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On the Effects of Infrastructure Investments on Industrial CO_2 Emissions in Portugal

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Abstract

We estimate the effects of infrastructure investments on industrial CO_2 emissions in Portugal based on the economic effects of twelve types of infrastructure investments on twenty-two different industries and the industry-specific CO_2 emission factors. Our conclusions are as follows. First, most infrastructure investments help the emissions intensity of the economy. The exceptions are investments in airports and healthcare. Second, the economic effects of the different types of infrastructure investments on the electrical power industry are central in determining the overall effects on emissions. Indeed, electric power accounts for 35% of CO_2 emissions and has extremely high emissions factor. Third, if the emissions from electricity generation were eliminated, most infrastructure investments would still lead to a decline in emissions intensity. Investments in national roads would leave the emissions intensity unchanged while investments in healthcare have adverse effects. There are several important policy implications of these results. Given the present electric generating mix, investment in national roads are appropriate from an environmental perspective, while investments in airport infrastructure are not. Under a scenario of aggressive use of renewable energy sources in electricity generation, however, the best investments would be in railroads and airports, two industries highly dependent on the use of electricity.

Keywords

Infrastructure investment, CO_2 emissions, industry-level economic effects, industry-level emission effects, VAR

1. Introduction

This article explores how infrastructure investments affect industrial CO_2 emissions. Using empirical evidence on the industry level economic effects of infrastructure investment, we consider industry-specific CO_2 emission factors and twelve different types of infrastructure investments carried out in twenty-two industries that jointly cover the whole spectrum of economic activity in Portugal.

The last thirty years in Portugal have witnessed substantial changes in the energy industry and in carbon dioxide emissions from fossil-fuel combustion activities. These constitute the bulk of greenhouse gas (GHG) emissions from energy activities, and about 70% of GHG emissions in the country. In 1990, a benchmark year for emissions data defined in the context of the United Nations Framework Convention on Climate Change and the Kyoto Protocol (Haita, 2012; European Commission, 2014a), carbon dioxide emissions from fossil-fuel combustion activities amounted to 40.9 Mt CO_2. Emissions grew 57% between 1990 and 2005, at which time they reached 64.1 Mt CO_2, the highest level recorded in two decades. Together, the introduction of natural gas in the late 1990s, the effective promotion of renewable energies, and the European Union Emissions Trading System (ETS) have allowed emissions to drop to 45.3 Mt CO_2, a 25% reduction between 2005 and 2012, a result driven, in part, by weak economic conditions and the recent global financial crisis.

Following these positive outcomes—both in terms of the increased reliance on domestic renewable energies and reductions in GHG emissions—Portugal, together with other European Union Member States, has set forth an ambitious program for 2030 to reduce emissions by 40%, relative to 1990 levels (see, for example, the national roadmap to low carbon in 2050 from Agência Portuguesa do Ambiente (2012), or the policy framework for climate and energy from the European Commission (2014b, 2014c)). In recent years, the targets have only become more ambitious (Seixas et al., 2017).

In a different vein, Portugal has engaged in very significant infrastructure development efforts over the last thirty years. Over this time, infrastructure investments averaged 4.2% of GDP (Pereira, 2013). More importantly, after a lull over the last decade, infrastructure investments are now back in the limelight of the policy debate (Ministério da Economia, 2014) for a comprehensive look at current infrastructure investment needs and priorities). In this context, it is of the utmost importance to identify the impact of these infrastructure investments on CO_2 emissions in the country, not only to help understand where we are, but also and, primarily, to be able to develop environmentally-friendly infrastructure policies in critical areas such as transportation and social infrastructures.

In this article we estimate the impact of different types of infrastructure investments on aggregate industrial CO_2 emissions in Portugal (Note 1) by following a two-step approach. First, we use a multivariate dynamic time series approach, based on the use of industry-infrastructure specific vector autoregressive (VAR) models including industry-specific output, employment, and private investment, in addition to different types of infrastructure investments, to calculate the economic effects at the industry level of different types of infrastructure investments. This approach was developed in Pereira (2000, 2001), and was subsequently applied to the U.S. in Pereira and Andraz (2003, 2004), and to

Portugal in Pereira and Andraz (2005, 2007, 2011). Second, we consider the industry-specific CO_2 emission factors which, coupled with the industry-specific marginal products of the different types of investments, are used to determine the marginal CO_2 emission effects of these different types of investments. We seek to establish if and under what conditions infrastructure investments will contribute to reducing CO_2 emissions, or at least contribute to the mitigation of in economy-wide CO_2 emission trends.

The timeliness and relevance of these issues is worth stressing. On one hand, the quest for policies that promote long-term growth in a framework of fragile public budgets is widespread, and the role of infrastructure investments in this quest increasingly recognized. Among international organizations, there has been, in recent years, a remarkable renewal of interest on issues relating to public investment and, in particular, to infrastructure investments (Council of Economic Advisers, 2016; European Central Bank, 2016; European Commission, 2014d, 2014e, 2016; IMF, 2014, 2015; World Bank, 2016, 2017). On the other hand, climate and energy are both at the center of the policy concerns and objectives in the E.U. (European Commission, 2014b, 2014c) and, as such, all European countries need to deal, albeit to different degrees, with these issues. In addition, there is a growing chorus of institutional voices urging different countries to adopt green taxes (Eurogroup, 2014; IMF, 2014; OECD, 2014; Parry et al., 2014; World Bank, 2014). In this policy environment understanding how different infrastructure investments affect CO_2 emissions is of the utmost importance.

The remainder of this article proceeds as follows. Section 2 presents the infrastructure investment and the industry-specific economic data. Section 3 presents preliminary econometric results. Section 4 presents the industry-specific economic effects of different types of infrastructure investments. Section 5 presents the implications of these effects for aggregate industrial CO_2 emissions considering the industry-specific CO_2 emission factors. Section 6 presents a summary, policy implications, and concluding remarks.

2. Data Sources and Description

2.1 The Infrastructure Investment Data Set

The data for infrastructure investment are from a new data set developed by Pereira and Pereira (2016), and cover the period between 1978 and 2011. Infrastructure investment is measured in millions of 2005 euros. We consider infrastructure investment in twelve individual types of infrastructures, which can be grouped in five main categories: road transportation infrastructure, other transportation infrastructure, social infrastructures, and utilities infrastructure. Table 1 presents some summary information for infrastructure investment effort, as a percent of GDP, as well as a percent of total infrastructure investment.

