Public infrastructure: definition, classification and measurement issues

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January 2009

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Abstract

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A peculiar feature of these studies is that, across them, different empirical and theoretical entities are referred to infrastructure.

Although the vast body of literature on infrastructures economic impact have been largely reviewed less attention have been paid to the term infrastructure *per se.*

This article, aiming to provide a helpful instrument to critically interpret the existing literature, zooms in on infrastructure definition and then reviews different categories of infrastructures utilised in literature, namely: personal, institutional, material, immaterial, economic, social, core and not-core, basic and complementary, network, nucleus, and territory infrastructures.

The final part deals with problems related to infrastructures measurement describing some financial-based measures and physical-based measures highlighting that both measures - due to economic and strictly computational problems - present pitfalls so that, in turn, both types of measures have critical aspects to be considered when interpreting results concerning infrastructures.

Keywords: infrastructure; public expenditure.

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1 Introduction

Moving essentially from Barro (1988) and Aschauer (1989) many studies analysing the relationship between infrastructures and the economic development have been realised.

On this field there is a broad spectrum of theoretical viewpoints some of them diametrically opposed to one another. A general consensus is achieved around the idea that basic infrastructure facilities are important features *related to* economic performance. Apart from this main idea opinions differs greatly: both magnitude and causality remain subjects of debate.

Indeed, the seminal work of Aschauer (1989) estimated an output elasticity of *core* infrastructure of .24 - i.e. a 1% increase in investment in public infrastructure will result on a 0.24% increase in the output of the private sector - so that, this high elasticity led the Author to argue that the decline in productivity growth during the 1970's was largely due to a decline in public investment in infrastructure.

Nonetheless, as research in the field progressed, disputes over this high impact of infrastructure arose. Gramlich (1994), for example, pointed out that Aschauer (1989)'s approach was affected by several problems. In relation to the magnitude of infrastructure impact he highlighted that generally a positive public capital elasticity forces the choice between increasing returns of scale and large factors rent, and that Aschauer (1989)'s work result in "pretty stratospheric estimates of the marginal product of government capital" (Gramlich, 1994, p. 1186).

Moreover, the statistical causality between infrastructure and productivity itself is questioned, indeed, in Looney and Frederiksen (1981)'s words, one the research question is: "is infrastructure the initiating factor in the development process or it is merely a passive or accommodating factor?"(Looney and Frederiksen, 1981, p.286)

At this regard, Evans and Karras (1994) - in their study regarding seven OECD countries between 1963 and 1988 - even founding strong correlations between the two variables, concluded that the direction of causality was the *opposite* of that reported by Aschauer (1989), i.e. increased stocks of public capital were the *result* of increased productivity and economic growth, not the cause: "there is no evidence that government capital is highly productive"(Evans and Karras, 1994, p.278). As possible theoretical justification of this empirical result can be invoked the Zegeye (2000)'s argument that infrastructure is a *normal good*, so that wealthy counties will tend to have more due to their higher level of income.

Many other studies often sustain intermediate thesis distinguishing between (more or less) productive and unproductive infrastructure and trying to deal with infrastructure endogeneity problem with appropriate econometric tests.

They could be grouped together into four approach:

i. The *production function* approach that models the amount of output that can be produced for each factor of production, given technological constraints. In this approach public infrastructure enters as a free input furnished by government.

ii. The *cost function* approach takes into account factor prices such as the price of labour, machinery, and finance. Public infrastructures are conceived as costs saving factors.

iii. *Growth models* belonging to the tradition of *endogenous* growth and augmented to consider as growth enhancing factors also public infrastructures.

iv. *Data-oriented models* analyze relations between several data series including infrastructures and GDP and do not rely heavily on economic theory.

However, approaching the theme regarding the link between infrastructure and productivity, especially in empirical terms, two important preliminary questions arise: what is infrastructure? And how to measure it?

Indeed, in absence of standard definition any comparison between studies is challenging: referring to "infrastructure" various *measures of* road, electricity generating plants, water and sewerage systems etc. have been utilised, often without a clear statement of the criteria utilised to define *what is infrastructure.* In addition, various *types of* measures (e.g. financial-flow, financial-stock, physical) have been utilised in literature.

Although many literature reviews concerning studies on infrastructures' impact on productivity have been realised – see Infrastructure Canada (2007); Romp and Haan (2007) - the issue of infrastructure's definition, classification, and, measurement received less attention and most often is treated only incidentally.

Bearing these issues in mind, this paper zooms in on infrastructure definition (section 2), on its classification (section 3), and, on problem related to the *measurement* of infrastructure (section 4). Section 5 presents some concluding remarks.

