Procurement and Productivity: Evidence on the Cold Case of Public-Private Partnership

Vincenzo Mollisi*

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Abstract

In the last two decades, public authorities have increasingly resorted to public-private partnership (PPP) arrangements for the delivery of public services. Under a PPP, the private contractor is in charge of building the infrastructure, as well as managing and maintaining the facility. Instead, under traditional procurement the construction and operation phases are separated and regulated by two different contracts. Relying on data collected from the Italian District Heating industry, I empirically evaluate if different forms of contractual arrangements induce differences in the technical efficiency of firms due to heterogeneous levels of capital quality. I find that the PPP contract allows a technological externality between the different phases of a project to be internalized leading to a positive effect of PPP contracts on TFP. In particular, a unit increase in the capital quality proxy shifts up the output of PPP firms by 15%.

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*PH.d. student at University of Rome Tor Vergata, DEDI Department, Faculty of Economics and attendant at EIEF graduate program, vincenzo.mollisi@gmail.com. I wish to thank Klenio Barbosa, Marco Buso, Francesco DeCarolis, Leonardo M. Giuffrida, Elisabetta Iossa, Martin Paldam, Ariel Pakes, Giulia Pavan, Andrea Pozzi, Gabriele Rovigatti, Philippe Schröder, Valerie Smeets, Friederich Wrazinsky and seminar participants at GSE Jamboree and EARIE 2016 for the helpful comments. This paper was previously circulated with the title "The Impact of Public-Private Partnerships on Productivity of the Italian District Heating Industry". All remaining errors are mine.

1 Introduction

Public-private partnership (PPP) is being increasingly employed for the provision of public utilities like transportation, energy, IT services and waste disposal. In the last two decades, public authorities have regularly resorted to PPP arrangements for the construction and operation of infrastructures. A PPP involves the bundling of these two phases which are typically contracted out to a consortium of private firms including both a building and a facility-management company. The bundling of these two phases into a single contract is the essence of a PPP procurement and what differentiates it from traditional procurement where the construction and operation phases are separately regulated.

Contract Theory literature has provided several contributions analysing the incentives for cost reduction and quality improvements of infrastructure under PPPs. Hart (2003), Bennett and Iossa (2006), Martimort and Pouyet (2008) and Iossa and Martimort (2015) isolate conditions for bundling to be optimal in the presence of a vertical technological externality. When the externality across stages is strong enough to offset the cost of its own internalization, these studies show that bundling induces the contractors to look at the long-term performance of the asset (the so-called "whole life asset management" concept). This, in turn, bolsters the contractors' incentives to invest in asset quality. Martimort and Pouyet (2008) provide an example through the case of the American circular prisons. The particular design of these buildings facilitates the work of prison officers by reducing the level of labour inputs required to control prisoners. The existence of a positive (negative) externality implies that improving the capital quality can reduce (increases) the firm's marginal cost at the operation stage. However, there is no empirical evidence documenting the impact of PPPs on the productivity of firms. Furthermore, many case studies do not find clear evidence of management costs reduction or service quality improvements.[1]

In this paper, I develop an empirical model to estimate technological efficiency after controlling for the capital quality induced by PPPs. The main contribution is to measure how much technological efficiency responds to a variation of the capital quality due to the procurement scheme. A structural approach is meant to retrieve a reliable proxy for the unobserved productivity term. For this purpose, I study the Italian District Heating industry (hereafter DH). A DH is an integrated network aimed at generation and distribution of thermal energy through a system of pipes and heat ex-changer substations. The DH embodies the perfect industry to observe the externality effect between the construction and the operation phase. In fact, the pipeline's design needs to be carefully planned in order to reduce excessive costs from future enlargement and connections works, as well as to preserve

[1] See Iossa and Martimort (2015) for a detailed list.

the thermal capacity of faraway nodes. In this sector, traditional procurement involves a serious problem of moral hazard. When the layout is chosen by company A, but the cost of providing energy is carried by company B, company A does not internalise the reduced future marginal cost from lower heat losses. Then, company A finds optimal to shirk on its delivered quality of the infrastructure. This results in higher operating costs for company B. However, when a consortium both constructs the pipeline and provides the service, it will account for the reduced marginal cost of providing heating in the construction stage. A procurement scheme, as PPP, which compels firms to temporarily join in a consortium, recreates the conditions to internalise this externality and to solve the moral hazard. I show that a positive externality exists in this industry and I measure the productivity effects of PPP contracts on DH firms. Using specific functional forms for production, I back out estimates for productivity and estimate its response to the specific award mechanism used.

In presence of a positive externality not implementing PPP implies a lower level of welfare, since firms could produce more efficiently at a lower marginal cost. Alternatively, in presence of a negative externality implementing PPP would be detrimental. PPP was heavily debated: it was seen until a few year ago only as a solution to keep investments high, despite reduced public budgets. I am the first to show that PPP works properly in an industry with characteristics in line with the assumptions stated in the literature. A public authority which knows beforehand the gains/losses in term of technical efficiency coming from PPP will have better guidance in the use of this procurement tool. Furthermore, this paper provides more evidence on how public procurement can affect productivity. PPP is proved as Fixed prices and Cost Plus contracts, see Gagnepain and Ivaldi (2002), to be a driver of productivity.

My results show that capital quality has a positive and significant impact on PPP firm's productivity. I find a non significant marginal effect of our proxy for capital quality for not PPP firms. There is, in turn, a strong and highly significant marginal effect on output for PPP firms. In particular, increasing by one unit the measure of quality shifts up the expected change in log of output by 0.142 for PPP firms. In level terms, it corresponds to an output increase of 15%. In particular, this effect is significantly strengthened in the presence of a PPP contract. I report a significant positive effect of the PPP dummy of 0.128, which in level terms corresponds to a 14% increase in output. Moreover, the estimates of the production function's parameters indicate the presence of decreasing returns to scale in the technology.

This work utilises a unique dataset on the universe of Italian DH facilities between 2007 and 2014. For each plant, I can observe accurate information on the physical quantities of output and inputs. Physical data are usually difficult to retrieve. Although, they are

essential to correctly identify production function since they avoid omitted price bias in estimates, see Tybout (2000). I can use this information to construct a reliable proxy for the capital quality. This is defined as the negative (-) ratio of the total length (m) of the pipeline to the total amount of heated volume (m^3) and is measured as the needed m of pipeline every $10^2 \times m^3$.

This paper relates to three different strands of literature. First, I contribute to the cited literature on PPP with an empirical test for the predictions of these models. Moreover, this paper is related to the contribution of Gagnepain and Ivaldi (2002) and Gagnepain et al. (2013), since it is an additional evidence on how procurement scheme can affect productivity.

Second, This paper relates to the path breaking results by Olley and Pakes (1996), Levinsohn and Petrin (2003) and Ackerberg et al. (2015). Their structural approach based on the timing of assumptions governing the firm's production process is meant to solve a problem of simultaneous endogeneity, see Klette and Griliches (1996). The capital quality is usually an unobserved state variable for the firm. This means that technical efficiency is not the only variable unobserved and any attempt of correct identification through structural approach results invalid.

Third, I contribute to the ongoing debate on productivity assessment. I retrieve a channel trough which the procurement scheme affects the productivity of firms. In fact, large differences in productivity across plants are usually observed in the same industry. Bartelsman and Doms (2000) find many cases where the highest productivity firm has more than twice the measured productivity of the lowest productivity firm. Fox and Smeets (2011) observe that the mean ratio of the 90th quantile of productivity to the 10th quantile of productivity is of 3.27 across eight Danish manufacturing and service industries. Moreover, literature focuses on the fact that pieces of capital equipment are of different vintages, see (Whelan, 2002), and machines lose their value due to technological progress. Balasubramanian and Sivadasan (2009) find that increases in capital resalebility are associated with a reduction in productivity dispersion. Then, capital quality seems of great concern relative to tfp dispersion.

The remainder of this paper is structured as follows. In Section 2 of the paper, I present the DH sector, highlighting the prevalence of PPP arrangements in this sector. In section 3, I describe in more detail the main data sources. In Section 4, I review two branches of literature, PPP contract theory and productivity. In Section 5, I introduce the empirical framework. This will be followed by the specific econometric strategy to identify the coefficients of the model. Finally in Section 6, I present the results from the estimation of the model.

2 Background

A DH is an integrated network system built under public authorization in service of a urban neighborhood. The plants are aimed at distribution of thermal energy and co-generation of electric energy. The electric energy produced is competitively sold to the national market and the thermal energy is fully redirected to the urban neighborhood.

DHs have the right to serve a neighborhood of dimension stated in the contract by the public authority. The thermal energy produced in co-generation is not sufficient to satisfy the needs of the network, then auxiliary boilers, which produce only thermal energy, satisfy the residual demand. We always observe an auxiliary boiler working, meaning that there is no free disposibility of the thermal energy.This implies that electric energy production is constrained by the thermal energy demand. Moreover, given the constant physical relation between electric energy and thermal energy production DH is usually considered as a single product industry and electric energy as a residual, see BrÃďnnlund and KristrÃűm (1999).

DH firms stipulate contracts of service with the customers of the network and each household could be served only by a DH network. As a consequence, DH firms are local monopolists. However, a recent study of The Italian Competition Authority (ICA) suggests the rare occurrence of extra-profits in Italian DH sector. Since households can install their own heating systems and this outside option has a cost of installation, DH firms optimally price heating at the price of installing an autonomous boiler plus the cost of producing heating with it.

Thermal energy distribution is carried out through a network of pipelines, that transport a heated vehicle and connect several heat exchange substations. Each substation connects the main network pipeline to the buildings. A single node can serve a certain amount of thermal power to the urban neighborhood.

Transporting thermal energy to households implies heat losses over the traveled distance. DHs deal with a trade-off between having more nodes or a shorter network of pipelines . Thus, an optimal layout becomes crucial in order to preserve temperature and pressure of the vehicle.

PPP scheme is usually used in substitution of a competed tender for construction and a public concession for the operation of the plant. In the last decade, PPP has represented the 13% of the contracts in the DH sector and the 35% in terms of the value of the entire market, SIOP (2013). The same study evaluates DH as a growing sector (as far as PPP), mainly in the more recent period.

3 Data

I can exploit an original dataset on DH industry in order to test and quantify the effect of PPP on productivity. These data are released every year by the Airu, the Italian association of DHs and concern a total of 148 plants, between 2007 and 2014, mostly the entire population, mainly distributed in north Italy. For each plant, I observe accurate information on output in terms of thermal and electric energy (mWh) produced and buildings' heated volume (m^3) every year. The thermal energy distributed is the main output variable in the model. Moreover, we observe the amount of heat losses (mWh), which it is the intermediate material and the proxy variable in the structural model. On the other hand, I use buildings' heated volume (m^3) every year quartiles to construct firm size dummies. I added these dummies, primarily, to fix the heated volume and be able to interpret capital quality in a meaningful way . Moreover, these dummies control for big shifts in thermal capacity of DH firms.