Road transportation infrastructures include national roads, municipal roads and highways, and account for 28.2% of total infrastructure investment over the sample period. Investment efforts and the extension of motorways in Portugal grew tremendously during the 1990s, with the last ten years marked by a substantial increase in highway investments. In absolute terms, this corresponds to an increase from 0.75% of the GDP in the 1980s to 1.56% in the last decade of the sample period.

The largest component of road transportation investments for the sample period was national road investment, amounting to 0.61% of GDP and 12.21% of total infrastructure investment. What is most striking, however, is the substantial increase in investment in highways since 2000. In the last decade, highway infrastructure investment amounted to 0.73% of GDP and surpassed national road infrastructure investment in importance, with highway investment amounting now to 11.70% of total infrastructure investment. In contrast, the past thirty years have seen a steady decline in municipal road infrastructure investments.

Other transportation infrastructures include railroads, airports and ports, and account for 9% of total infrastructure investment. These investments reached their apex in the nineties with the modernization of the railroad network and port expansion projects, while the last ten years also saw substantial growth in investment in airports. In absolute terms, this reflects an increase from 0.22% of GDP in the 1980s to 0.48% in the last decade of the sample period.

Railroads represent the bulk, nearly 75%, of investment in other transportation infrastructures. Investment in railroad infrastructures amounted to 0.34% of GDP over the sample period, reaching 0.45% of GDP during the 1990s. Investment in ports and airports represented relatively smaller investment volumes due to the rather limited number of major airports and major ports in the country. Nonetheless, very substantial investments in the airports of Lisbon and Porto were undertaken in the last decade with investment volumes reaching 0.08% of GDP, nearly double that seen in the 1980s.

Table 1. Infrastructure Investment by Type of Asset

	1980-2009	1980-1989	1990-1999	2000-2009
Infrastructure Investment as Percent of GDP				
Infrastructure Investment	**4.18**	**2.88**	**4.40**	**5.04**
Road Transportation	**1.19**	**0.74**	**1.32**	**1.52**
National Roads	0.52	0.33	0.61	0.57
Municipal Roads	0.36	0.34	0.41	0.36
Highways	0.32	0.07	0.30	0.59
Other Transportation	**0.38**	**0.22**	**0.47**	**0.46**
Railroads	0.29	0.15	0.37	0.35
Airports	0.04	0.03	0.03	0.06
Ports	0.05	0.03	0.06	0.06
Utilities	**1.65**	**1.11**	**1.53**	**2.04**
Water Infrastructures	0.31	0.14	0.27	0.42
Electricity and Gas	0.61	0.46	0.38	0.87
Petroleum Refining	0.16	0.09	0.18	0.15
Telecommunications	0.57	0.41	0.70	0.61
Social Infrastructures	**0.96**	**0.81**	**1.08**	**1.02**
Health Facilities	0.46	0.28	0.47	0.60
Educational Buildings	0.50	0.53	0.60	0.41
Percentage of Total Infrastructure Investment				
Infrastructure Investment	**100.00**	**100.00**	**100.00**	**100.00**
Road Transportation	**28.49**	**25.99**	**30.35**	**30.23**
National Roads	12.46	11.52	14.09	11.43
Municipal Roads	9.16	11.90	9.47	7.10
Highways	6.86	2.56	6.79	11.70
Other Transportation	**8.91**	**7.57**	**10.52**	**9.21**
Railroads	6.64	5.17	8.31	6.92
Airports	1.06	1.17	0.81	1.21
Ports	1.21	1.23	1.40	1.08
Utilities	**38.85**	**38.04**	**34.61**	**40.43**
Water Infrastructures	6.99	4.90	5.98	8.17
Electricity and Gas	14.44	15.97	8.45	17.53
Petroleum Refining	3.64	3.22	4.06	2.83
Telecommunications	13.77	13.94	16.12	11.89
Social Infrastructures	**23.76**	**28.41**	**24.52**	**20.13**
Health Facilities	10.82	9.89	10.73	11.97
Educational Buildings	12.94	18.52	13.79	8.16

Public utilities include electricity and gas infrastructures, water supply and treatment facilities, and petroleum refining plants, and account for 25.72% of total infrastructure investment in the sample period. Investment in public utilities reached a high level in the 1980s, driven by substantial investment in coal powered power plants and in refineries. More recently, investments in renewable energies and natural gas network have contributed to sustained growth in investment in utilities. In absolute terms, the importance of these investments increased from 0.94% of GDP in the eighties to 1.78% in the last decade.

Investment in electricity and gas infrastructures, the most important of the public utility assets in terms of the investment effort, averaged 0.73% of GDP, or 14.34% of total infrastructure investment. In the 2000s, it reached 1.09% of GDP, and accounted for 17.53% of total infrastructure investment. In turn, water and waste water investments averaged 0.37% of GDP or 6.8% of total investment for the period with a clear increasing trend while investments in refineries averaged 0.22% of GDP or 4.58% of total investment with a declining trend over the last two decades.

Finally, investments in **telecommunications** amounted to 0.67% of GDP, or 13.34% of total investment over the sample period. In the nineties, with the expansion of mobile communications networks, they reached their peak with 0.85% of GDP, or 16.12% of total infrastructure investments.

Social infrastructures include health facilities and educational buildings and account for 23.8% of infrastructure investment. These investments showed a slowly declining pattern over time in terms of their relative importance in total infrastructure investment. In absolute terms, however, they remained stable over the last two decades representing just over 1.0% of GDP.

Investment in health facilities amounted to 0.55% of GDP or 10.7% of total investment, while investment in educational facilities amounted to 0.60% of GDP or 13.1% of total investment. While both are comparable in terms of their relative magnitude over the sample period, their evolution was markedly different. Investment in health facilities increased steadily both as a percent of GDP and as a percent of total infrastructure investment, the opposite being the case in general terms for investment in educational buildings. Indeed, investment in educational facilities reached their highest level in the nineties with 0.73% of GDP while investment in health facilities reached its greatest volumes in the last decade with 0.75% of GDP.