2 What is infrastructure?

There is no standard definition of infrastructure across economic studies. Tinbergen (1962) introduces the distinction between infrastructure (for example, roads and education) and superstructure (manufacturing, agricultural and mining activities) without neither a precise definitions nor any theoretic references of these terms.

The reason for this unsatisfactory situation comes from the need for simultaneous realization of three analytic objectives: (i) the formulation of a concept for the term "infrastructure"; (ii) the incorporation of theoretic approaches (for example, the theory of public goods), and (iii) the description of the reality of infrastructure provision.

According to Buhr (2003) the broadest *economic* version of the term "infrastructure" – referring to the works of List (1841) and Malinowski (1944) - dates back to Jochimsen (1966)'s book on the theory of infrastructure in which the author aims to present preparatory studies for a *modern* theory of the development of a market economy based on the study of infrastructure endowment.

By dividing the relevant time-paths of economic development in (a) quasi-stagnation, (b) economic dualism, and (c) self-sustained development - where *quasi-stagnation* is characterized by a relatively constant level of economic activities, mostly the subsistence level, due to the absence of any stimuli to change; *dualism* results in the disintegrating decomposition of the economy into segments with differently changing activity levels with respect to sectors, regions and firm sizes due to the linkages of external effects, institutional rigidities, technological discontinuities and other frictions of the market economy and *self-intensifying* growth, is characterised by an increasing level of economic activities - he denotes “infrastructure” as the *important preconditions of economic development* concerning the time-path mentioned above and the transformation processes leading from one step to another; in this framework infrastructures are provided by the state or controlled by it.

More deeply, the author defines infrastructure as

the sum of material, institutional and personal facilities and data which are available to the economic agents and which contribute to realizing the equalization of the remuneration of comparable inputs in the case of a suitable allocation of resources, that is complete integration and maximum level of economic activities (Jochimsen, 1966, p.100).

Or, in a pragmatic sense, material infrastructure is understood as

"[…] 1. the totality of all earning assets, equipment and circulating capital in an economy that serve energy provision, transport service and telecommunications; we must add 2. structures etc. for the conservation of natural resources and transport routes in the broadest sense and 3. buildings and installations of public administration, education, research, health care and social welfare" (Jochimsen, 1966, p.103).

However even Jochimsen (1966)’s definition, as noted by Buhr (2003), “has the disadvantage of not making factor price equalization concrete”(Buhr, 2003, p.1). A second problematic aspect of this definition is that it "understands material infrastructure to be an enumeration of essentially public facilities characterized by specific attributes" (Buhr, 2003, p.1). Indeed, in Buhr (2003) the main stream approach based on infrastructure attributes is reject as a whole in favour of an approach base on infrastructure specific functions (see further on this section).

Therefore, in the absence of a standard (precise) definition, various authors model a variety of different indicators of infrastructure and this fact, in turn, makes challenging any comparison involving different studies.

In addition, in terms of policy, having no common definition of infrastructure makes difficult to develop uniform policies in this field (Infrastructure Canada, 2007).

Despite this difficulties related to its exact meaning, in the public discussion, the term made a successful terminological career, rising to a formula of political technocracy so that we "have" to confront with it.

Aiming to highlight general features of "goods" from time to time utilised can be said that the term "infrastructure" - stemming from the usage of military language (where it refers to permanent military installations such as barracks and airports) - in economic sense refers to two main criteria: i) infrastructure is a *capital good* (provided in large units) in the meaning that it is originated by investment expenditure and is characterised by long duration, technical indivisibility and a high capital-output ratio; ii) infrastructure is also a *public* (sometimes a *merit*) *good,* not necessarily in the sense that it is owned by the public sector, rather in the proper economic sense that it fulfil the criteria of being *not excludable* and *not rival* in consumption for which economic agents show real (in the case of merit goods) or *opportunistic* (in the case of public goods) "wrong" preferences. Sometimes the characteristic of being a public good is "weakened" so that infrastructure do create *external effects* but do not achieve the maximal level of externalities represented by public goods.

As mentioned above, the approach based on technical, economic and institutional infrastructure *features* (Youngson, 1967; Biehl, 1986) could be considered the main stream approach.

Nevertheless, an alternative approach has been developed based on infrastructures *essential functions*: the so-called "functional approach". Here the term "essential" refers to the fact that infrastructure initiate the changes of economic variables.

The starting point of this last approach is represented by the idea that the creation of the social product is due to economic agents interacting with each others and that the contribution of each agent is based on the provision of infrastructures. Put differently, the peculiar characteristic of the term "infrastructure" should be individuated both in the *activation* and in mobilisation of the economic agents' potentialities.

Therefore, according to this approach, material infrastructure, for example,

> has the *function* of rendering possible the opening and development of the economic agents' activities. It puts into action the potentialities of economic units for the benefit of society (Buhr, 2003, p.13).