Furthermore, the dataset shows useful information on the inputs. Two proxies of capital are available, the count of heat ex-changer substations, which distribute thermal energy to buildings, and the length of the network pipes measured in m. The former is the proxy for the capital input and presents some heterogeneity since the heat ex-changer substations differ in terms of thermal capacity. Assuming a constant temperature of operation, I use the firm size dummies to kill this kind of heterogeneity.

Other aspects related to capital's quality may influence the DH's distribution process and the length of the pipeline is employed to construct a capital quality proxy. I investigate for a mechanism trough which PPP influences the quality of the infrastructure. In order to retrieve a proxy for the capital's quality, I exploit the network nature of the DH's capital. Capital quality, a, is given by the negative (-) ratio of the total length of the pipeline to the total amount of heated volume

$$a = \frac{pipeline's\, legnth}{heated\, volume}$$

and measured as the needed m of pipeline every $10^2 m^3$ heated. Decreasing value of this index should have a positive impact on output since heat losses (that decrease the total thermal energy distributed) are physically correlated to the average length of the pipeline. Note that theoretical literature suggests that under traditional procurement the builder has no incentive to set the optimal level of capital's quality not exerting enough effort in the design of the facility. Under PPP, since the operator is involved in the building's design phase, she can state the optimal level of capital's quality design she needs.

A set of dummies which indicate some key differences in DH technologies are introduced in the model. First, I control for the thermal vehicle used, steam or heated water, which

can make a difference in the rate of dispersion. Second, the majority of plants produce in co-generation thermal energy and electricity. Producing thermal energy only has severe impacts on the final dimension of the firm.

I am able to observe the thermal energy implied in the distribution process in term of megawatt per hour (mWh) and the heat losses of the pipeline. I use heat losses as intermediate materials instead of the whole thermal energy implied. This separate the thermal energy delivered from the thermal energy directly related to the distribution process. By using homogeneous input greatly simplifies the analysis since a single input is considered in place of several propellants implied in the production process.

Moreover, there are important demand shifters which influence production decisions of DH firms. First, geographical dummies are introduced to control for difference in average temperature between different areas. I constructed three main geographical zones exploiting a thermal energy index referred as "*heating degree-days*" (abbreviated as GG from the Italian version of the index) used to assess the energy used for space heating in buildings. This measure was introduced by European standard EN ISO 15927-6 and defined as:

$$GG = \sum_{1}^{d} (20 - T_e)$$

where d is the number of days of the conventional heating period and ranges between 90 and 365; 20 Celsius degree is the conventional ambient temperature in Italy; T_e is the daily average outer temperatures. A low value of GG indicates a short period of heating and daily temperatures near to the prescribed temperatures for the environment. The three zones are constructed based on climatic bands defined by Italian law and Zone 1 is comprised between 1400-2100 GG, Zone 2 between 2100-3000 GG and Zone 3 above 3000 GG.

Second, I introduce a continuous variable which measures the amount of thermal energy extracted by the avarage building. I exploit the percentage of Celsius degree difference in incoming and outgoing water's temperature. This difference is usually used in engineering literature and the index is a standardized measure of average thermal energy dispersion and catches shifts of the heating demand due to thermal isolation of houses.

In order to identify the plants constructed under PPP, I exploit a research published by "Siop" and the Chamber of Commerce. I account for a total of 25 projects in exercise realized using the PPP between 2002 and 2013.

Finally, I integrate data on the number of workers directly collecting them from the balance sheet of each company. These data refer to full-time blue collars.

In table 1, I report selected descriptive statistics of the entirety of firms along with those for each group, PPP or not. The average heated volume for Italian DH firms is around

$2377 \times 10^3\, m^3$. Only 24% of not-PPP firms do not produce electric energy, whereas almost the whole PPP sub-sample, 95%, produces in cogeneration regime. 44% of the entire sample use heated water as a thermal vehicle over steam. The average temperature extracted is 30.45 Celcius degree and buildings served by PPP are more energy efficient of 1 degree. PPP firms are mostly located in Zone 2 (85%) and show smaller value (higher quality) of the capital quality proxy .

	(1) whole Firms	(2) no PPP Firms	(3) PPP Firms
Total energy, mwH	86487.42	90484.34	46689.48
Heat Energy lost, mwH	37674.17	40423.89	8188.78
Number of Workers	54.44	58.59	13.11
Network Length, m	28070.51	28447.37	24012.00
Heat Exchanger Substations	504.89	510.08	449.05
Heated Volume, 1000xm3	2377.80	2466.65	1270.55
Quality Design, m/100xm3	2.60	2.61	2.42
Between 1400-2100 GG	0.10	0.11	0.00
Between 2100-3000 GG	0.55	0.53	0.86
Above 3000 GG	0.35	0.36	0.14
Cogeneration	0.78	0.76	0.95
Heat vehicle: steam	0.56	0.58	0.32
Average Temp extracted, cï£¡	30.45	30.56	29.36

Table 1: Summary Statistics

4 Literature review

4.1 PPP literature review

The first two papers that investigate the effects of public-private partnership are Hart (2003) and Bennett and Iossa (2006). These papers built on Schmitz (2005), who sets a principal-agent model in which the principal decides how to organize a project that consists of two stages. In particular, Hart (2003) provides a setting where a builder implements two kinds of non-contractible investments, productive and unproductive. Both reduce operating costs, although only the productive investment increases the benefit of providing the service. Under traditional procurement, the builder has no direct advantage in terms of benefit's increase or cost's reduction from implementing the unproductive investment, finding optimally to exert too much of the productive investment, but the right amount of the unproductive one. Under PPP, the builder partly internalizes the externality of his unproductive investment

although the level of the productive one remains too high.

Bennett and Iossa (2006) introduce a model where investments are ex-ante non-contractible but ex-post verifiable. In such setting, they study in depth the desirability of bundling project phases and of assigning ownership to the investor. Ownership assigns the right to the owner to implement quality enhancing or cost-reducing investment. The problem of keeping from optimally investing in the first phase of the project is less severe under PPP when a positive externality between the building and managing phases exists. Furthermore, the authors show that public ownership imposes on government a commitment to renegotiate and share with the investor the surplus from the implemented investments.

Martimort and Pouyet (2008) relaxes the hypothesis of non-contractible operational costs and service's quality and retrieve results similar to Bennett and Iossa (2006)'s ones. In particular, they find that granting ownership imperfectly aligns incentives between agents and the important point is not who owns the asset, but instead whether phases are bundled or not. Agency costs are found lower under a PPP arrangement compared with traditional procurement, in presence of a positive externality between building and managing .

Chen and Chiu (2010) introduce an "interim contractibility" framework and assume that the operation task becomes contractible subsequent to the building stage. Their results suggest that under private ownership, task externality and task interdependence still plays an important role in shaping the trade-offs between bundling and separation. In particular, some degree of convexity of the cost function, which allows for task complementarity, plays the interesting role to favor the builder's ownership and disfavors the consortium's ownership.

Lastly, Hoppe et al. (2013) conducted a laboratory experiment on PPP. The authors find that a PPP provides stronger incentives to make cost-reducing investments which may increase or decrease service quality.

4.2 Productivity literature review

The most common approach in literature to assess the productivity of firms is recovering Solow's residual from some well-behaved production function:

$$F(z_i;\alpha)\cdot exp(\omega_i+\epsilon_i) \tag{1}$$

where ω is individual i productivity, z_i is a vector of inputs and α is the vector of marginal productivity of each inputs. The error component ϵ is meant to capture both measurement errors and unobserved productivity shocks.

OLS issues in estimation of log-linearized version of equation (1) are twofold. First, the error component is correlated with z_i because firms exploit information on ω_i in their decision

concerning inputs quantity. Klette and Griliches (1996) refer this endogeneity as simultaneity since output and inputs result as the solution of a simultaneous equations system. Secondly, data in physical terms are commonly not available. In place of physical output and inputs econometricians use proxies. Sales deflated by an industry-wide price index are commonly used in place of output and balance sheet data as substitutes of inputs. Such substitutions have no consequences under perfect competition since all firms observe the same prices. Instead, with imperfectly competitive markets estimated firm-level productivity is likely to be misstated due to the demand shifters' effect passed trough prices to output and input's proxies. Since the problem is originated by omitted prices, it is usually referred as omitted price bias.

Methods of solving the simultaneity problem include finding instruments for inputs or assuming a fixed over time productivity and using a fixed-effects estimator, Mundalk (1961). Both methods seem to have failed. Input prices have shown weak predictive power and the data can be difficult to obtain. Moreover, implementing the fixed-effects assumption would not solve the endogeneity problems if changes in productivity are responsible for changes in input and quality choices. Olley and Pakes (1996) and following Levinsohn and Petrin (2003) and Ackerberg et al. (2015) propose a solution in terms of a structural approach which exploits observed plant decisions as proxies for unobserved productivity shocks. The intuition relies on the existence of a proxy variable for productivity which reacts to variations in the TFP. If this function is proved to be invertible, then the inverse function can be estimated and plugged in the production function to control for endogeneity.

Olley and Pakes (1996) isolate the proxy variable directly from the investment dynamic optimization problem of a firm, by inverting the amount of investment. From the dynamic problem also the terminology is inherited, such that the variables which constitute the minimum set of information in order to retrieve the policy function (the stock of capital, the age of a firm, etc.) are referred as dynamic state variables. On the other hand, inputs (labor, materials etc.) which can be modified in a successive moment, after productivity shocks occur, are referred as static free variables.

Investment as a proxy for the TFP presents an enormous problem in terms of data availability. Since in many occasions investment assumes zero values, it becomes not invertible in these points. Consequently, many observations must be dropped out and the remaining sample needs to be representative. Levinsohn and Petrin (2003) propose a solution slightly changing the timing of firm's decision. Supposing intermediate materials (energy, fuels etc.) are chosen between the occurrence of the productivity shock and the decision regarding free variables (labor and eventually others intermediate materials), they respond to productivity and act as a proxy variable The static variable intermediate materials do not suffer from the

zeros problem and guarantee greater data availability.

Ackerberg et al. (2015) point out how the choice of free variables (labor etc.) may be a function of previous choices in terms of state variables. Consequently, any attempt to estimate separately free variables coefficients could suffer from a serious problem of collinearity. They propose to give up any attempt to separately estimate the coefficients and to estimate the whole coefficient vector α non-linearly.

The omitted bias problem, as highlighted by Katayama et al. (2003) constitutes a serious problem which invalidates many attempts of TFP estimation. Solutions involve considering a demand model like in De Loecker (2007) or relying on data in physical terms like in this paper.