Overall, infrastructure investments grew substantially over the past thirty years, averaging 2.92% of the GDP in the 1980s, 4.45% in the 1990s and 5.17% in the 2000s. The increase in infrastructure investments is particularly pronounced after 1986, the year in which Portugal joined the E.U., and in the 1990s in the context of the E.U. Structural and Cohesion Funds, with the Community Support Framework I (1989-1993) and the Community Support Framework II (1994-1999). The infrastructure investment effort decelerated somewhat during the Community Support Framework III (2000-2006) and more significantly with the QREN (2007-2013). These landmark dates for joining the E.U., as well as the start of the different community support frameworks, are all considered as potential candidates for structural breaks in every single step of the empirical analysis that follows.

2.2 The Industry Data Set

The data on industry-specific output, employment, and private investment are obtained from different annual issues of the National Accounts, published by National Institute of Statistics (Statistics Portugal) and available on-line at http://www.ine.pt. Output and private investment are measured in millions of constant 2005 Euros, while employment is measured in thousands of employees.

Table 2. Industry Classification Grouped by Sector

Primary Sector - Agriculture	
Agriculture (S1)	Agriculture, forestry and fishing
Mining (S2)	Mining and quarrying
Secondary Sector – Manufacturing	
Food (S3)	Manufacture of food products, beverages and tobacco products
Textiles (S4)	Manufacture of textiles, wearing apparel and leather products
Paper (S5)	Manufacture of wood and paper products, and printing
Chemical and Pharmaceutical (S6)	Manufacture of chemicals and chemical products. Manufacturing of basic pharmaceutical products and pharmaceutical preparations.
Non-metallic minerals (S7)	Manufacture of rubber and plastics products, and other non-metallic mineral products
Basic metals (S8)	Manufacture of basic metals and fabricated metal products, except machinery and equipment
Machinery and equipment (S9)	Manufacture of computer, electronic and optical products; Manufacture of electrical equipment; Manufacture of machinery and equipment; Manufacture of transport equipment; Manufacture of furniture; other manufacturing; repair and installation of machinery and equipment
Tertiary Sector - Private Services	
Electricity and gas (S10)	Electricity, gas, steam and air-conditioning supply
Water (S11)	Water, sewerage, waste management and remediation activities
Construction (S12)	Construction
Wholesale and retail trade (S13)	Wholesale and retail trade, repair of motor vehicles and motorcycles
Transportation and storage (S14)	Transportation and storage
Hospitality (S15)	Accommodation and food service activities
Telecommunications (S17)	Telecommunications
Finance (S17)	Financial and insurance activities
Real estate (S18)	Real estate activities
Professional services (S19)	Publishing, audiovisual and broadcasting activities; Computer programming, consultancy and related activities; information service activities; Legal and accounting activities; activities of head offices; management consultancy activities; architecture and engineering activities; technical testing and analysis; Scientific research and development; Advertising and market research; other professional, scientific and technical activities; veterinary activities; Administrative and support service activities; Arts, entertainment and recreation; Other services activities
Tertiary Sector - Public Services	
Public administration (S20)	Public administration and defense; compulsory social security
Education (S21)	Education
Health (S22)	Human health services; Social work activities

Table 3. Share of GDP by Industry

	1980-2009	1980-89	1990-99	2000-09
Agriculture	**8.6**	**14.1**	**6.6**	**3.4**
Agriculture (S1)	6.7	10.2	5.6	2.9
Mining (S2)	1.9	3.9	1.0	0.5
Manufacturing	**18.1**	**20.5**	**18.5**	**15.1**
Food (S3)	2.1	2.0	2.2	2.1
Textiles (S4)	3.7	4.2	4.2	2.7
Paper (S5)	2.2	2.4	2.2	1.8
Chemical and pharmaceutical (S6)	1.7	2.3	1.5	1.2
Non-metallic minerals (S7)	2.7	3.4	2.6	2.0
Basic metals (S8)	2.5	3.5	2.1	1.8
Machinery and equipment (S9)	3.3	2.7	3.7	3.7
Private Services	**56.3**	**52.7**	**56.7**	**60.3**
Electricity and gas (S10)	2.1	1.8	2.4	2.2
Water (S11)	0.6	0.5	0.6	0.9
Construction (S12)	7.1	6.8	7.0	7.7
Wholesale and retail trade (S13)	15.4	16.8	15.1	14.1
Transportation and storage (S14)	4.6	5.2	4.3	4.6
Hospitality (S15)	3.7	2.7	3.9	4.7
Telecommunications (S16)	1.9	1.4	2.0	2.3
Finance (S17)	6.3	6.3	6.1	6.6
Real estate (S18)	7.5	6.0	7.4	8.0
Professional services (S19)	7.2	5.2	7.8	9.1
Public Services	**17.0**	**12.8**	**18.2**	**21.2**
Public administration (S20)	8.5	7.2	8.9	9.9
Education (S21)	5.3	3.6	6.0	6.8
Health (S22)	3.2	2.0	3.3	4.5
Total	**100.0**	**100.0**	**100.0**	**100.0**

We consider twenty-two industries divided in four main groups: two primary industries (agriculture and mining), seven manufacturing (food, textiles, paper, chemical and pharmaceutical, non-metallic minerals, metallic, and machinery), ten private services industries (electricity, water, construction, trade, transportation, hospitality, telecommunications, finance, real estate, and professional services) and three public services industries (administration, health and education). In Table 2 we include details on the definition of the different sectors. Summary statistics on industry output are provided in Table 3.

3. Preliminary Data Analysis (Note 2)

3.1 Unit Roots, Cointegration, and VAR Specification

We start with unit root and cointegration analyses. Having determined based on standard ADF tests that stationarity in growth rates seems to be a good specification for all of the series considered, and in the absence of any evidence for cointegration as determined by a barrage of Engle-Granger tests, we follow the standard procedure in the literature and determine the specifications of the VAR models using growth rates of the original variables.

We estimate twelve VAR models for each of the twenty-two industries, one for each of the different infrastructure types, for a total of two-hundred-and-sixty-four models. Each model includes industry-specific output, employment, and private investment, as well as the relevant infrastructure investment variable. We use the BIC to determine structural breaks and deterministic components to be included. Our test results suggest that a VAR specification of first order with a constant and a trend, as well as structural breaks in 1989, 1994, and 2000, the years of the inception of the first three community support frameworks, is the preferred specification in the overwhelming majority of the cases.