Hence, each type of infrastructure can be defined according to its effect. So that, for example *market-oriented material infrastructure* could be defined as all capital goods *serving* the coordination and interaction of economic units to realise their economic plans.

Following this alternative approach to the problem of infrastructure definition – i.e. the functional one – Buhr (2003) defines infrastructure as "the sum of all relevant economic data such as rules, stocks, and measure with the function of mobilising the economic potentialities of economic agents" (Buhr, 2003, p.16).

To summarise: this section presented tow different general defition of infrastructure based respectively on its *attribute* and on its *functions*.

Next section will focus on different infrastructure classification introduced in literature with the purpose to better define the borders of this "elusive" term.

3 Infrastructure classification

Once introduced, in previous section, a general definition of infrastructure, this section considers the different ways in which infrastructures have been classified by different authors. In what follow I will briefly describe the criteria used in literature to identify the categories of personal, institutional, material and immaterial infrastructures; economic and social infrastructures, as well as core and not-core, basic and complementary, network, nucleus and territory infrastructures.

As key to an understanding of this classification should be noted that classifications developed here are potentially overlapping, for instance, roads belong to *material-economic-network* infrastructures according to the different point of view of the analysis (see table 3.2).

Personal, institutional and (im)material infrastructures. To begin with, I will take into account Jochimsen (1966)'s distinction between material, personal and institutional infrastructures.

I will describe personal and institutional infrastructure first, in order to develop more in detail the material one.

Personal infrastructure refers to " … the number and the qualities of people in the market economy characterized by the division of labour with reference to their capabilities to contribute to the increase of the level and the degree of integration of economic activities" (Jochimsen, 1966, p 133).

A general way to refer to personal infrastructure is represented by *human capital* defined by OECD as

the knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being" (Organisation for Economic Co-operation and Development (OECD), 2001, p. 18).

So that the concept of human capital entails

a) the capacity of interpreting flows of sensory data and structured information required for purposive individual actions and inter-personal transactions among economic agents;
b) the capacity for providing a variety of physical labour service-inputs in ordinary production processes;
c) the cognitive basis of entrepreneurial market activities;
d) the key resource utilised for managing market and non-market production, as well as household consumption activities;
e) the creative agency in the generation of new knowledge underlying technological and organisational innovations." (David, 2001, p. 19)

As Buhr (2003) pointed out, the role of personal infrastructure for determining the quality of the economic agents' values (achievement motivation, productive capacity, value integration) results in three essential approaches: (a) the tasks of economic agents in the economic process (entrepreneurial guidance, unskilled and qualified labour, teaching etc.), (b) the importance of personal infrastructure for the individual (short-term and long-term consumption of education), and (c) the social relevance of personal infrastructure (integration effect of education).

Institutional infrastructure "comprises the grown and set norms, institutions and procedures in their reality of constitution, insofar as it refers to the degree of actual equal treatment of equal economic data, excluding *meta-economic* influences. It determines the framework within which economic agents may formulate their own economic plans and carry them out in co-operation with others" (Jochimsen, 1966, p 117).

In the sense introduced above institutional infrastructure stems from term "economic constitution" and can be considered the real implementation of the norms in the "institutional basis" of the market economy (see Buhr, 2003). Thus institutional infrastructure, being assigned the function of social integration of values, is the object of economic and legal policy.

Let turn to the definition of material infrastructure. Given an economic setup (preferences of the population, the levels of technology, the institutional rules, the level of development and the geographical particularities of a community) material infrastructure is essentially characterized by two distinguishing qualities: i) fulfilment of social needs and (economic necessity of) ii) mass production.

The first attribute refers to the essential needs of human life. Following this perspective, material infrastructures can be defined as goods and services able to satisfy those wants of economic agents originating from physical and social requirements of human beings. For example, the need of drinking water is met by the corresponding supply of water collected, say, in a reservoir which, as a capital good, is a specific type of material infrastructure.

The output relative to a material infrastructure results from the interplay of its corresponding supply and demand depending on physical or social wants.

The supply side depend on production functions, finance situation, and organizational structures of infrastructure producers such as industrial enterprises and administrative units. As general rule it can be said that the production functions relate infrastructure outputs to the factors of production. In other cases -e.g. in the case of roads- infrastructure outputs are related to the direct utilization of capital stocks over time as result of preceding production processes.

With respect to the demand side, the different requirements of human life to be satisfied by material infrastructure could be driven –without any pretension of completeness - from the first column of table 3.1 taken from Buhr (2003).

Table 3.1: Material infrastructure to satisfy requirements of human life.
Source: Buhr (2003), p.22.