5 Model

5.1 Theoretical framework

Under traditional procurement, a public authority could offer to the builder (B) a contract such that the payment scheme is $\tau_B + \gamma_B C_B$ with $\{(\tau_B, \gamma_B)\} \in \mathbb{R} \times [0, 1]$, where τ_B is a transfer from the authority and γ_B the percentage of cost (C_B) shared with the firm. The case $\gamma_B = 1$ corresponds to a cost-plus contract where the contractor is fully reimbursed for its own costs, whereas $\gamma_B = 0$ stands for a fixed-price contract, where the contractor receives a fixed payment. Fixed price contracts are of common use for DH construction, then τ_B only is contractible.

The same public authority could offer to the operator (O) another contract such that the payment scheme is $\tau_O + \gamma_O R_O$ with $\{(\tau_O, \gamma_O)\} \in \mathbb{R} \times [0, 1]$, where α_O is a transfer from the authority and γ_O the percentage of unit revenues shared with the firm. A payment mechanism solely based on user charges corresponds to $\tau_O = 0$ and $\gamma_O = 1$, so that the contractor keeps all the revenues. On the other hand, payment mechanism based on availability corresponds to $\tau_O > 0$ and $\gamma_O = 0$, so that the contractor's reward is fixed . DH firms collect revenues from customers only and revenues cannot be contracted upon.

Each builder faces the problem to implement a minimum level $\underline{a} \in \mathbb{R}_+$ of facility's quality, below which the plant does not work, and eventually a quality investment $a^i \in \mathbb{R}_{++}$, which will influence the operational cost of the operator and increases the overall quality of capital, a.

5.2 Moral hazard

Suppose the following well behaved differentiable in every point DH's cost function:

$$C(ED,\, a,\, e;)$$

with $\frac{\partial C(.)}{\partial a} \leq 0, \frac{\partial C(.)}{\partial e} \leq 0$ and $\frac{\partial C(.)}{\partial ED} \geq 0$ The total cost is a function of the effort, e, and the capital quality, a, which reduce the needs of each input to produce the same level of output. The effort, e, encompasses all these factors which IO literature has recognised as effectively able to reduce firm unit cost, see Syverson (2011) for a complete survey. This can be like Gagnepain and Ivaldi (2002)'s cut of inefficiency in the public transportation sector due to the enforcement of procurement contract on suppliers.

Under traditional procurement, the builder knows nothing about the cost structure of the operator, so implementing a particular quality investment level a^iaffects her own cost negatively. This cost of implementing a^i is an unknown function $g(a^i)$ with $\frac{\partial g(.)}{\partial a^i} > 0$. Then, the builder's optimisation problem , who receives a first price payment scheme, $\tau_B > 0$ and $\gamma_B = 0$, would be:

$$\underset{a^i}{max}\, \tau_B - g(a^i)$$

where the builder decides to optimally implement the smallest capital quality level, $\underline{a}$, in order to make the plant working [2]. Successively, the DH (the operator) can exert an effort e in order to reduce the "input" inefficiency of her own cost C, whose implementing cost is the unknown function $z(e)$ with $\frac{\partial z(.)}{\partial e} \geq 0$. The optimization problem of the operator, who receives a payment schemes $[\tau_O, \gamma_O]$ and takes $a = \underline{a}$ is:

$$\underline{e} = \underset{e \geq 0}{argmax}\; \tau_O + \gamma_O R_O - C(ED,\, \underline{a},\, e;) - z(e) \tag{2}$$

In a PPP, a public authority offers to the builder and the DH, joint in a consortium, a unique contract. The optimisation problem is:

$$\left(a^{PPP},\, e^{PPP}\right) = \underset{a^i,\, e \geq 0}{argmax}\; \tau_c + \gamma_c R_c - C(ED,\, a,\, e;) - z(e) - g(a^i) \tag{3}$$

which delivers the following capital quality level and effort investment:

[2] A FP contract will not determine a quality investment, a, if the quality investment is not implement as a reducing Builder's cost effort. A different payment scheme linked on the quality investment provided by the builder obviously determines some quality investment implemented also under classical procurement.

$$a^{PPP} \coloneqq \underline{a} + a^i_{PPP}$$

$$e^i_{PPP} \coloneqq e^{PPP} - \underline{e}$$

Under traditional procurement, the level of capital quality implemented cannot exceed the level of quality under PPP, which means that the total level of capital investment a^i_{PPP} is set at zero. The optimal capital quality increases when the gain from increasing the capital quality through investing $\frac{\partial C(.)}{\partial a^i}$ is not neutralized by the cost loss term, $\frac{\partial z(.)}{\partial a^i}$. The effect on the total level of effort is less clear, since it is related to convexity of the cost function, trough the cross derivative $\frac{\partial C(.)}{\partial a^i \partial e^i}$. When $\frac{\partial C(.)}{\partial a^i \partial e^i} > 0$, we should observe substitution between the total level of effort and the capital quality. I do not have any hint about the true direction of the cross derivative, but I can rely on the control function approach to control for such effects. In appendix A, I propose an explicit solution under the assumption of a cobb-douglas cost structure and exponential cost of implementation. of a and e.

5.3 Empirical model

I assume the following DH firm's single-output structural valued-added cobb-douglas production function:

$$ED = \Omega\,(a,\, e) \cdot K^{\alpha_c} \cdot L^{\alpha_l}$$

where ED, K, L are respectively output, capital, labour. $\Omega\,(.)$ is the unobserved term for productivity, which results crucial for the identification. In particular, ED is the $mhwh$ of thermal energy delivered. Firstly introduced by Gandhi and Rivers (2014) and employed by Ackerberg et al. (2015), this specification suppose proportionality between intermediate material, ET , and output, ED[3]. In particular, ET is the thermal energy implied to cover heat losses and plays a main role in the empirical model since it is my proxy variable for productivity estimation.

Under traditional procurement firms implement the lower capital quality level $\underline{a}$. On the other hand, PPPs induce firms to make a quality investment a^i_{PPP}. The following expression

[3] The structural value-added production function is directly derived from the following DH firm's single-output gross output Leontief production function:

$$ED = \min\left\{\Omega \cdot K^{\alpha_c} \cdot L^{\alpha_l},\, \alpha_{et} ET\right\} \tag{4}$$

The intermediate materials, ET, are considered proportional to the output. After controlling for capital quality and other climatic and environmental factors such hypothesis seems plausible since a physical constant exists between the amount of heat loss and the pipeline length.

defines the total capital quality implemented by a DH firm (considering both PPP and not PPP) :

$$a = a^{PPP} \cdot PPP + \underline{a} \cdot (1 - PPP) = \underline{a} + a^{i}_{PPP}$$

where PPP is a binary variable to identify PPP plants. Secondly, based on the curvature of the cost function PPP firms adjusts the operating effort, e, given the quality design investment, a. Similarly to the quality, I can define the total effort,

$$e = e^{PPP} \cdot PPP + \underline{e} \cdot (1 - PPP) = \underline{e} + e^{i}_{PPP}$$

The two procurement scheme give rise to two separate tfp functions for PPP and not PPP firms [4]. Suppose these two functions $\omega^{notPPP}$and ω^{PPP} are at least C^1 and ω_{it} is an unobserved productivity shock term. Taking a first order Taylor expansion of $\omega^{notPPP}$and ω^{PPP} in $(\underline{a}, \underline{e})$ and collecting PPP and not PPP firms, I obtain:

$$\omega(a,\,\mathrm{e}) \backsimeq \underbrace{\left[\frac{\partial \omega^{not\,PPP}\,(\underline{a}, \underline{e})}{\partial a_{it}}\right]}_{\beta_a} a_{it} + \underbrace{\left[\frac{\partial \omega^{PPP}\,(\underline{a}\,\underline{e})}{\partial a_{it}} - \frac{\partial \omega^{not\,PPP}\,(\underline{a}, \underline{e})}{\partial a_{it}}\right]}_{\beta_{int}} a_{it} PPP +$$

$$+ \underbrace{\left[\omega(\underline{a}\,\underline{e})^{PPP} - \omega(\underline{a}\,\underline{e})^{not\,PPP}\right]}_{\beta_{PPP}} PPP \tag{5}$$

where the constant components are omitted for sake of simplicity. Plugging $\omega(a,\,\mathrm{e})$ into the linearized Cobb-Douglas production function, equation (4), the reduced form model for a DH firm i in time t can be written as:

$$ed_{it} = \alpha_s k_{it} + \alpha_l l_{it} + \beta_a a_{it} + \beta_{int} a_{it} * PPP_i + \beta_{PPP} PPP_i + \omega_{it} + \epsilon_{it} \tag{6}$$

where small cases stay for logs of output and input variables. The unobserved terms relative to e_{it} are absorbed inside ω_{it} along with the others unobserved factors which influence productivity. The idiosyncratic error ϵ_{it} accounts for measurement error. The coefficient β_{PPP} should be interpreted as the average PPP additional effect on TFP, which is the mixed effect of trading off quality investment and operational effort. The interaction term β_{int} is the incremental effect of a unit increase of capital quality when a firm is built and operated under PPP. This should be interpreted as the externality effect on productivity. On the

[4] In this case the points $\left(a^{PPP},\, e^{PPP}\right)$ and $(\underline{a},\, \underline{e})$ identify two single points in just as many tfp functions. In Appendix A, I parametrize the domain of this two functions through two exogenous parameters $\delta,\, \kappa \in [-\infty, +\infty]$. These parameters capture the externality effect of capital quality and labour effort.

other hand, the coefficient β_a measures the overall marginal effect of the capital quality a_{it}.

The identification of β_{int} and its interpretation as the effect of the technological externality is based on a simple feature of the linear model. Introducing size dummies, S_{it}, for the quartile of the heated volume $m3$ I avoid variation in the quality index due to variation of the heated volume. In this way, changes in this index are only due to changes in the pipeline's length. In addition, the model accounts for others control variables, $\tilde{X}_{it}$, controlling for technological and supply shifters:

$$ed_{it} = \alpha_s k_{it} + \alpha_l l_{it} + \beta_a a_{it} + \beta_{int} a_{it} * PPP_i + \beta_{PPP} PPP_i + S_{it}\rho_s + \tilde{X}_{it}\rho_{\tilde{x}} + \omega_{it} + \epsilon_{it}$$

For sake of simplicity, I collect all the other control variables in a matrix X_{it}, collapsing the model to:

$$ed_{it} = \alpha_s k_{it} + \alpha_l l_{it} + X_{it}\rho + \omega_{it} + \epsilon_{it}$$

As already pointed out in the review part, estimates of equation (6) by OLS will incur the well-known endogeneity problem associated with estimating production functions: the presence of $\omega_{it}\,(e_{it})$ being possibly correlated with plant's capital, labour and material demand. In this industry, productivity's differences may be owed to unobserved differences in quality of inputs as well as to previously unobserved differences in plant's characteristics due to the form of procurement used to realise the plant. In order to account for endogeneity, I adapt the Levinsohn and Petrin (2003)'s approach corrected by Ackerberg et al. (2015) to the DH industry introducing a new control variable for the capital quality and controlling for PPP effect.