3.2 Identifying Exogenous Innovations in Infrastructure Investment

The key issue in determining the impact of infrastructure investment is the identification of exogenous shocks representing innovations in infrastructure investments that are not contaminated by other contemporaneous innovations and avoid reverse causation. In dealing with this issue, we draw on the approach followed in dealing with the effects of monetary policy (Christiano, Eichenbaum, & Evans, 1996, 1999; Rudebusch, 1998) and adopted by Pereira (2000) in the context of the analysis of the effects of infrastructure investment.

The identification of exogenous shocks to infrastructure investment would, in general, result from knowing what fraction of the government appropriations in each period is due to purely non-economic reasons. The econometric counterpart to this idea is to consider a policy function which relates the rate of growth of infrastructure investment to the relevant information set. The residuals from these policy functions reflect the unexpected component of the evolution of infrastructure investment and are, by definition, uncorrelated with innovations in other variables.

We assume that the relevant information set for the policy function includes past but not current values of the economic variables. In the context of the standard Choleski decomposition, this is equivalent to assuming that innovations in investment lead innovations in economic variables, i.e., while innovations in infrastructure investment affect the economic variables contemporaneously, the reverse is not true. This also means that the estimated effects of infrastructure investments are invariant to the ordering of the three economic variables.

We have two conceptual reasons for this assumption. First, it seems reasonable to assume that the economy reacts within a year to innovations in infrastructure investments. Second, it also seems reasonable to assume that the public sector is unable to adjust infrastructure investment decisions to innovations in the economic variables within the same year. This is due to the time lags involved in information gathering and public decision-making.

Furthermore, this assumption is reasonable also from a statistical perspective. Invariably, the policy functions point to the exogeneity of the innovations in infrastructure investment, i.e., the evolution of the different infrastructure investments does not seem to be affected by the lagged evolution of the remaining variables. This is to be expected, because infrastructure investments were very much linked to E.U. support programs and therefore not responsive to the ongoing economic conditions. Moreover, we would not expect any single economic sector to have an impact on decision making for infrastructure investments at the national level.

3.3 Measuring the Effects of Innovations in Infrastructure Investment

To measure the effects of a one-percentage point, one-time shock in the rates of growth of the different types of infrastructure investment on output for the different industries, we estimate the accumulated impulse-response functions for each of the VAR models. The accumulated impulse response functions typically converge within a relatively short time period. The error bands surrounding the point estimates for the accumulated impulse responses are computed via bootstrapping methods. We consider 90% intervals, although bands that correspond to a 68% posterior probability are the standard in the literature (see Sims & Zha, 1999). From a practical perspective, when the 90% error bands for the accumulated impulse response functions include zero we consider that the effects are not significantly different from zero (Note 3).

To measure the effects of shocks in infrastructure investment, we calculate the long-term accumulated elasticities and the long-term accumulated marginal products of the different industry-specific outputs with respect to each type of infrastructure investment. These concepts depart from the conventional understandings, because they are not based on *ceteris paribus* assumptions, but, instead, they include all the dynamic feedback effects among the different variables.

Long-term accumulated elasticities are to be interpreted as the total accumulated percentage-point long-term change in output per one-percentage point accumulated long-term change in infrastructure investment. In turn, long-term accumulated marginal products measure the monetary change output for each additional euro of investment in infrastructures. The marginal products are obtained by multiplying the average output to infrastructure investment ratio by the corresponding elasticity. We use the average ratio over the last ten years of the sample. Using a recent time period allows the marginal products to reflect the relative scarcity of the different types of infrastructures at the margin of the sample period, while the choice of ten years prevents these ratios from being overly affected by business cycle factors.

4. On the Effects of Infrastructure Investments on Economic Performance

We now consider the first of our two conceptual steps in our analysis. In this step, we will determine the effects of different types of infrastructure investments on economic activity at the industry level, as well as the implied aggregate economy-wide effects.

4.1 On the Aggregate Effects of Infrastructure Investments

We start by considering the aggregate long-term effects of the different types of infrastructure assets. These total aggregate effects are obtained as the sum of all statistically significant industry-specific marginal products. See the bottom row of Tables 4 to 7 for details. Broadly speaking, we can divide the set of infrastructure assets in three groups, in terms of the magnitude of their total long-term effects. First, we have a group of assets with high marginal products of around 20 euros. These are national roads, railroads, airports, ports, health and education. A second group has medium-sized magnitude effects. These are municipal roads, highways, refineries, and telecommunication. Finally, we have water facilities and electricity and gas facilities, for which we estimate a negative marginal product. This reflects a great level of maturity of the water and electrical systems in the country, already in the beginning of the sample period.

4.2 On the Industry-Specific Effects of Infrastructure Investments

We now give a general overview of the industry-specific effects by type of infrastructure asset. Details are presented in Tables 4 to 7. In terms, of **roads infrastructure** investments, we estimate the following effects. For investments in national roads, the industries that benefit the most are machinery and equipment (S9), construction (S12), real estate (S18), professional services (S19) and education (S21) and concentrate 82.2% of the total long-term effects of this investment. For municipal roads, the greatest beneficiaries are basic metals (S8), construction (S12), trade (S13), hospitality (S15), and public administration (S20) which combine 94.7% of the total long-term effects. For investment in highways, 79.8% of the benefits go to construction (S12), finance (S17), real estate (S18), public administration (S20) and education (S21).

In terms of investments in **other transportation infrastructures** the effects, are as follows. For railroad investments, most of the benefits go to electricity (S10), construction (S12), trade (S13), real estate (S18), and public administration (S20), which together account for 110.7% of the benefits (Note 4). For airport investments, the most important effects are on electricity (S10), trade (S13), transportation (S14), hospitality (S15), and education (S21), together with 91% of the total effects. Finally, for investments in ports the sectors that benefit the most are trade (S13), hospitality (S15), finance (S17), real estate (S18), and professional services (S19), with a combined share of 64.3% of the total effect.

