (Jalava & Pohjola, 2008). However, the contribution of electricity in Spain in the period analysed is half the contribution of ICT in Finland in the period 1990-2004 (50%) and also lower than the ICT contribution in the U.S in the 1990s[29].

In the two decades when a wider, more efficient and integrated electricity network was established in Spain, the economy had more scope to develop the technologies of the Second Industrial Revolution, most of them related to a more efficient use of electricity and electrical machinery. It was then that electrification could show itself as a general purpose technology, with a contribution to GDP per capita growth of 22%.

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[29] Oliner & Sichel (2000, 2002); Jorgenson & Stiroh (2000), Jorgenson, Ho & Stiroh (2002, 2005); Oliner, Sichel & Stiroh (2007); Brynsolfsson & Hitt (2000, 2003); Stiroh (2002).

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