First, I specify the inputs timing decision and the static optimisation problem of a DH firm, in order to identify amongst proxy variables the state variables from the free variables. Second, I identify the input coefficients exploiting the identified information set at time t.

5.4 Identification

The main problem for identification is the endogeneity due to simultaneous output and inputs. In this case, identification is obtained through a structural model exploiting the timing assumption behind DH firm's dynamic optimisation of profits. Moreover, the possibility to crowd out intermediate materials demand through a Leontief production function avoid

collinearity issue due to the estimation of intermediate material input elasticity [5].

5.4.1 Timing assumptions

A DH plant chooses the amount of intermediate materials based on its stock of capital, k_{it}, labor, l_{it} and a vector of observable characteristics of the plant, $\mathbf{x}_{it}$. This vector of observable characteristics of the plant, $\mathbf{x}_{it}$, contains information about the technology, demand and, as hypothesized in this papers, procurement shifters which affect the optimal level of capital quality of the network, a_{it}. The decisions unfold as follows:

1. Output choice made: a plant's manager begins the period knowing the current level of capital, k_{it}. The plant's manager also observes ω_{it}^{BEFORE}, belief on productivity this period given the information set at the beginning of the period, which is also function of the effort e, the quality investment a and a vector of other observable control variables. Consequently, relying on this information set a plant's manager decides the targeted level of output.

2. In an intermediate period between output choice and production, DH firm's manager decides the amount needed of labour inputs, l_{it}. Note how labour is not a "perfectly variable" input decided at the time production takes place, the above timing of input decisions implies that labour is a less variable input than intermediates, since labour is chosen one sub period before productivity shocks occur.

3. Production occurs. Based on its chosen targets, the plant carries out its distribution activity and observes realised outcomes for output and losses of the network. The DH firm's manager also updates his knowledge about its productivity , ω_{it}^{AFTER}.

4. Intermediate inputs choices. During production in a dynamic process, the plant's free variables are adjusted to reflect what has been learned about productivity, the information set $I_{it} = (k_{it}, l_{it}, \mathbf{x}_{it}, \omega_{it}^{AFTER})$ is updated. With this information, every plant decides on intermediate inputs, et_{it};

5. New period decision.

[5] As highlighted by Gandhi and Rivers (2014), the Leontief form could be not sufficient to guarantee the identification of the elasticities parameters. To understand, suppose K_{it} and L_{it} are chosen before ET_{it} and the price of ET_{it} suddenly varies such that revenues do not cover the cost of the intermediate material required to produce that output. In this case, DH firms would not generally choose ET_{it} to satisfy ED=α_{et}ET= $\Omega \cdot K^{\alpha_c} \cdot L^{\alpha_l}$, and thus the data could contain points where production is equal to zero. Although, this doesn't appear as a big problem. Since DH firms will either satisfy ED=α_{et}ET= $\Omega \cdot K^{\alpha_c} \cdot L^{\alpha_l}$ or produce 0 output, and if they produce zero, they will presumably not be in the dataset of those operating and thus it is not a problem for estimation.

Considering the evolution of the process up to now, it is reasonable to model the plant's expectation of productivity as an exogenous Markov Process,

$$\omega_{it}^{BEFORE} = E[\omega_{it}^{AFTER}|I_{it}] = E[\omega_{it}^{AFTER}|\omega_{it-1}^{AFTER}]$$

As expectations on productivity at t are formed, the plant chooses whether to remain active in the market in period t, and if it is so a new cycle starts.

I assume as in Pakes (1994) that the process is stochastically increasing in ω_{it}^{AFTER} and that the ω_{it} moves according to an exogenous Markov process. Productivity ω_{it} considers the entire of unobserved factors which can modify the volume heated by a DH firm, once observable characteristics and quality are kept constant.

5.4.2 Firm's Static optimization problem

I follow the examples of Olley and Pakes (1996), Levinsohn and Petrin (2003) and Ackerberg et al. (2015) solving only the static profit maximisation problem, which is sufficient in order to identify the production function parameters. After production occurs, the plant updates its beliefs about its productivity and it will observe the new variable:

$$\omega_{it}^{A} = \omega_{it}^{B} + \epsilon_{it}^{\omega} \tag{7}$$

I assume that $(\epsilon_{it}, \epsilon_{it}^{\omega})$ are mean zero and uncorrelated with the information available to the plant, although the components of this vector may be correlated with each other. Because the plant will not learn about $(\epsilon_{it}, \epsilon_{it}^{\omega})$ until it operates, it has to optimise its output choice under uncertainty. The plant chooses its expected output to solve the following static profit maximization problem:

$$\pi(K_{it}, ET_{it}, L_{it}, \omega_{it}, \mathbf{x_{it}}) = \max_{et_{it}, l_{it},} E[P^{ED} \cdot ED_{it}(ET_{it}) - P^{K}K_{it} - P^{l}L_{it}]$$

$$s.t.\ ED_{it} = F(K_{it}, L_{it}, \omega_{it}^{B}|\mathbf{x_{it}})$$

Lastly, the following lemma establishes that the intermediate materials demand, ET_{it} is strictly increasing in productivity, which it is a sufficient condition for the invertibility, and allows to use intermediate materials demand as a proxy for productivity in our estimation strategy. The following is proved in appendix B:

Lemma 1. The plant's intermediate material demand, et_{it}, is strictly in-

creasing in ω_{it}^{BEFORE} if the following condition on the production function holds:

$$\frac{\partial F}{\partial ET \partial L}\frac{\partial F}{\partial ET \partial \omega_{it}^{B}} - \frac{\partial F}{\partial ET \partial \omega_{it}^{B}}\frac{\partial F}{\partial L^2} + \frac{1}{\eta F}\left(\frac{dF}{dET}\frac{\partial F}{\partial \omega_{it}^{B}}\frac{\partial F}{\partial L^2} - \frac{\partial F}{\partial ET \partial \omega_{it}^{B}}\frac{d^2 F}{dL} - \frac{\partial F}{\partial L \partial ET}\frac{\partial F}{\partial L}\frac{\partial F}{\partial \omega_{it}^{B}} - \frac{\partial F}{\partial L}\frac{dF}{dET}\frac{\partial F}{\partial L \partial \omega_{it}^{B}}\right) > 0$$

5.4.3 Selection concerns

Buyers do not involve sellers in discussions before the contract awarding if a direct negotiation is not used to select the seller. A firm's "expertise" to deal with a particular form of contract or to enforce the public body's choice of this particular contractual form may be an issue. In presence of this form of selection, the effect of the PPP on the DH firms' performance could be the result of the selection of a particular sub-sample. In order to avoid such concerns, I conducted a preliminary market analysis. I exploit tender awards data to assess the dynamic of firms' market shares. Seven firms represent the 56,51 % of the entire PPP market (table 4). Conversely, the same seven firms (Cofely and Siram are connected) account for the 47,53 % of the not-PPP market (table 5). Confronting PPP with not PPP projects, firms seem to retain their relative market share.

PPPs and not PPPs are not directly comparable in terms of awards, since the former bundles different tasks. Such heterogeneity could induce some restrictions to competition amongst DH firms, which translates in selection: some small firms cannot compete in very big tenders. The poor / good outcome of PPP plants could be again the result of selection of big / small or low / high quality firms. In order to check, I analysed a sample of 33 tenders in the period 2007-2012 (earlier data were not available). In table 6, you can compare the average number of bids made in PPP tenders with the average number of bids for building, operating and maintenance tenders. In this case, the number of bids proxies the level of competition in participating in the tender, the same number of bids attains to the same level of competition. The average number of bids for a PPP tender is 4,08 with a standard deviation of 5,99 (right column in table 6). The average number of bids for a not PPP tender is 5,39 bids with a standard deviation of 2,85 (left column in table 6). A non directional t-test (t-statics equal to 0,77 with 31 df) confirms that the difference between the means of two independent samples is not statistically different from zero.

Finally, Buso et al. (2016) use a database on french tenders and find a positive relation between tightness of Public Body's budget constraints and the use of PPP. This finding strengthens my point of PPP's effect being exogenous to firms' manipulation.

5.5 Estimation

Plugging identity equation (7) into model equation (6), it can be rewritten as:

$$ed_{it} = \alpha_s k_{it} + \alpha_l l_{it} + \mathbf{x_{it}}\beta + \omega^A_{it} - \epsilon^\omega_{it} + \epsilon_{it}$$

The vector $\mathbf{x_{it}} = [a_{it},\, PPP_i,\, a_{it} * PPP_i,\, \mathbf{D}_i,\, Cog_i,\, Tech_i,\, dTemp_{it},\, \mathbf{S}_{it},\, 2014_t]$ contains all the relevant control variables for the DH's distribution process. The PPP_i identifies PPP plants. The $\mathbf{D}_i$ vector includes all the geographical dummies. The Cog_i dummy controls for plants in cogeneration regime. A *tech* dummy, equal to 1 for heated water, is included to control for technological differences in the physical state of the thermal vehicle (heat water, steam). The $dTemp_{it}$ variable is the continuous index which measures average thermal dispersion of buildings. The $\mathbf{S}_i$ vector includes firms size dummies. The 2014_t is a dummy I added to control for particularly hot 2014's winter.

The vector $(\epsilon^\omega_{it}\, \epsilon_{it})$ does not raise any endogeneity problems. These vector is revealed to the DH firm after it makes its input choices and it is uncorrelated with the firm's information set at the time output choices are made. On the other hand, DH firms' expectation about ω^A_{it} is a function of ω^B_{it}, which forces to control for ω^A_{it} since $l_{it}(\omega^B_{it})$ is also a function of ω^B_{it}. From Lemma 1, DH firm's expectation about its productivity can be recovered by inverting the series of intermediate materials choices such that

$$\omega^A_{it} = et^{-1}_{it}(et_{it},\, k_{it},\, l_{it},\, \mathbf{x_{it}}) \tag{8}$$

I follow Levinsohn and Petrin (2003) and Ackerberg et al. (2015), substituting 8 into the production function in order to obtain the first stage equation:

$$ed_{it} = \alpha_s \cdot k_{it} + \alpha_l \cdot l_{it} + et^{-1}_{it}(k_{it}\, et_{it}\, l_{it}\, \mathbf{x_{it}}) - \epsilon^\omega_{it} + \epsilon_{it}$$

$$= \Phi(k_{it}\, et_{it}\, l_{it}\, \mathbf{x_{it}}) + \varepsilon_{it} \tag{9}$$

where Φ is a polynomial in $(k_{it},\, et_{it},\, l_{it},\, \mathbf{x_{it}})$. In order to prevent collinearity issue, coefficients are not identified in this step. First stage is meant to get rid of the error component, $\varepsilon_{it} = \epsilon^\omega_{it} + \epsilon_{it}$, and obtain the sample counterpart $\hat{\Phi}$, from non parametrical estimation of equation (9).