As **utilities** are concerned, as we noted that for investments in water and in electricity, the estimated effects are negative. In both cases, a very large fraction of such negative effects—88.2% and 78.3%, respectively, come from adverse effects on two sectors, hospitality (S15) and real estate (S18). For investments in refineries, the effects occur in construction (S12), trade (S13), professional services (S19), public administration (S20), and education (S21) with 102.7% of the net total effects. In terms of investments in telecommunications, most of the effects go to construction (S12), trade (S13), finance (S17), real estate (S18), and professional services (S19).

Finally, in terms of investments in **social infrastructures**, we observe that the most important effects of health infrastructure investments are on machinery and equipment (S9), construction (S12), transportation (S14), real estate (S18), and professional services (S19) with 96.7% of the total, while the most important effects of education infrastructure investments occur in construction (S12), finance

(S17), real estate (S18), professional services (S19), and public administration (S20) with 80.1%.

From these results, two important conclusions follow. First, the effects of the different types of infrastructure assets tend to be highly concentrated in a small number of industries. Second, there are some industries that seem to particularly benefit overall. These are, primarily, construction (S12) and real estate (S18), but also trade (S13), hospitality (S15), and professional services (S20), and to a lesser extent finance (S17) and education (S21). These are all service sectors.

Table 4. Industry-Specific Effects of Investments in Road Transportation Infrastructure

	National Roads		**Municipal Roads**		**Highways**	
	Elasticity	**Marginal Product**	**Elasticity**	**Marginal Product**	**Elasticity**	**Marginal Product**
Agriculture and Mining						
Agriculture (S1)	0.1147	0.47	-0.1381	-0.90	-0.0028*	*
Mining (S2)	-0.5102	-0.35	0.2890	0.32	-0.0833	-0.06
Manufacturing						
Food (S3)	0.0510	0.15	0.1115	0.53	0.0057*	*
Textiles (S4)	0.1321	0.49	0.0870	0.52	-0.0044*	*
Paper (S5)	0.1046	0.26	-0.1499	-0.59	0.0470	0.11
Pharmaceuticals (S6)	-0.0294*	*	-0.1280	-0.25	-0.0092*	*
Non-metallic minerals (S7)	0.3105	0.85	0.0764	0.34	0.0351	0.09
Basic metals (S8)	-0.0295*	*	0.1865	0.74	0.0013*	*
Machinery & equipment (S9)	0.3756	1.93	-0.0897*	*	0.0423	0.21
Private Services						
Electricity and gas (S10)	-0.4776	-1.49	0.0174*	*	-0.0213*	*
Water (S11)	-0.5831	-0.71	0.0152*	*	-0.0196*	*
Construction (S12)	0.2841	3.06	0.0670	1.16	0.0526	0.56
Wholesale & retail trade (S13)	0.0759	1.51	0.0934	2.97	0.0123	0.24
Transportation, storage (S14)	0.0605	0.39	0.0439	0.45	-0.0020*	*
Hospitality (S15)	0.0837	0.56	0.1643	1.75	0.0180	0.12
Telecommunications (S16)	-0.0295*	*	-0.0274*	*	-0.0027*	*
Finance (S17)	-0.0672*	*	0.0386*	*	0.0489	0.45
Real estate (S18)	0.6682	7.48	-0.1126*	*	0.1918	2.12
Professional services (S19)	0.1472	1.89	0.0134*	*	0.0135	0.17
Public Services						
Public administration (S20)	0.1002	1.23	0.0505	0.99	0.0289	0.35
Education (S21)	0.3291	3.16	-0.0173*	*	0.0438	0.41
Health (S22)	0.0644	0.41	0.0309*	*	0.0194	0.12
TOTAL		**21.29**		**8.03**		**4.89**

Note. Values marked with * are not statistically significant as implied by the standard deviation bands around the impulse response functions.

Table 5. Industry-Specific Effects of Investments in Other Transportation Infrastructure

	Railroads		**Airports**		**Ports**	
	Elasticity	**Marginal Product**	**Elasticity**	**Marginal Product**	**Elasticity**	**Marginal Product**
Agriculture and Mining						
Agriculture (S1)	-0.0428*	*	0.0085*	*	0.0046	0.20
Mining (S2)	0.0148*	*	-0.0914	-0.59	0.0242	0.18
Manufacturing						
Food (S3)	0.0083*	*	0.0304	0.85	0.0258	0.82
Textiles (S4)	-0.0394*	*	0.0067*	*	0.0258	1.03
Paper (S5)	-0.0962	-0.39	-0.0287	-0.67	0.0208	0.55
Pharmaceuticals (S6)	-0.0681	-0.14	-0.0017*	*	-0.0275	-0.35
Non-metallic minerals (S7)	-0.0598	-0.27	0.0115*	*	0.0216	0.63
Basic metals (S8)	-0.0582	-0.24	-0.0212*	*	0.0368	0.96
Machinery & equipment (S9)	-0.1894	-1.62	0.0141	0.68	-0.003*	*
Private Services						
Electricity and gas (S10)	0.1829	0.95	0.1008	2.97	-0.024*	*
Water (S11)	0.2035	0.41	0.0917	1.06	-0.0382	-0.50
Construction (S12)	0.1518	2.72	-0.0074*	*	0.0124	1.43
Wholesale & trade (S13)	0.0517	1.70	0.0253	4.74	0.0122	2.58
Transport & storage (S14)	-0.0532	-0.57	-0.0474	-2.87	0.0226	1.54
Hospitality (S15)	0.0399	0.44	0.0502	3.16	0.0289	2.05
Telecommunications (S16)	-0.0078*	*	0.0035*	*	-0.0097	-0.34
Finance (S17)	-0.0283*	*	0.0254	2.24	0.0228	2.28
Real estate (S18)	0.8968	16.69	-0.0576*	*	0.0419	5.00
Professional services (S19)	-0.0367	-0.78	-0.0158*	*	0.0293	4.01
Public Services						
Public administration (S20)	0.0482	0.98	0.0234	2.70	0.0143	1.86
Education (S21)	0.0500	0.80	0.0432	3.92	0.0085*	*
Health (S22)	0.0149	0.16	0.0200	1.19	0.0130	0.87
TOTAL		**20.84**		**19.38**		**24.80**

Note. Values marked with * are not statistically significant as implied by the standard deviation bands around the impulse response functions.