Want	infrastructure output (good or service)	material infrastructure
	Physical requirements	
Water	drinking water, water for industrial uses, irrigation water, water for generating hydro-electric power	reservoirs, canals, waterways, pipes, irrigation facilities
Warmth	gas, oil, electricity, coal, nuclear energy	drilling platforms, pipelines, generation plants, coal mines
Light	electricity, gas	generation plants, drilling plants, circuits, pipelines
Health	medical care, refuse collection, waste water disposal	hospitals, dumps, sewerage systems
protection against nature, shelter	accommodation, working places, flood protection	houses, buildings, plants, levees
	Social requirements	
Security	legislation (laws), judiciary, stability of the value of money, protection against crimes, outward defense, military goods	public buildings, police stations, military installations
information	usage of telephones, mobile phones, radios, television, Internet, newspapers	telecommunication facilities, post offices, newspaper production works
education	child care, lectures, research, lending out books	kindergartens, schools, universities, research institutions, libraries
mobility	usage of roads by cars, buses, trucks	roads, highways
	usage of tracks by trains	Tracks, train stations
	usage of airports by airplanes	airports
	usage of ports by ships	Ports
environmental protection	clean air and water	air purification filters, waterworks

From what stated above should be clear that material infrastructure facilities are usually highly complementary to each other. An example for all is housing in relation to public utility networks (e.g., water and energy supply equipment).

The second peculiar feature of material infrastructure cited above is the non-availability of infrastructure goods and services to the individual household or firm for production and cost reasons, i.e., economic necessities of *mass production*. The usually high fixed costs of facilities- generating economies of scale- require the (often joint) production of large volumes of outputs.

Moreover, since the fixed costs are very different comparing various capital stocks, material infrastructure provision takes place under the conditions of different market structures ranging from the prevalent form of (natural) monopoly (e.g., electricity supply), to competition (e.g., housing construction).

In conclusion about material infrastructures, they can be defined as

"those immobile, non-circulating capital goods that essentially contribute to the production of infrastructure goods and services needed to satisfy basic physical and social requirements of economic agents and unavailable to the individual economic agents (households, firms etc.) for production and cost reasons so that mass production is economically cogent"(Buhr, 2008)

In literature it is also frequent the use of *immaterial infrastructure* (by contrast to material infrastructure) in order to indicate some kind of infrastructure -primarily innovation and education infrastructures- linked to the development of the material one as intended above, for instance, research centres, innovation networks, services to the enterprises, etc..

Economic and social infrastructures. Hansen (1965) distinguishes the infrastructures into *economic* and *social* according to the fact that they acts on the level of economic development of a territory in direct or indirect way. The result of this point of view consists in

the division of local public overhead capital (OC) into two components, "social" overhead capital (SOC) and "economic" overhead capital (EOC). […] Those items classified as EOC are primarily oriented toward the support of directly productive activities or toward the movement of economic goods. SOC items […] may also increase productivity, the way in which they do so is much less direct than in the case for EOC items (Hansen (1965)).

Thus, *economic* infrastructures, directly support productive activities; they are: roads, highways, airports, naval transport, sewer networks, aqueducts, networks for water distribution, gas networks, electricity networks, irrigation plant and structures dedicated to the commodities transfer.

While *social* infrastructures, are those finalized to increase the social comfort and to act on the economic productivity; they are: schools, structures for public safety, council flat (not referable to expenses of economic nature), plant of waste disposal, hospitals, sport structures, green areas, and so on (Hansen, 1965).

Core and not-core infrastructures. It was said above that Aschauer (1989) attributed a conclusive role to the public capital for the economic growth of a country, particularly to the component of the *cores* infrastructure.

The *cores* infrastructures include, for the Author, roads and highways, airports, public transport, electric and gas networks, network for water distribution and sewer networks. The *not-core* infrastructures are a residual component (Aschauer (1989)).

The same type of classification is adopted in Mastromarco and Woitek (2004) in which the public capital is expressly separated into *core* and *not core* component, and where empirically it is underlined the role that every component assumes in determining the different degree of development in the Italian regions of the Center-north in comparison to those belonging to the southern part of the country.

Sturm, Jacobs et al. (1995) use also a similar distinction between *basic and complementary infrastructure.* Where basic infrastructure refers to main railways, roads, canals, harbours and docks, the electromagnetic telegraph, drainage, dikes, and land reclamation as opposed to *complementary* infrastructure category which includes light railways, tramways, gas, electricity, water supply, and local telephone networks.

Network, nucleus and territory infrastructures. In Biehl (1991) a distinction emerges among *network infrastructures* and *nucleus infrastructures*. The first ones referring to roads, railroads, “water's highway”, networks of communication, systems for energy and water provisioning; while the nucleus infrastructures, referring to schools, hospitals and museums, are relatively characterized by an elevated degree of immobility, indivisibility, “not-interchangeability” and multi-purpose features.