Under the LP assumptions and at the true value of the coefficient vector $(\alpha^*_j,\, \beta^*_x)$ with $j = c,\, l$ and $x = a,\, ...,\, D^1, .., D^n,\, ...2014_t$, $\hat{\Phi}$ could be used to recover a reliable proxy of the productivity ω_{it}, then $\widehat{\omega_{it}}$ is calculated as:

$$\hat{\omega}_{it} = \hat{\Phi}_{it} - \alpha^*_s \cdot k_{it} - \alpha^*_{et} \cdot et_{it} - \alpha^*_l \cdot l_{it} - \mathbf{x_{it}}\beta^*$$

I consider a process where lagged level of capital quality is allowed to impact productivity

of PPP firms and thereby affects productivity changes as :

$$\omega_{it} = g(\omega_{it-1,} a_{it-1} * PPP_{it-1}) + \xi_{it}$$

i.e. the productivity follows a first order markov process, where g is a non-parametric function of ω_{it} and $a_{it-1} * PPP_{it-1}$. This captures productivity changes due to active investments based on the capital quality level of a PPP firms. When PPP firms update their expectation to higher productivity level and have to decide changes to the capital stock, then they adjust their capital in order to keep the optimal capital quality.

The term, ξ_{it}, is a shock to productivity between time $t-1$ and t, which is independent of the DH firm's time-t information set. The sample counterpart of the polynomial $g(.)$ is recovered by regressing non-parametrically $\widehat{\omega_{it}}$ on a polynomial of $\widehat{\omega_{it-1}}$, which is used to identify the series of shocks

$$\xi_{it} = \hat{\omega}_{it} - \widehat{g(.)}$$

Finally, exploiting the timing assumption, you can construct a moment estimator using the following set of moments:

$$E\begin{bmatrix} \xi_{it} \cdot l_{it-1} \\ \xi_{it} \cdot k_{it} \\ \xi_{it} \cdot a_{it} \\ \xi_{it} \cdot a_{it} PPP_i \\ \xi_{it} \cdot PPP_i \\ \xi_{it} \cdot D_i^n \; \forall n \\ \xi_{it} \cdot Cog_i \\ \xi_{it} \cdot Tech_i \\ \xi_{it} \cdot dTemp_{it} \\ \xi_{it} \cdot S_i^n \; \forall n \\ \xi_{it} \cdot 2014_t \end{bmatrix} = 0$$

Standard errors are calculated through block bootstrap. Optimisation is carried out through the Nelder-Mead algorithm and to ensure convergence different starting points were tried. Finally, I recover TFP estimates as following:

$$\widehat{\omega_{it}} = ed_{it} - \alpha_c^* \cdot k_{it} - \alpha_l^* \cdot l_{it} - \mathbf{x_{it}} \beta^* \tag{10}$$

6 Results

In table 2, I present the estimates of our single output production function model along with the ordinary least square (OLS) and the fixed effect (FE) estimators which are respectively presented in column 1 and 2 as touchstones of our model. The point estimates are associated with bootstrapped standard errors in parenthesis.

First, I consider the estimates of the inputs' elasticities $\alpha_j \; with \, j = k,, l$ and it is immediately evident as estimates of these parameters differ significantly across methods. In particular, a comparison between OLS and the FE model, enlightens how using only the crossectional variation to identify input elasticities implies not accounting for productivity differences amongst DH firm. Treating the same DH firm across time as several different observed units greatly biases the results since more productive firms are likely to use more quantity of the inputs. This induces to strengthen (weaken) increasing (decreasing) return to scale. On the other hand, FE estimator exploits only the year-to-year variation in DH firms' inputs: estimation by FE accounts for differences across DH firms, but these differences remain constant over time.

I observe decreasing return to scale as expected from technical literature on DH plants, see BrÃďnnlund and KristrÃűm (1999), even after controlling for size dummies[6]. Moreover, estimated coefficients are consistent with previous estimation of capital and labor's marginal productivity in a valued added production function context, see for reference the cited article of BrÃďnnlund and KristrÃűm (1999). I find that simultaneity bias affects upward coefficients of capital. A capital's coefficient, equal to0.344, is in line with a capital intensive industry like DH firm. This is also in line with our hypothesis of restrained substitution between capital and thermal energy.

I move to the main focus of this paper, the effects of the capital quality and PPPs . In line with the theoretical framework, I find a non significant marginal effect of our proxy for total quality investment in building's design, which controls for the capital quality a_i. I report a significant positive effect of the PPP dummy of 0.128, which in level terms corresponds to a 14% increase in output. I find a strong and highly significant marginal effect on output of a quality investment in building's design for PPP firms, the interaction term. In particular, reducing by one unit (negative) the length of pipeline every $10^2 \, m^3$, shifts up the expected change in log of output by 0.142 for PPP firms. In level terms, it corresponds to an output increase of 15%.

Amongst the control variables, the cogeneration dummy is strongly significant and positive, suggesting that the contemporaneous production of electricity and thermal energy

[6] Decreasing return to scale are not in contrast with a natural monopoly with U-shaped cost function.

affects the heat distribution thermal capability of DH firms. I find a strong significant positive effects, respectively equal to 0.921 and 0.783, of the geographical dummies. A dummy for the 2014's hot winter is negative and strongly significant. Differences in average extracted have no meaningful effect on the thermal energy distribution.

7 Robustness check

7.1 Alternative Approach

As a first robustness check, I propose the Wooldridge (2009) estimator. This estimator is robust to the criticism of Ackerberg et al. (2015) and can be constructed relying on either intermediate materials or investment to proxy for productivity. The literature refers to the former as the Wooldridge–LP and the latter as the Wooldridge–OP. The Wooldridge (2009) consists of a two-equation system GMM estimator, where contemporaneously the first accounts for the dynamic process of productivity and the second directly approximate the unobserved technical efficiency term. The Markov process of technical efficiency andω_{it} are both obtained by the approximation of two unknown functions, $g(.)$ and $h(.)$. This estimator exploits moments on the vector error term :

$$E\begin{bmatrix} \xi_{it} & \\ & \mid I_{it} \\ \epsilon_{it} & \end{bmatrix} = 0$$

where I_{it} is the usual information set of a DH firm i at t. This approach avoids bootstrapping to obtain standard errors on the production function coefficients since the two equations are jointly estimated in a single step. However, this procedure requires jointly estimation of all polynomial coefficients that approximate the unknown functions $g(.)$ and $h(.)$, together with all production coefficients and the control variables. This means that you need a search over a larger parameter space than ACF methodology since you have to search jointly for the production function coefficients, the control variables coefficients, and all polynomial coefficients. In table 6, I report the estimates. In the first column, I used the intermediate material as proxy. The elasticities estimates do not differ significantly from the two stages model. Focusing on the PPP effect, the interaction term β_{int} has a positive and significant effect of 0.139, consistent with the baseline model estimates. A unit increase in capital quality increases the output in level terms by 15%. The PPP dummy results positive, but not significant. A shift in the status of plant increases output by 17%.

In column 2, I used the yearly variation in pipeline's length as a measure of investment. Using investment greatly affects the dimension of the sample, due to the presence of many

zeros. In this case, I find biased downward estimates for the labor and capital coefficients. The interaction coefficient is still significant and positive, with a unit effect equal to 0.170, which in level term represents a 18% increace in output.

7.2 Translog production function

In order to check if any misspecification of the functional form can affect the estimates of the PPP effect, I consider the following "structural value added" translog production function:

$$ed_{it} = \alpha_c k_{it} + \alpha_l l_{it} + \alpha_{cc} k_{it}^2 + \alpha_{ll} l_{it}^2 + \alpha_{cl} k_{it} l_{it} + \mathbf{x_{it}} \beta + \omega_{it} + \epsilon_{it}$$

The translog production function knows 50 years of continuous research since its first introduction in 1967 by J. Kmenta for the approximation of the CES production function with a second order Taylor series. Differently from the Cobb-Douglas production function, translog does not assume "smooth" substitution between production factors or perfect competition for the markets of production factors (J.Klacek, et al., 2007). In addition, the family of translog production functions gathers the linear additivity relationship between the output and the inputs as a special case of the nonlinear ones.

The first stage polynomial is not affected by this different production function form since the squared and the interaction term are already included. Similarly, I can recover the residual ξ_{it} from the non-parametric equation of the dynamic process of ω_{it} and use it to construct the new moment conditions:

$$E \begin{bmatrix} \xi_{it} \cdot l_{it-1} \\ \xi_{it} \cdot k_{it} \\ \vdots \\ \xi_{it} \cdot l_{it-1}^2 \\ \xi_{it} \cdot k_{it}^2 \\ \xi_{it} \cdot k_{it} l_{it-1} \\ \vdots \\ \xi_{it} \cdot S_i^n \; \forall n \\ \xi_{it} \cdot 2014_t \end{bmatrix} = 0$$

In Table 8, I replicate the specifications used in Table 1 with the translog production function. In the last column, both the PPP dummy and the interaction with the capital quality remain positive and significant. Their effect on output is slightly larger, by 0.155 and 0.165, respectively for the PPP dummy and the interaction term. The estimated input elasticities are a linear combination of the estimated coefficients of the production function. The inputs

elasticities for the capital and labor inputs are given by :

$$\hat{\theta}_{kit} = \hat{\alpha}_c + 2\hat{\alpha}_{cc}k_{it} + \hat{\alpha}_{cl}l_{it}$$
$$\hat{\theta}_{lit} = \hat{\alpha}_l + 2\hat{\alpha}_{ll}l_{it} + \hat{\alpha}_{cl}k_{it}$$

In Table 2, I report the calculated elasticities in term of averages of three different models: the simple ols, the fixed effect model and the control function approach model. Both ols and fixed effect model show upward bias for capital elasticity. Furthermore, the estimates are in line with what I find under the Cobb-Douglas specification.

	Capital	Labour
Model	.3175	.0978
OLS	.3743	.0484
Fe	.4741	-.0019

Table 2: Average Translog Elasticities

7.3 More dummies

As a further robustness check, I verify how the structure of the size dummies can affect the estimates. I propose two different specifications. The first considers a deeper structure of dummies, in terms of deciles of the heated volume distribution. The second directly uses the continuous variable. Estimations are reported in table 3. In column 3, the magnitude of the interaction term is strengthened by the presence of a more dense structure of the dummies. A unit change in capital quality increases log output by 0.243, which in level terms means a 26% increase in output. Moreover, the PPP dummy continues to be positive and significant with an effect similar to the baseline specification. In column 6, the model is augmented with a continuous variable controlling for the household heated volume. Estimates of the interaction term remain similar to the model with a deeper structure of dummies, but the PPP dummy loses its effect. Both the specifications in column 3 and 6 show smaller estimates of the labour elasticity, respect to the baseline model. Measurement error in labor can be the reason of the variability in labor elasticities estimates.