Table 6. Industry-Specific Effects of Investments in Public Utilities

	Water		Electricity		Refineries	
	Elasticity	**Marginal Product**	**Elasticity**	**Marginal Product**	**Elasticity**	**Marginal Product**
Agriculture and Mining						
Agriculture (S1)	-0.0537	-0.33	-0.0311	-0.08	-0.0033*	*
Mining (S2)	0.1996	0.20	-0.0345*	*	0.0080*	*
Manufacturing						
Food (S3)	0.0155	0.07	-0.0110*	*	0.0027*	*
Textiles (S4)	0.0218	0.12	-0.0036*	*	0.0001*	*
Paper (S5)	-0.0548	-0.20	0.0152	0.02	0.0080*	*
Pharmaceuticals (S6)	-0.0325	-0.06	-0.0224	-0.02	-0.0160*	*
Non-metallic minerals (S7)	0.0102*	*	-0.0071*	*	0.0001*	*
Basic metals (S8)	0.0345*	*	0.0318	0.05	0.0069*	*
Machinery and equipment (S9)	-0.1811	-1.39	0.0045*	*	-0.0042*	*
Private Services						
Electricity and gas (S10)	-0.0482*	*	-0.0288	-0.06	-0.0347	-0.43
Water (S11)	-0.0436*	*	-0.0192*	*	-0.0160*	*
Construction (S12)	-0.0006	-0.01	0.0010*	*	0.0258	1.10
Wholesale and retail trade (S13)	0.0201	0.60	-0.0007*	*	0.0057	0.44
Transportation & storage (S14)	0.0217	0.21	-0.0150	-0.06	0.0019*	*
Hospitality (S15)	0.0702	0.70	-0.0208	-0.09	-0.0024*	*
Telecommunications (S16)	-0.0043*	*	0.0019*	*	-0.0009*	*
Finance (S17)	0.0074*	*	-0.0406	-0.25	0.0065*	*
Real estate (S18)	-0.1687	-2.82	-0.1324	-0.96	0.0252*	*
Professional services (S19)	-0.0012*	*	0.0016*	*	0.0186	0.94
Public Services						
Public administration (S20)	-0.0196	-0.36	0.0143	0.11	0.0154	0.74
Education (S21)	-0.0225	-0.32	-0.0088*	*	0.0161	0.61
Health (S22)	-0.0190	-0.18	0.0022*	*	0.0133	0.33
TOTAL		**-3.99**		**-1.34**		**3.73**

Note. Values marked with * are not statistically significant as implied by the standard deviation bands around the impulse response functions.

Table 7. Industry-Specific Effects of Investments in Telecommunications and Social Infrastructure

	Telecom		Health		Education	
	Elasticity	Marginal Product	Elasticity	Marginal Product	Elasticity	Marginal Product
Agriculture and Mining						
Agriculture (S1)	0.0126*	*	-0.0648*	*	-0.3254	-1.85
Mining (S2)	0.0706*	*	0.1137*	*	-0.3136	-0.30
Manufacturing						
Food (S3)	0.0194*	*	-0.0507*	*	0.0718	0.30
Textiles (S4)	-0.0146*	*	-0.0338*	*	-0.1441	-0.75
Paper (S5)	0.0955	0.20	0.0728	0.41	0.0938	0.32
Pharmaceuticals (S6)	-0.0117*	*	-0.0655*	*	-0.1597	-0.27
Non-metallic minerals (S7)	0.0746	0.17	0.1517	0.94	0.1644	0.63
Basic metals (S8)	0.1609	0.33	0.0944*	*	-0.0430	-0.15
Machinery and equipment (S9)	0.0276*	*	0.1650	1.93	0.1969	1.41
Private Services						
Electricity and gas (S10)	0.0283*	*	-0.1839*	*	-0.2802	-1.22
Water (S11)	0.0294*	*	-0.2439	-0.68	-0.1959	-0.33
Construction (S12)	0.1994	1.79	0.2421	5.93	0.2896	4.35
Wholesale & retail trade (S13)	0.0701	1.16	0.0155*	*	0.0628	1.74
Transport and storage (S14)	0.0327*	*	0.2272	3.31	0.1365	1.22
Hospitality (S15)	0.0946	0.52	-0.0042*	*	-0.0430*	*
Telecommunications (S16)	-0.0397*	*	-0.0270*	*	-0.0100*	*
Finance (S17)	0.2044	1.59	0.0848*	*	0.2075	2.71
Real estate (S18)	0.4784	4.46	0.2611	6.64	0.3925	6.13
Professional services (S19)	0.1112	1.19	0.0674	1.97	0.1599	2.86
Public Services						
Public administration (S20)	0.1024	1.04	-0.0275*	*	0.1486	2.53
Education (S21)	0.0671	0.54	-0.0015*	*	0.2057	2.75
Health (S22)	0.0185*	*	-0.0295*	*	0.1349	1.18
TOTAL		**12.99**		**20.17**		**23.26**

Note. Values marked with * are not statistically significant as implied by the standard deviation bands around the impulse response functions.

5. On the Effects of Infrastructure Investments on CO_2 Emissions

We now consider the second of our two conceptual steps in our analysis, where we use CO_2 emission factors and the marginal products obtained above to identify the effects of infrastructure investments on CO_2 emissions.

5.1 Aggregate and Industry-specific CO_2 Emission Factors

In the first columns of Table 7, we present summary information on the industry shares of CO_2 emissions on total industrial CO_2 emissions. Clearly, industrial CO_2 emissions are highly concentrated. Electricity production (S10) is responsible for 35.5% of emissions, followed by chemical and pharmaceutical (S6), non-metallic minerals (S7), and transportation (S14), with 10.7%, 16.7%, and 9.6%, respectively. Equally important are emissions in construction (S12), with 4.1%, and trade (S13) with 5.0%. These six sectors account for 81.6% of CO_2 emissions over the sample period.