This last distinction recalls another aspect typical of the nucleus or *punctual* infrastructures, tied up to their ability of attraction. According to this last criterion *network infrastructure* are such that the basin of use coincides with the territorial unity in which the infrastructure is located, or is permissible to hypothesize that its ability of attraction is next to zero. Thus, it is (rather should be) diffused in capillary way on the territory.

Finally, *territory* infrastructures include services that, even if object of private investments and activities, have effects on the territory attractiveness, on its quality of the life and on the dynamics of development.

Table 1.3.2 aims to summarise the different ideas about infrastructure classification introduced above updating ISTAT (2006), p.17.

Table 3.2- Infrastructure classification.

Hansen (1965)	Aschauer (1989)	Sturm, Jacobs et al. (1995)	Di Palma, Mazziotta et al. (1998)	Biehl (1991)
Economic	**Core**	**Basic (main)**	**Material**	**Network**
Roads	roads	(main) railways	transport network	roads
highways	highways	(main) roads	water-system	railroads
airports	airports	Canals	energy network	"water highways"
naval transport	public transport	harbours and docks		networks of communication
sewer networks	electricity networks	electromagnetic telegraph		systems for energy and water provisioning
aqueducts	gas networks	drainage		
networks for water distribution	network for water distribution	Dikes		
gas networks	sewer networks	land reclamation		
electricity networks				
irrigation plant				
structures dedicated to commodities transfer				
Social	**Not-core**	**Complementary**	**Immaterial**	**Nucleus**
Schools	residual component	light railways	structures dedicated to development, innovation and education	schools
structures for public safety		tramways		hospitals
council flat		gas networks		museums
plant of waste disposal		electricity network		
Hospitals		water supply		
sport structures		local telephone network		
green areas				

Focusing on the empirical side it is worthwhile noting that all (empirical) studies regardless of theoretical consideration heavily depends on data availability.

Therefore it is of some interest taking into account how official statistics address the theme of infrastructure. In what follows – as example - I will zoom in on the Italian case reporting how infrastructures are recorded both in *physical* terms and in financial – i.e. public expenditure – terms.

Regarding the physical side, the scheme that follows illustrates the composition of the macro-areas divided into areas and sub-areas according to ISTAT's classification.

Table 3..3 – Infrastructure classification according to macro-area area and sub-area.
Source: ISTAT (2006), p.16

Economic infrastructures	
Transport Network	road Transport railway Transport air Transport sea Transport other aspects
Energy Network	electricity network gas Network water-system other aspects
Social Infrastructures	
Health Infrastructures	free hospital treatment health service social security Other aspects
Educational Infrastructures	nursery primary school for pupils aged 11 – 14 secondary school compulsory education University other aspects
Culture Infrastructures	Cultural, artistic and historic heritage Theatre, music, cinema and entertainment Sport other aspects
Environmental Infrastructures	Water purification plant Waste disposal Green areas Other aspects
Territory Infrastructures	
Tourist infrastructures	Tourist receptiveness other aspects
Trade Infrastructures	Retail trade Wholesale trade Other aspects
Monetary intermediation Infrastructures	Monetary intermediation other aspects

As can be seen, the economic infrastructures include areas related to the network for commodities and people transport those for the energy, water, and gas transportation.

The *macro-area* related to social infrastructures comprises four areas: the infrastructures of the health, education, culture and of the environment infrastructures.

The last *macro-area* concerns the territory infrastructures and includes resources for commerce, tourism and for monetary intermediation.

Turning the attention to the financial side following table 3.4 below shows how the 30 sectors of public spending contained in the Regional Public Accounts (RPA) system are join up into macro-sectors.

Table 3.4 - Macro-sectors (4) and RPA sectors (30). Source: Volpe (2007) p.110.

Macro-sectors	RPA sectors
Economic infrastructures	Roads Other transport Telecommunication Environment Waste disposal Water Sewers and water treatment Energy Agriculture Marine fishing and aquaculture Industry and artisans Wholesale and retail distribution Tourism Other public works Other economic sectors
Human capital	Education Training Research and development Pensions and wage supplementation Labour
Social infrastructure	Culture and recreational services Health Other social affairs (assistance and charity) Other health and sanitation Defences Public order Justice General administration Unclassified expenditure
Residential building	Residential building

A detailed description of each subcategory of table 3.3 and 3.4 goes beyond the scope of this paper, interested readers are addressed to ISTAT (2006) and to Volpe (2007) for a methodological guide to RPAs.