8 Conclusion

Recently, Public Private Partnership has widespread in popularity as a contractual scheme. At the same time, more and more PPPs were used in district heating industry. This combination constitutes the perfect environment to test for the long debated productivity effect of PPP. Up to now, the increasing popularity of PPP has due to the financial aspects of the contract, which takes off the burden of financing projects from public authorities shoulders. Moreover, cost increasing evidence along with great dispersion in quality of the service has frequently reported.

In this paper, I separately identify the externality effect from the effort trade-off. I find a significant and prominent in magnitude positive effect of PPP on productivity. The effect on productivity is striking, reducing by one unit (negative) the length of pipeline every $10^2\, m^3$, shifts up the expected change in log of output by 0.142 for PPP firms. In level terms, it corresponds to an output increase of 15%. This effect main driver is the presence of a strong interconnection between the different tasks collected by the PPP contract and the DH.

9 Tables

	2002-2013	
	# PPP won	Market share % (100=326,47 mln)
SIRAM SPA (Veolia)	1	18,38%
Hera	1	9,95%
ATZWANGER SPA	1	8,21%
A2A SPA	3	6,46%
Egea SPA	4	5,27%
METANALPI ENERGIA SRL	1	5,05%
T.E.S.I. SRL	1	3,19%
% share of PPP market		56,51%

Table 3: PPP market

	2002-2013	
	# non-PPP won	Market share % (100=4244 mln)
HERA SPA	9	9,07%
COFELY	10	8,55%
A2A SPA	5	6,49%
Egea SPA	8	5,94%
ATZWANGER SPA	1	5,19%
METANALPI ENERGIA SRL	4	5,18%
SIRAM SPA (Veolia)	4	3,90%
T.E.S.I. SRL	5	3,21%
% share of non-PPP market		47,53%

Table 4: non-PPP market

	2007-2013			
not-PPP phases	not-PPP Average bids / (SD)	n	PPP Average bids / (SD)	n
Operating managment	2,14 (2,90)	7	4,08 (5,99)	13
Mantainance	5,33 (1,48)	6	$\ddots$ $\ddots$	$\ddots$
Building	8,71 (6,80)	7	$\ddots$ $\ddots$	$\ddots$

Table 5: Tenders dynamic

	Simple		Augmented			
	Pooled OLS	FE	Pooled OLS	Pooled OLS	LP	Model
L, number of workers	0.054	0.003	0.055	0.052	-0.009	0.174***
	(0.031)	(0.026)	(0.031)	(0.031)	(0.026)	(0.043)
Number of Substations	0.371***	0.490***	0.370***	0.379***	0.201	0.344***
	(0.048)	(0.117)	(0.048)	(0.046)	(0.188)	(0.050)
Quality of Capital, a			-0.002*	-0.002*	-0.003	-0.085
			(0.001)	(0.001)	(0.025)	(0.052)
PPP contract				-0.046	-0.520	0.128**
				(0.182)	(0.835)	(0.040)
Interaction, a*PPP				0.104***	- 0.050	0.142***
				(0.031)	(0.158)	(0.038)
Cogeneration dummy	0.406**	0.149	0.404**	0.437**	0.476	0.409***
	(0.135)	(0.180)	(0.135)	(0.132)	(0.304)	(0.037)
Heat vehicle dummy	0.492***	0.093	0.491***	0.464***	0.214	0.400***
	(0.115)	(0.084)	(0.116)	(0.119)	(0.136)	(0.038)
Zone 2	0.509*	0.091	0.510*	0.524*	0.193	0.412***
	(0.235)	(0.139)	(0.235)	(0.238)	(0.176)	(0.036)
Zone 3	0.530*	0.266	0.532*	0.542*	0.197	0.457***
	(0.241)	(0.197)	(0.241)	(0.242)	(0.274)	(0.038)
2014 dummy	-0.351***	-0.262*	-0.355***	-0.350***	-0.435***	-0.351***
	(0.101)	(0.106)	(0.102)	(0.101)	(0.126)	(0.059)
Extracted Temperature	0.003	0.010	0.003	0.003	0.023	0.005
	(0.006)	(0.007)	(0.006)	(0.006)	(0.018)	(0.017)
Small (<p25)	-0.943***	-0.227	-0.950***	-0.911***	-0.662	-0.970***
	(0.142)	(0.218)	(0.142)	(0.142)	(0.376)	(0.035)
Big (p75<>p50)	0.649***	0.348*	0.650***	0.660***	0.260	0.664***
	(0.133)	(0.167)	(0.133)	(0.133)	(0.199)	(0.035)
Very Big (>p75)	1.410***	0.433**	1.415***	1.411***	0.231	1.371***
	(0.193)	(0.165)	(0.194)	(0.189)	(0.264)	(0.039)
N	742.000	742.000	742.000	742.000	741.000	742.000

Capital quality and interaction term with the PPP dummy have inverted sign such that increasing values correspond to higher levels of quality.
Zone 2 between 2100-3000 GG. Zone 3 above 3000 GG.
All SD errors are clustered. The model SD are block bootstrapped
* $p < .05$, ** $p < .01$, *** $p < .001$

Table 6: Model Estimates

	Material as proxy	Investment as proxy
L, number of workers	0.080	-0.013
	(0.063)	(0.042)
Number of Substations	0.387*	0.177*
	(0.174)	(0.069)
Quality of Capital, a	0.004***	0.157***
	(0.001)	(0.041)
PPP contract	0.165	0.218
	(0.153)	(0.140)
Interaction, a*PPP	-0.139*	-0.170*
	(0.058)	(0.080)
Cogeneration dummy	0.467**	0.854*
	(0.163)	(0.340)
Heat vehicle dummy	0.189	0.355***
	(0.102)	(0.089)
Zone 2	0.539	0.305
	(0.290)	(0.227)
Zone 3	0.568	0.548
	(0.329)	(0.295)
2014 dummy	-0.407***	-0.363*
	(0.104)	(0.146)
Extracted Temperature	0.018*	0.003
	(0.008)	(0.004)
Small (<p25)	-0.464**	-0.147
	(0.151)	(0.197)
Big (p75<>p50)	0.401*	0.666**
	(0.174)	(0.229)
Very Big (>p75)	0.827**	1.036***
	(0.257)	(0.288)
N	563.000	276.000

Capital quality and interaction term with the PPP dummy have inverted sign such that increasing values correspond to higher levels of quality.

Zone 2 between 2100-3000 GG. Zone 3 above 3000 GG.

* $p < .05$, ** $p < .01$, *** $p < .001$

Table 7: Robustness Checks: Wooldridge estimator

	Simple		Augmented		
	Pooled OLS	FE	Pooled OLS	Pooled OLS	Model
L, number of workers:					
1st degree term	-0.088	-0.091	-0.091	-0.031	-0.059***
	(0.129)	(0.077)	(0.129)	(0.078)	(0.017)
2nd degree term	-0.002	0.034***	-0.002	0.001	0.000
	(0.023)	(0.012)	(0.023)	(0.009)	(0.016)
Number of Substations:					
1st degree term	-0.187	0.185	-0.200	0.017	-0.174***
	(0.136)	(0.284)	(0.137)	(0.107)	(0.012)
2nd degree term	0.046***	0.038	0.046***	0.034***	0.044***
	(0.012)	(0.032)	(0.012)	(0.011)	(0.011)
Interaction term	0.031	-0.028*	0.031	0.016	0.033*
	(0.024)	(0.015)	(0.024)	(0.018)	(0.018)
Quality of Capital, a			0.003***	0.002***	0.008
			(0.001)	(0.001)	(0.023)
PPP contract				-0.013	0.155***
				(0.177)	(0.011)
Interaction, a*PPP				0.114***	0.165***
				(0.027)	(0.013)
Cogeneration dummy	0.439***	-0.063	0.434***	0.454***	0.465***
	(0.156)	(0.099)	(0.156)	(0.129)	(0.015)
Small (<p25)	-1.030***	-0.255	-1.046***	-0.982***	-1.006***
	(0.163)	(0.179)	(0.163)	(0.143)	(0.014)
Big (p75<>p50)	0.756***	0.110	0.760***	0.735***	0.767***
	(0.157)	(0.141)	(0.157)	(0.130)	(0.011)
Very Big (>p75)	1.448***	0.175	1.456***	1.390***	1.436***
	(0.229)	(0.172)	(0.229)	(0.188)	(0.011)
N	742.000	742.000	742.000	742.000	742.000

Tech, 2014 dummy the Extracted Temperature, Zone 2 and Zone3 variables are not reported.
Capital quality and interaction term with the PPP dummy have inverted sign such that increasing values correspond to higher levels of quality.
Zone 2 between 2100-3000 GG. Zone 3 above 3000 GG.
All SD errors are clustered. The model SD are block bootstrapped.
* $p < .1$, ** $p < .05$, *** $p < .01$

Table 8: Robustness Checks: Translog specification

	Discrete Dummies			Continous Heated Volume		
	Pooled OLS	LP	Model	Pooled OLS	LP	Model
L, number of workers	0.042*	0.014	0.068	0.021	-0.001	0.108
	(0.018)	(0.025)	(0.058)	(0.017)	(0.022)	(0.081)
Number of Substations	0.329***	0.187	0.318***	0.271***	0.341*	0.311***
	(0.022)	(0.150)	(0.062)	(0.022)	(0.163)	(0.091)
Quality of Capital, a	0.004*	0.004	0.139	0.007***	0.002	0.153
	(0.002)	(0.029)	(0.074)	(0.002)	(0.025)	(0.087)
PPP contract	-0.165	-0.304	0.122*	-0.153	-0.742	-0.017
	(0.151)	(0.663)	(0.054)	(0.147)	(0.617)	(0.089)
Interaction, a*PPP	-0.069	0.013	-0.243***	-0.034	0.099	-0.263**
	(0.045)	(0.144)	(0.056)	(0.044)	(0.130)	(0.092)
Cogeneration dummy	0.368***	0.260	0.437***	0.394***	0.612*	0.310**
	(0.079)	(0.236)	(0.051)	(0.075)	(0.257)	(0.113)
Heat vehicle dummy	0.310***	0.198	0.264***	0.206**	0.224	0.264**
	(0.083)	(0.126)	(0.057)	(0.078)	(0.120)	(0.093)
Zone 2	0.381**	0.233	0.412***	0.233*	0.179	0.312***
	(0.116)	(0.236)	(0.053)	(0.112)	(0.207)	(0.090)
Zone 3	0.371**	0.152	0.301***	0.259*	0.129	0.287**
	(0.131)	(0.287)	(0.051)	(0.125)	(0.312)	(0.109)
2014 dummy	-0.330***	-0.427***	-0.356***	-0.299***	-0.437***	-0.381***
	(0.072)	(0.117)	(0.074)	(0.071)	(0.106)	(0.088)
Extracted Temperature	0.006	0.023	0.012	0.009*	0.012	0.023
	(0.004)	(0.014)	(0.023)	(0.004)	(0.012)	(0.026)
N	742.000	741.000	742.000	742.000	741.000	742.000

Capital quality and interaction term with the PPP dummy have inverted sign such that increasing values correspond to higher levels of quality.