Table 8. Industry-Specific CO_2 Emissions Information

	CO_2 Industrial Emissions Share (%)	**CO_2 Industry Emissions Factor** (thousand tons per million euros)
Agriculture and Mining	**3.6**	
Agriculture (S1)	2.7	0.3998
Mining (S2)	0.9	0.7763
Manufacturing	**35.5**	
Food (S3)	2.2	0.4409
Textiles (S4)	2.3	0.3591
Paper (S5)	2.2	0.5309
Pharmaceuticals (S6)	10.7	3.8906
Non-metallic minerals (S7)	16.3	3.533
Basic metals (S8)	1.1	0.2736
Machinery and equipment (S9)	0.7	0.751
Private Services	**42.1**	
Electricity and gas (S10)	35.5	6.8666
Water (S11)	1.0	0.4742
Construction (S12)	4.1	0.2264
Wholesale and retail trade (S13)	5.0	0.1485
Transport. and storage (S14)	9.6	0.8899
Hospitality (S15)	1.1	0.0923
Telecommunications (S16)	0.1	0.0105
Finance (S17)	0.2	0.0102
Real estate (S18)	0.1	0.0057
Professional services (S19)	1.0	0.0428
Public Services	**3.0**	
Public administration (S20)	1.4	0.0592
Education (S21)	0.3	0.0157
Health (S22)	1.3	0.1278
TOTAL	**100.0**	**0.4216**

We measure the CO_2 emission factors in thousand tons of CO_2 emissions per millions of euros of GDP in 2005 values. To obtain these indicators we simply divide the total CO_2 emissions per industry, from the Satellite Accounts for the Environment published by National Institute of Statistics and available on-line at http://www.ine.pt, by the industrial output values as presented in Section 2. We consider the last ten years of the sample period to match the period considered in the calculations of the marginal products of the different infrastructure investments. Summary information is presented in Table 8.

At the aggregate level, the economy-wide CO_2 emission factor is 0.42. This figure, however, hides a wide dispersion emission factors across different industries. Industries such as chemicals and pharmaceuticals (S6), non-metallic minerals (S7), and electricity (S10) have very high emission factors, 3.89, 3.53, and 6.87, respectively. These are followed at a great distance by mining (S2) and transportation (S14), with 0.78 and 0.89 respectively. As to the remaining industries, the different primary and manufacturing sectors have values close to the average while private and public services values well below the average. The exceptions are machinery and equipment (S9), among the former, and water (S12) among the latter.

These figures, reflecting average aggregate and per industry CO_2 emission intensities, are key to calculating of the effects of different types of infrastructure investments on CO_2 emissions. Given the values of the marginal products of the different infrastructure investments and the corresponding CO_2 emission factors, we can trivially estimate the marginal CO_2 emission effects of the different infrastructure investments.

5.2 Marginal CO_2 Emissions from Infrastructure Investments

The effects of infrastructure investments on CO_2 emissions based on the economy-wide emission factors are reported in the first column of Table 9. Considering the aggregate average of 0.42, we would obtain emission effects of the different infrastructures investments assuming a uniform distribution of infrastructure emission effects across industries. These represent the emissions effect of each infrastructure investment that would leave the aggregate average emissions unaltered.

While useful as a benchmark, these figures would be rather misleading with respect to the actual effects of infrastructure investment in light of the inter-industry disparities in CO_2 emissions intensities. We get a much sharper picture by considering the marginal effects using the industry-specific economic effects and the industry-specific CO_2 emission factors. The results are reported in the second column of Table 9.

Naturally, to make matters clear, it is useful to consider the relationship between the marginal effect obtained from the industry-specific calculations and the average economy-wide effects. The ratio between the two is presented in the third column of Table 9. A negative value (positive, in the cases of water and electricity) reflects a reduction in emissions. A positive value and lower than one implies marginal effects below the average and are, therefore, cases in which the infrastructure investment leads to a reduction in the energy and industrial CO_2 emissions intensity. A positive value greater than one implies that such infrastructure investments increase the energy and industrial CO_2 emissions intensity.

We observe that infrastructure investments in national roads, water, electricity, refining, and education reduce CO_2 emissions in absolute value. In the case of water and electricity this is due to the fact that these investments have negative, albeit small, effects on GDP. As to national roads, petroleum refining and education infrastructures, the negative results are mainly induced by the negative effects they have on electricity production (S10) despite overall positive GDP effects. These negative effects on electricity production can be easily understood as substitution effects in the cases of national roads and petroleum.

Table 9. CO_2 Emissions Effects of Different Infrastructure Investments

Unit: Thousand tons per millions euros

	Emissions based on economy-wide factor (all industries) (1)	**Emissions based on industry-specific factors (all industries) (2)**	**(2)/(1) (all industries)**	**Emissions based on economy-wide factor (excluding electricity) (3)**	**Emissions based on sector-specific factors (excluding electricity) (4)**	**(4)/(3) (excluding electricity)**
Road Transportation						
National Roads	8.98	-4.21	**-0.47**	6.30	6.03	0.96
Municipal Roads	3.39	1.75	**0.52**	2.22	1.75	**0.79**
Highways	2.06	0.73	**0.35**	1.35	0.73	**0.54**
Other Transportation						
Railroads	8.79	4.28	**0.49**	5.50	-2.24	**-0.41**
Airports	8.17	19.80	2.42	4.54	-0.59	**-0.13**
Ports	10.46	4.84	**0.46**	6.86	4.84	**0.71**
Utilities						
Water (*)	-1.69	-2.59	**1.54**	-1.04	-1.01	**0.97**
Electricity & Gas (*)	-0.57	-0.56	**0.99**	-0.35	-0.15	**0.42**
Petroleum Refining	1.57	-2.50	**-1.59**	1.15	0.45	**0.39**
Telecom	5.48	1.59	**0.29**	3.59	1.59	**0.44**
Social Infrastructures						
Health	8.62	9.08	1.05	5.66	9.08	1.61
Educational	9.81	-4.42	**-0.45**	6.77	3.96	**0.58**

(*) These industries have negative economic effects. So positive figures in the third and sixth columns reflect a decline in CO_2 emissions.

At the opposite end, we find infrastructure investments in airports greatly increase CO_2 emissions. Again, this is directly associated with large output effects on the electricity sector (S10). In turn, investments in health infrastructures, with non-significant effects on electricity (S10), leave energy and industrial CO_2 emissions intensity unaltered.