However, without going deeply to the question, from tables 3.3 and 3.4 can be drawn the consideration that the accountability of infrastructures has not an unique solution, that is why once presented different definition of infrastructure and presented some classification introduced in literature, next section will focus on the problem of its measurement.

4 How to measure infrastructure?

Preliminarily, note that the goal of the measurement of infrastructure is essentially twofold. First, one could be interested in calculating a *measure* of infrastructure that aims to quantify the existing infrastructure in order to insert it into the national statistical system (see table 3.3 and 3.4 with respect to two sources of the Italian national statistical system). Second, one could be interested in obtaining a measure of infrastructure with the purpose to *analyse* its effects in terms of (competitiveness and) development of a territory (Brancalente, Di Palma et al 2006).

Certainly each *category* of infrastructure introduced in section 3 presents peculiar difficulties related to both purposes. For example, the measurement of institutional infrastructure goes deeply in the character of civic life - involving political stability, quality of government, and, social infrastructure - so that its exact "measurement" is rather ambitious. Another significant example is constituted by human capital representing a crucial factors in *endogenous growth models* and widely used despite difficulties regarding its measurement.

At this regard it is worth noting – just to give the idea - that while Easterly and Rebelo (1993) included "two school enrolment variables […] as proxies for the initial level of human capital" (Easterly and Rebelo, 1993, p. 424), Marrocu, Paci et al. (2005), with the same purpose, use a 1996-2002 average of public spending on various categories; namely: education, training, research and development, pension and wage supplementation, and, labour.

In order to generalise across studies and categories of infrastructures could be said that in literature the problem of infrastructure quantification has received two main different solutions: the first measuring the level of infrastructure endowment in *monetary* terms, the second measuring it in *physical* terms.

Furthermore, a second sub-distinction inside both methods can be operated.

In monetary terms, infrastructure may be intended as a flow or a stock variable. In the first case, (government) spending correspond to the provision of public services that instantaneously affect the production. In the second case, instead, what government spends "today" is added to the stock of public capital and affects the future production process (Irmen and Kuehnel, 2008).

Typically, in order to calculate the stock measure of infrastructure from financial flow, researchers use the perpetual inventory method (PIM) which consists in adding up past gross investments, adjusted for depreciation. For the rationale for using gross investments see Alvaro (1999) and for computational details see appendix A.

As noted above, both method have been utilised in literature. For instance, Barro (1988) *productive* government expenditure as a flow variable and after this seminal many studies have done similarly, among others Everaert and Heylen (2004); Ghali (1998; Everaert and Heylen (2004; Belloc and Vertova (2006); Mittnik and

Neumann (2001); Pereira (2000; Pereira (2001). Infrastructure is instead considered as stock variable, for example, in Albala-Bertrand, Mamatzakis et al. (2004); Bonaglia, La Ferrara et al. (2001); Ferrara and Marcellino (2000), and, Kamps (2006).

When infrastructure is considered in physical terms – especially with respect to material infrastructures - two variations are possible. The physical endowment can be considered simply in physical terms (e.g. kilometres of roads, electrical generating capacity, number of hospitals, etc.) or can be measured the physical endowment and then transformed in monetary terms attributing a price to each category of good, that is adopting the so-called *common inventory method* (CIM) .

As Brancalente, Di Palma et al. (2006) noted with respect to the Italian case, adopting one or the other approach leads to results that can differ greatly. Moreover, the difference between the two measures increases with the territorial detail of the analysis. In particular, comparing two studies utilising the physical approach (Di Palma and Mazziotta, 2002; Istituto Guglielmo Tagliacarne, 1998) and other two studies adopting the PIM (Montanaro, 2003; Picci, 1995) the Authors find that the strong regional north-south disparities reported in both works regarding the physical approaches *disappear* in the works using the PIM.

From the prospective of the analysis which aims to study the infrastructure's impact on productivity this variety of methodologies – potentially leading to significantly different results one from the other- raises the opportunity to consider critically each method in order to assess its advantages and disadvantages that should considered when interpreting the results of the analysis as a whole.

First, as Romp and Haan (2007) noted, with regard to the financial side one should be aware that in "applying the […] perpetual inventory method, the researcher has to make certain assumption about the assets' lifespan and depreciation. Furthermore, one needs an initial level of the capital stock. Especially with infrastructure these assumption are far from trivial"(Romp and Haan, 2007, p.13).

Furthermore, Brancalente, Di Palma et al. (2006) argue that the same concept of *withdrawing* is debatable when applied to (public) infrastructure. Indeed, the Authors argue that, while it is reasonable to think about *withdraw* concerning industrial machine and various equipment owned by private sector especially for those subject to rapid technical obsolescence, it is not the same in the public infrastructure case: roads, bridges, ports.