Zone 2 between 2100-3000 GG. Zone 3 above 3000 GG.

All SD errors are clustered. The model SD are block bootstrapped

* $p < .05$, ** $p < .01$, *** $p < .001$

Table 9: Robustness Checks: Dummies Treatment

References

Ackerberg D. A., Caves K., and Frazer G. Identification properties of recent production function estimators. *Econometrica*, 83(6):2411–2451, November 2015.

Bajari P. and Tadelis S. Incentives versus transaction costs: a theory of procurement contracts. *RAND Journal of Economics*, 32(3):387–407, Autumn 2001.

Balasubramanian N. and Sivadasan J. Capital resalability, productivity dispersion, and market structure. *The Review of Economics and Statistics*, 91(3):547–557, August 2009.

Bartelsman E. J. and Doms M. Understanding productivity: Lessons from longitudinal microdata. *Journal of Economic Literature*, 38(3):569–594, September 2000.

Bennett J. and Iossa E. Building and managing facilities for public services. *Elsevier*, 90 (10-11):2143–2160, November 2006.

Bloom N., Sadun R., and Reenen J. V. Americans do it better: Us multinationals and the productivity miracle. *American Economic Review*, 102(1):167–201, 2012.

BrÃďnnlund R. and KristrÃűm B. Too hot to handle? - benefits and costs of stimulating the use of biofuels in the swedish heating sector. *Working paper 283, , Department of Forest Economics, SLU.*, 1999.

Buso M., Marty F., and Tra F. Public private partnerships from budget constraints: Looking for debt hiding? *R&R at International Journal of Industrial Organization*, 2016.

Chen B. R. and Chiu Y. S. . Public-private partnerships: Task interdependence and contractibility. *International Journal of Industrial Organization*, 2010.

De Loecker J. Product differentiation, multi-product firms and estimating the impact of trade liberalization on productivity. *Econometrica*, 79(5):1407–1451, 2007.

DeSouza S. Levinsohn and petrin's (2003) methodology works under monopolistic competition. *Economics Bulletin*, 12(6):1–11, 2006.

Fox J. T. and Smeets V. Does input quality drive measured differences in firm productivity? *International Economic Review*, 52(4):961–989, November 2011.

Gagnepain P. and Ivaldi M. Incentive regulatory policies: the case of public transit systems in france. *RAND Journal of Economics*, 33(4):605–629, 2002.

Gagnepain P., Ivaldi M., and Martimort D. The cost of contract renegotiation: Evidence from the local public sector. *American Economic Review*, 103(6):2352–2383, 2013.

Gandhi S., A. Navarro and Rivers D. On the identification of production functions: How heterogeneous is productivity. *Journal of Political Economy, revised and resubmitted (2nd round)*, 2014.

Grieco P. L. E. and McDevitt R. C. Productivity and quality in health care: Evidence from the dialysis industry. *Working Paper*, 2014.

Hart O. Incomplete contracts and public ownership: remarks, and application to public-private ownership. *Economic Journal*, 112(386):C69–C76, March 2003.

Hoppe E. l. and Schmitz P. W. Public versus private ownership: Quantity contracts and the allocation of investment tasks. *Journal of Public Economics*, 94(3-4):258–268, 2010.

Hoppe E. l., Kusterer D. J., and Schmitz P. W. Public-private partnerships versus traditional procurement: An experimental investigation. *Journal of Economic Behavior & Organization*, 89:145–166, 2013.

Iossa E. and Martimort D. The simple micro-economics of public-private partnerships. *Journal of Public Economic Theory*, 17(1):4–48, February 2015.

Katayama H., Lu S., and Tybout J. Why plant-level productivity studies are often misleading, and an alternative approach to interference. *NBER WP*, vol. 9617, 2003.

Klette T. and Griliches Z. The inconsistency of common scale estimators when output prices are unobserved and endogenous. *Journal of Applied Econometrics*, 11(6):343–361, 1996.

Levinsohn J. and Petrin A. Estimating production functions using inputs to control for unobservables. *The Review of Economic Studies*, 70(2):317–341, 2003.

Martimort D. and Pouyet J. To build or not to build: Normative and positive theories of public private partnerships. *International Journal of Industrial Organization*, 26(2): 393–411, March 2008.

Mundalk Y. Empirical production function free of management bias. *Journal of Farm Economics*, 43:44–56, 1961.

Olley G. S. and Pakes A. The dynamics of productivity in the telecommunications equipment industry. *Econometrica*, 64(6):1263 ss., 1996.

Ornaghi C. Assessing the effects of measurement errors on the estimation of production functions. *Journal of Applied Econometrics*, 21(6):879–891, 2006.

Pakes A. The estimation of dynamic structural models: Problems and prospects. *Advances in Econometrics: Proceedings of the 6th World Congress of the Econometric Society*, 2: 171–259, 1994.

Schmitz P. W. Allocating control in agency problems with limited liability and sequential hidden actions. *RAND Journal of Economics*, 36:318–336, 2005.

SIOP. Gli impianti a biomasse in partenariato pubblico privato manuale operativo. *Siop Lazio manuali operativi*, 2013.

Syverson C. What determines productivity? *Journal of Economic Literature*, 49(2):326–365, 2011.

Tybout J. Manufacturing firms in developing countries. *Journal of Economic Literature*, 38: 11–44, 2000.

Van Beveren I. Total factor productivity estimation: A practical review. *Journal of Economic Surveys*, 26(1):98–128., 2012.

Whelan K. Computers, obsolescence, and productivity. *Review of Economics and Statistics*, 84(3):445–461, 2002.

Wooldridge J. M. On estimating firm-level production functions using proxy variables to control for unobservables. *Economics Letter*, 104:112–114, 2009.

Appendices

Appendix A

Consider the following total cost minimization problem:

$$
\begin{gathered}
min\ P_c K + P_l L + P_{et} \cdot ET \\
st\ ED = exp(\underline{a} + \delta a + \kappa e) \cdot K^{\alpha_c} \cdot L^{\alpha_l} \cdot ET^{\alpha_{et}}
\end{gathered}
$$

The associated cost function[7] for a DH firm operator obtained trough duality is:

$$B \cdot \exp(-\delta a - \kappa e) \tag{11}$$

where $\theta = \alpha_c + \alpha_l + \alpha_{et}$ and $B = \frac{\theta \cdot ED^{\frac{1}{\theta}}}{(\alpha_c^{\alpha_c}\alpha_l^{\alpha_l}\alpha_{et}^{\alpha_{et}})^{\frac{1}{\theta}}} \cdot \exp\left(\frac{a}{\theta}\right)$, and P_J are input prices with$j = c,\, et,\, l$. The total cost is a function of the effort, e, and the quality design investment, a, which reduce the needs of each input to produce the same level of output. The operator's cost results affected by the technological externality, δ, such that the effect of the quality design investment, a, on cost is δ. A unit increase in operational effort, e, induces a reduction in cost equal to the parameter κ. I am supposing that the cost of the quality design investment a is an exponential function, $exp(a-1)$. The operator could exert the effort e in order to reduce the "input" inefficiency of her own cost C, whose implementing cost is the exponential function $exp(e-1)$.

Proposition. *Under unbundling, the optimal effort, $\underline{e}$, is equal to the following expression:*

$$\underline{e} = \frac{\theta}{\kappa + \theta}\left[\ln B_O + \ln\left(\frac{P_s^{\frac{\alpha_c}{\theta}} \cdot P_l^{\frac{\alpha_l}{\theta}} \cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta}\right) + \ln \kappa\right]$$

where $\theta = \alpha_c + \alpha_l + \alpha_{et}$ *and* $B_O = \frac{\theta \cdot ED^{\frac{1}{\theta}}}{(\alpha_c^{\alpha_c}\alpha_l^{\alpha_l}\alpha_{et}^{\alpha_{et}})^{\frac{1}{\theta}}} \cdot \exp\left(\frac{a}{\theta}\right)$.

Proof. Since under unbundling the optimal quality investment in design is $a^i = 0$, the operator's objective function would be:

$$\underset{e \geq 0}{max} - \left[B_O \cdot \exp\left(-\frac{\kappa e}{\theta}\right) \cdot (P_s^{\frac{\alpha_s}{\theta}} \cdot P_l^{\frac{\alpha_l}{\theta}} \cdot P_{et}^{\frac{\alpha_{et}}{\theta}})\right] - [\exp(e) - 1]$$

where $B_O = \frac{\theta \cdot ED^{\frac{1}{\theta}}}{(\alpha_c^{\alpha_c}\alpha_l^{\alpha_l}\alpha_{et}^{\alpha_{et}})^{\frac{1}{\theta}}} \cdot \exp\left(\frac{a}{\theta}\right)$. Optimizing behavior implies the following first order condition and optimal effort level $\underline{e}^*$:

$$\kappa \cdot B_O \cdot exp\left(-\frac{\kappa e}{\theta}\right) \cdot \frac{P_c^{\frac{\alpha_c}{\theta}} \cdot P_l^{\frac{\alpha_l}{\theta}} \cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta} = exp(e) \Rightarrow$$

$$\ln B_O + \ln\left(\frac{P_c^{\frac{\alpha_c}{\theta}} \cdot P_l^{\frac{\alpha_l}{\theta}} \cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta}\right) + \ln \kappa = e + \frac{\kappa}{\theta} e \Rightarrow$$

[7] Using a Cobb-douglas cost function along with an explicit exponential expression for Tfp obviously departs from generality, but satisfies our goal to show the transmission mechanism in a simple closed form.

$$\underline{e} = \frac{\theta}{\kappa+\theta}\left[\ln B_O + \ln\left(\frac{P_c^{\frac{\alpha_c}{\theta}}\cdot P_l^{\frac{\alpha_l}{\theta}}\cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta}\right) + \ln\kappa\right]$$

where in the second step, I applied logs to both sides.

$\square$

In a PPP arrangement a public authority offers to the builder and operator, joint in a consortium, a unique contract. The technological externality, δ, affects directly the cost of the operator, since the operator in consortium with the builder takes part in the decision relative to the quality investment, a.