Finally, investments in municipal roads, highways, railroads, ports, and telecommunications, while increasing CO_2 emissions in absolute terms contribute to a reduction in the average CO_2 emissions intensity of the economy. For municipal roads, highways, ports, and telecommunications, the output effects on electricity production (S10) are not statistically significant, while for railroads, with a completely electrified rail system, the effects are positive.

5.3 Marginal CO_2 emissions under Aggressive Renewable Electricity Production Policies

From the discussion of Table 8, the central role of electricity production (S10) is clear. Electricity production (S10) is not only responsible for more than one-third of CO_2 industrial emissions but it does so with by far the highest CO_2 emission factor among the sectors considered. In turn, the discussion in the previous sections makes it clear the central role of the economic effects of infrastructure investments on this sector on the magnitude and nature of their CO_2 emissions effects.

In this section, we consider an alternative scenario in which emissions from the electricity industry are excluded. This extreme alternative can be conceptualized as all electricity being produced using renewable sources. Indeed, the extremely high emissions levels from electricity production is bound to be greatly reduced with the closing in the next decade of the only two remaining coal power plants which are currently responsible for more than half of thermal electricity production (see http://www.dgeg.pt). In addition, there is a deliberate and deep commitment to producing electricity from renewable sources—currently more than half of total electricity production comes from renewable sources (see again http://www.dgeg.pt) and by 2050 this value is projected to be close to 95% (Seixas et al., 2017). Accordingly, the results in this section can be considered as the likely effects of infrastructure investments in an environment of clean electricity production. Yet, the main objective of this alternative scenario is to highlight the key importance of the electric power industry (S10) in the definition of the different impacts. The results under this alternative scenario are reported in the last three columns of Table 9.

Under this alternative scenario, we observe negative effects on CO_2 emissions from infrastructure investments in railroads and airports, sectors highly dependent on electricity, whose impact is now being ignored. In fact, the case of airports is paradigmatic as investments in airports sharply increase the economy-wide CO_2 emissions intensity with the current emissions intensity level for electricity production. Negative effects are also estimated for water and electricity, again sectors with aggregate negative output effects.

In turn, infrastructure investments in municipal roads, highways, ports, refining, telecom, and education increase CO_2 emissions in absolute terms, but reduce the economy-wide average CO_2 emissions intensity. As mentioned, investments in municipal roads, highways, ports, refining, telecom had zero output effects on electricity (S10) while investments in refining and education had negative effects and were demoted to this category

Finally, investments in national roads leave the CO_2 emissions intensity essentially unaltered. This is due to the fact that now that the negative impact of reductions of emissions in electricity production (S10) is ignored, the positive effects on emissions from non-metallic mineral (S7) and construction (S12) assume a more central role. Investments in health infrastructures actually increase the average CO_2 emissions intensity under this alternative scenario. In this case, the increase in emissions again in non-metallic mineral (S7) and construction (S12) as well as transportation (S14) account for this result.

6. Summary and Concluding Remarks

In this paper, we estimate how infrastructure investments affect energy and industrial CO_2 emissions in Portugal. We use the empirical evidence on the economic effects of twelve types of infrastructure investments at the industry level considering twenty-two industries, covering the whole spectrum of economic activity, as well as corresponding sector-specific CO_2 emission factors.

Our main conclusions are as follows. First, given present emissions intensities, almost all types on infrastructure investments help in reducing the average economy-wide CO_2 emissions intensity. Only for investments in airports and health facilities we do not find such positive effects. Investment in airports has an adverse effect on emissions while investments in health infrastructures leave the emissions intensity essentially unchanged. In the cases of investments in water and electricity, however, the favorable emissions effects observed are driven by adverse economic effects. Second, the relevance of the economic effects of the different types of infrastructure investments on electricity production is central in determining the effects on emissions. This is not surprising given that the extremely high emissions factor of this industry amplifies even small economic effects. Third, under an alternative scenario in which the emissions of the electric power industry have been eliminated by a transition to the production of electricity from renewable sources or are otherwise ignored, we still see that most infrastructure investments help with the CO_2 emissions intensity of the economy. In this case, however, investments in national roads leave the emissions intensity essentially unaltered while investments in health infrastructure have adverse emissions effects.

There are several important policy implications of these results when we consider infrastructure investment strategies that are mindful of their CO_2 emission effects. Consider first transportation strategies. Given the present production structure for electric power, investment in national roads are a sound policy recommendation from an environmental perspective, while further investments in airport infrastructure should be avoided. Investments in municipal roads, highways, railroads and ports are also good, although they would not reduce emissions in absolute terms but only the average economy-wide emissions intensity.

A completely different recommendation would follow a scenario of aggressive use of renewable energy sources in the production of electricity. In this case, the best investments which would actually reduce emissions would be in railroads and airports, two sectors highly dependent on electricity. Investments in municipal roads, highways, and ports, are also desirable in that they reduce the average emissions intensity, while investments in national roads would leave the average emissions intensity unaltered. Consider now the case of investments in petroleum refining infrastructures. They are particularly desirable in the current scenario of high emission factors in electricity production, circumstances under which substituting away from electricity, with its still a heavy user of coal in thermal production, can actually reduce emissions. In the alternative case of aggressive RES policies, however, the benefits of investment in petroleum refining infrastructures would only have an effect in reduction of average CO_2 emissions. Finally, in terms of social infrastructure investments, investments in education are always advantageous from the perspective of CO_2 emissions, although more so under the current electricity production standards. For investments in health infrastructures, which have a relatively large economic effect in emissions intensive industrial sectors, a complete decarbonization of electricity production would make such investments undesirable with respect to their overall impact on the economy-wide CO_2 emissions intensity.

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Notes

Note 1. It should be highlighted that industrial CO_2 emissions correspond to about 82% of total CO_2 emissions from the use of fossil fuels. These include, what is often classified as agriculture, manufacturing, services and transportation uses. The remaining 18% are due to household activities, both from residential energy consumptions and transportation activities. For more information, refer to the Satellite Accounts for the Environment at http://www.ine.pt.

Note 2. For the sake of brevity, we just sketch here the different steps in the preliminary data analysis. Full documentation is available from the authors upon request.

Note 3. Again, for the sake of brevity, the impulse response functions have been omitted. Full documentation is available from the authors upon request.

Note 4. Since there are industries with negative effects, the most important positive effects may turn out to be greater than the effects on aggregate.