Second, Pritchett (1996) argued that due to (in)efficiency or structural reasons public stock based on investment series will tend to be overevaluated.

While Montanaro (2003) focusing on the Italian case attributes the difference between the financial and the physical side to morphology, population density and inefficiency, Golden and Picci (2005), once tested the statistic (in)significance of the first two factors, attribute the difference to *corruption* since, they argue, corruption and inefficiency are strictly (rather perfectly, as implicitly assumed in their paper) correlated.

Moreover, public investment series itself depend heavily on the definition of public sector adopted by the national account system. It is worthwhile referring once more to Romp and Haan (2007) citing the piece in which they noted that thinking about infrastructure

"[m]ost people probably think about roads and other infrastructure – such as electricity generating plants and water and sewage systems – when they refer to the public capital stock. However, it is important to point out here that this does not fully correspond to the concept of public sector Investment expenditure as defined in national accounts statistics, which are typically used to construct data on public capital stock. [Because] only spending by various government sectors is included. That implies that spending by the private sector (including public utility firms concerned with electricity generation, gas distribution, and water supply) is excluded."(Romp an Haan, 2007, p 13).

Third, simply adding up past investment do not take into account that the effects of public investment might depend on the level of corresponding capital stock (Kamps (2006)).

Fourth, from a network perspective PIM values have certain pitfalls: the internal composition of the stock matters, since the marginal productivity of one link depend on the capacity and configuration of all links in the network. Using measures of total stock may thus allow one to estimate the average marginal product of road, say, in the past, but these estimates may not be appropriate for considering the marginal product of additional roads today (Fernald (1999)).

Finally, on the strict computational side, PIM requires long-term time series on public investment and this type of data are not always available for all country and for all level of government. It does exists data for most OECD countries, but for many developing countries public stock infrastructure cannot be constructed.

Let now switch the attention to the physical side. In general terms can be said that this kind of measure have been employed in order to deal with the most part of problems arising from PIM, see Canning and Pedroni (1999); Sanchez-Robles (1998), and, Esfahani and Ramìres (2003).

In fact, the measures utilised – such as number of kilometres of paved roads, kilowatts of electricity generating capacity, number of telephones line and so on- have the advantage that they do not rely on the concept of public investment as employed in the national accounts and, in addition, some of the measures do not necessarily refer to (the results of) government spending.

However, we still need a measure strictly related to some instrument in terms of policy (first of all public spending) and, perhaps more important, simple physical measures do not correct for quality which is a crucial point in infrastructure effectiveness.

For instance, in ISTAT (2006) the indicators, let say in the area of the sanitary infrastructure, report the availability of hospitals and beds for each of the various specializations or, in the area of the educational infrastructures, the availability of scholastic buildings and classrooms without any information about the quality of such elements.

Coming back to the main distinction between monetary and physical measurement treated in this section should be noted that although the financial and the physical approach potentially produce completely different measures, the two approaches could be combined in view to draw important conclusions, for example, about the *return rate* of public expenditure, in different areas of the Country.

5 Concluding Remark

Many studies utilise the term “infrastructure” with particular respect to its economic impact.

Nonetheless, it does not exist a standard definition of the term, so that from time to time many *goods* have been labelled as infrastructure according to various classification and with different techniques of measurement making challenging any comparison between them.

This paper aimed to provide a general framework of analysis regarding infrastructure’s definition and related issues of its classification and measurement.

In so doing, this paper makes an original contribution to already existent literature reviews on infrastructure to the extent that it represents an attempt to critically illustrating difficulties arising in answering to the question "what is infrastructure?" according to the massive literature on infrastructures.

Therefore, this work started posing the main question of infrastructure definition concluding that a precise definition is difficult to achieve because of difficulties in simultaneously achieving three main objectives. Namely, formulating a "concept" for the term infrastructure, incorporation of theoretic approaches, and, the description of empirical evidence of infrastructure provision.

Despite these difficulties general *attributes* and *functions* of infrastructures – essentially being a capital public good with the function of rendering possible the opening and development of the economic agents' activities - are illustrated in section 2.

Once introduced the issue of infrastructure definition a review of different infrastructure classification is presented, showing that, generally, various category of infrastructures are overlapping. This fact could be read as an additional source of ambiguity, given that referring to the same good, scholars could refer their analysis to different infrastructures categories.

Translated in terms of policy this evidence is not irrelevant. Indeed, since often measures instead of being good-based are sector-based attributing result to one or the other category could result in a different policy measure.

The problem of infrastructure measurement, considered in the final part of this article, is often an underlying issue of studies developed in this field.

However, each of the four different approaches to infrastructure measurement (financial-flow, financial-stock, physical, and common inventory method) is potentially leading to different values, and in turn, to different results.

While both the problem of infrastructure definition and classification could not have a unique solution given that the "best" solution depends on authors' preference and purposes, regarding the problem of measurement Brancalente, Di Palma et al. (2006) argued that for (national) accountability purposes the *preferable* approach is the monetary one, given that the whole framework is characterised by monetary values. By contrast, aiming to study the impact of infrastructure – by means of one of the approaches mentioned in section 1 – a physical-based measure should rend one more confident about results achieved to the extent that such a measure is able to better represent the *real* infrastructure endowment of the economic system from time to time considered, regardless of corruption-efficiency considerations.

Nevertheless, concluding on this argument, should be noted that even if the two main approaches – monetary and physical – are, in general, "neither convergent nor compatible" (Brancalente, Di Palma et al., 2006, p.265), the possibility to use them in a complementary way, as in Montanaro (2003) and Golden and Picci (2005) with respect to the Italian case, is not precluded.

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APPENDIX A

The Permanent Inventory Method: theoretical and methodological aspects

The Permanent Inventory Method (PIM) is the technique used in order to achieve a stock measure of infrastructure installed starting from the flow of financial investment. This is the most common way that statistical agencies measure public capital stock. Essentially, it involves adding up past capital formation in constant prices while deducting the value of assets as they reach the end of their service life.

The idea underlying PIM is that the consistence of capital stock for the good at a given year (K_t) depends on what was spent during the previous *L* years with a cumulative process in which the expenditure of each year is added to the previous one. Where *L* is the *g* good's average live. A complete review on this method is available on Goldsmith (1953).

PIM requires an evaluation of the consistence of the stock in one basic year, that can be achieved cumulating the series of the fixed gross investments along the period corresponding to the good's average life.

If we hypothesize a *simultaneous exit* (i.e. a capital created in a certain year is withdrawn *in bulk* at the end of its economic life), then the gross capital stock at a given year (*t*) can be expressed according to the following equation

$$K_t = \sum_{i=0}^{L-1} I_{t-i} \qquad \text{(A.1)}$$

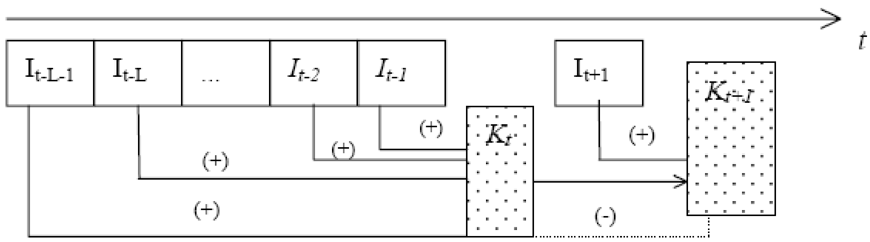
where I_t is the fixed gross investment in the *t* year. An alternative method is represented by a gradual exit in which capital created in a certain year is withdrawn gradually during the time of its economic life.
Once obtained the benchmark for a certain year, the stock during the following years is simply given by the equation

$$K_{t+1} = K_t + I_{t+1} - I_{t-(L-1)} \qquad \text{(A.2)}$$

Thus, in words, first I find the consistence to the beginning of the period using the equation (1), subsequently using the equation (2) I add the new investments and I subtract the value of the good(s) that have exhausted to the time *t* their life of *L* years (that is why it is used the sub-index *t - (L-1)*). For a more elaborate formulation see OECD (1993).

A graphic representation may be useful to explain the mechanism.

Figure A.1 – Permanent Inventory Method



Obviously this is a gross measure based on the idea that each good maintain its value substantially unaltered during its economic life. A "sophisticated" measure of net stock, K_t^n - i.e. a measure that take into account the deterioration and the obsolescence of each good- needs some hypothesis regarding the *depreciation function*. Such a measure might be obtained considering that each good gradually lose its value during its economic life.

At this regard the National Accounting System adopts a constant depreciation function that means that a constant fraction of the instrumental good is consumed during every year of its economic life (i.e. the depreciation rate is $\delta = \frac{1}{L}$). In formula this idea can be expressed as follows

$$K_t^n = K_{t-1}^n + I_t - D_t \qquad \text{(A.3)}$$

Where D_t represents the depreciation in the t year. Moreover, if we hypothesize, as the National account do, a linear depreciation function we can express D_t as follows

$$D_t = \frac{1}{L}\sum_{i=1}^{L-1} I_{t-i} \qquad \text{(A.4)}$$

Hence, we can write the (3) in the following form

$$K_t^n = K_{t-1}^n + I_t - \frac{1}{L}K_{t-1} \qquad \text{(A.5)}$$