Proposition. *Under bundling, the optimal effort, e^{PPP}, and the optimal quality design, a^{PPP}, are equal to*

$$e^{PPP} = \frac{\theta}{\kappa+\delta+\theta}\left[\ln B_C + \ln\left(\frac{P_c^{\frac{\alpha_c}{\theta}}\cdot P_l^{\frac{\alpha_l}{\theta}}\cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta}\right) - \frac{\delta}{\theta}\ln\delta + \frac{(\delta+\theta)}{\theta}\ln\kappa\right]$$

$$a^{PPP}, = \frac{\theta}{\kappa+\delta+\theta}\left[\ln B_C + \ln\left(\frac{P_c^{\frac{\alpha_c}{\theta}}\cdot P_l^{\frac{\alpha_l}{\theta}}\cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta}\right) + \frac{\theta+\kappa}{\theta}\ln\delta - \frac{\kappa}{\theta}\ln\kappa\right]$$

where $\theta = \alpha_c + \alpha_l + \alpha_{et}$ and $B_C = \frac{\theta\cdot ED^{\frac{1}{\theta}}}{(\alpha_c^{\alpha_c}\alpha_l^{\alpha_l}\alpha_{et}^{\alpha_{et}})^{\frac{1}{\theta}}}\cdot\exp\left(\frac{a}{\theta}\right)$.

Proof. The builder and the operator in consortium solve the following optimization problem:

$$\max_{a,e} \; -\left[B_C\cdot exp\left(\frac{-\delta a-\kappa e}{\theta}\right)\cdot(P_c^{\frac{\alpha_c}{\theta}}\cdot P_l^{\frac{\alpha_l}{\theta}}\cdot P_{et}^{\frac{\alpha_{et}}{\theta}})\right] - [exp(a)-1] - [exp(e)-1]$$

$$s.t.\, e \geq 0$$

where $B_C = \frac{\theta ED^{\frac{1}{\theta}}}{(\alpha_c^{\alpha_c}\alpha_l^{\alpha_l}\alpha_{et}^{\alpha_{et}})^{\frac{1}{\theta}}}\cdot\exp\left(\frac{a}{\theta}\right)$. Optimizing behavior implies the following first order conditions:

$$FOC\, wrt\, a: \quad exp(a) = B_C\cdot(P_c^{\frac{\alpha_c}{\theta}}\cdot P_l^{\frac{\alpha_l}{\theta}}\cdot P_{et}^{\frac{\alpha_{et}}{\theta}})\cdot\left(\frac{\delta}{\theta}\right)\cdot exp\left(\frac{-\delta a-\kappa e}{\theta}\right)\Rightarrow$$

$$\Rightarrow \frac{a(\delta+\theta)}{\theta} = -\frac{\kappa e}{\theta} + \ln B_C + \ln\left(\frac{P_c^{\frac{\alpha_c}{\theta}}\cdot P_l^{\frac{\alpha_l}{\theta}}\cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta}\right) + \ln\delta \Rightarrow$$

$$\Rightarrow a = \frac{\theta}{\delta+\theta}\left[\ln B_C + \ln\delta + \ln\left(\frac{P_c^{\frac{\alpha_c}{\theta}}\cdot P_l^{\frac{\alpha_l}{\theta}}\cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta}\right) - \frac{\kappa e}{\theta}\right]$$

$$FOC\, wrt\, e: \quad exp(e) = B_C\cdot(P_c^{\frac{\alpha_c}{\theta}}\cdot P_l^{\frac{\alpha_l}{\theta}}\cdot P_{et}^{\frac{\alpha_{et}}{\theta}})\cdot\left(\frac{\kappa}{\theta}\right)\cdot exp\left(\frac{-\delta a-\kappa e}{\theta}\right)\Rightarrow$$

$$\Rightarrow \frac{e(\kappa+\theta)}{\theta} = -\frac{\delta a}{\theta} + \ln B_C + \ln\left(\frac{P_c^{\frac{\alpha_c}{\theta}}\cdot P_l^{\frac{\alpha_l}{\theta}}\cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta}\right) + \ln\kappa \Rightarrow$$

$$\Rightarrow e = \frac{\theta}{\kappa+\theta}\left[\ln B_C + \ln\left(\frac{P_c^{\frac{\alpha_c}{\theta}}\cdot P_l^{\frac{\alpha_l}{\theta}}\cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta}\right) - \frac{\delta a}{\theta} + \ln\kappa\right]$$

where in the second line of each FOC, I applied logs to both sides.

Substituting a into e

$$e = \frac{\theta}{\kappa+\theta}\left\{\ln\kappa + \frac{\theta}{\delta+\theta}\left[\ln B_C + \ln\left(\frac{P_c^{\frac{\alpha_c}{\theta}}\cdot P_l^{\frac{\alpha_l}{\theta}}\cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta}\right)\right] - \frac{\delta\ln\delta}{\delta+\theta} + \frac{\kappa e}{\theta}\frac{\delta}{\delta+\theta}\right\}\Rightarrow$$

$$e - \frac{\delta\kappa}{\delta+\theta}\frac{e}{\kappa+\theta} = \frac{\theta}{\kappa+\theta}\left\{\frac{\theta}{\delta+\theta}\left[\ln B_C + \ln\left(\frac{P_c^{\frac{\alpha_c}{\theta}}\cdot P_l^{\frac{\alpha_l}{\theta}}\cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta}\right)\right] - \frac{\delta\ln\delta}{\delta+\theta} + \ln\kappa\right\}\Rightarrow$$

$$\frac{(\delta+\theta)(\kappa+\theta)e - \delta\kappa e}{\theta} = \theta\left[\ln B_C + \ln\left(\frac{P_c^{\frac{\alpha_c}{\theta}}\cdot P_l^{\frac{\alpha_l}{\theta}}\cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta}\right)\right] - \delta\ln\delta + (\delta+\theta)\ln\kappa\Rightarrow$$

$$\frac{[(\kappa+\delta)\theta+\theta^2]}{\theta}e = \theta\left[\ln B_C + \ln\left(\frac{P_c^{\frac{\alpha_c}{\theta}}\cdot P_l^{\frac{\alpha_l}{\theta}}\cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta}\right)\right] - \delta\ln\delta + (\delta+\theta)\ln\kappa\Rightarrow$$

$$(\kappa+\delta+\theta)e = \theta\left[\ln B_C + \ln\left(\frac{P_c^{\frac{\alpha_c}{\theta}}\cdot P_l^{\frac{\alpha_l}{\theta}}\cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta}\right)\right] - \delta\ln\delta + (\delta+\theta)\ln\kappa\Rightarrow$$

$$e^{PPP} = \frac{\theta}{\kappa+\delta+\theta}\left[\ln B_C + \ln\left(\frac{P_c^{\frac{\alpha_c}{\theta}}\cdot P_l^{\frac{\alpha_l}{\theta}}\cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta}\right) - \frac{\delta}{\theta}\ln\delta + \frac{(\delta+\theta)}{\theta}\ln\kappa\right]$$

Substituting e^{PPP} into a

$$a^{PPP} = \frac{\theta}{\delta+\theta}\left\{\frac{\delta+\theta}{\kappa+\delta+\theta}\left[\ln B_C + \ln\left(\frac{P_c^{\frac{\alpha_c}{\theta}}\cdot P_l^{\frac{\alpha_l}{\theta}}\cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta}\right)\right] + \frac{(\delta+\theta)(\theta+\kappa)}{(\kappa+\delta+\theta)\theta}\ln\delta - \frac{\kappa(\delta+\theta)}{(\kappa+\delta+\theta)\theta}\ln\kappa\right\}\Rightarrow$$

$$a^{PPP} = \frac{\theta}{\kappa+\delta+\theta}\left[\ln B_C + \ln\left(\frac{P_c^{\frac{\alpha_c}{\theta}} \cdot P_l^{\frac{\alpha_l}{\theta}} \cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta}\right)\right] + \frac{\theta+\kappa}{\kappa+\delta+\theta}\ln\delta - \frac{\kappa}{\kappa+\delta+\theta}\ln\kappa \Rightarrow$$

$$a^{PPP} = \frac{\theta}{\kappa+\delta+\theta}\left[\ln B_C + \ln\left(\frac{P_c^{\frac{\alpha_c}{\theta}} \cdot P_l^{\frac{\alpha_l}{\theta}} \cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta}\right) + \frac{\theta+\kappa}{\theta}\ln\delta - \frac{\kappa}{\theta}\ln\kappa\right]$$

□

Proposition. *Under bundling, TFP is an increasing function of the externality effect δ*

Proof. Plugging the optimal effort, e^{PPP} and the optimal quality design, a^{PPP}, into the productity term:

$$exp\left\{\frac{\theta(\kappa+\delta)}{\kappa+\delta+\theta}\left[\ln B_C + \ln\left(\frac{P_c^{\frac{\alpha_c}{\theta}} \cdot P_l^{\frac{\alpha_l}{\theta}} \cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta}\right) + \frac{\delta}{(\kappa+\delta)}\ln\delta + \frac{\kappa}{(\kappa+\delta)}\ln\kappa\right]\right\}$$

where $\phi = \frac{(\kappa+\delta)(\theta)}{\kappa+\delta+\theta}$ and $\zeta = \frac{\delta}{(1+\delta)}$, which $\phi \rightarrow \theta$ and $\zeta \rightarrow 1$ when $\delta \rightarrow \infty$, and $exp\{\phi \cdot lg[B_C \cdot \frac{P_c^{\frac{\alpha_c}{\theta}} \cdot P_l^{\frac{\alpha_l}{\theta}} \cdot P_{et}^{\frac{\alpha_{et}}{\theta}}}{\theta} \cdot \zeta\delta]\} \rightarrow \infty$ at the speed $lg\delta$. □

Appendix B

In this Appendix it is showed how intermediate materials ET_{it} can be exploited as a proxy for productivity. The proof is meant to state sufficient conditions for intermediate materials demand to be a strictly increasing function of productivity ω_{it}.

Input markets are supposed competitive. Conversely, output market is a natural monopoly. DH firms exert their market power up to a cap prize $\bar{P}$, such that switching to the outside technology, autonomous boilers, results convenient for customers. DH firm's ability to exploit its monopoly power depends on the height of switching costs which create lock-in effects for customers. A recent study of The Italian Competition Authority (ICA) suggests rare occurrence of lock-in effect in Italian DH sector.

Capital is considered quasi-fixed, so optimal investment stems from a policy function which is the solution a dynamic optimization problem. Practically, It means that capital is not a variable to optimize at time t in the firm's static problem.

Proposition. Assume that a DH firm has a production technology $F(K,\, L,\, ET,\, \Omega) : \, R^4_+ \rightarrow R_+$ twice continuously differentiable in labor, L, and intermediate materials input, ET; the partial derivatives $\frac{\partial F}{\partial L \partial \omega^B_{it}}$, $\frac{\partial F}{\partial ET \partial \omega^B_{it}}$ and $\frac{\partial F}{\partial ET \partial L}$ exist for all values of $(K,\, L,\, ET,\, \Omega,\,) \in R^4_+$; the input markets are competitive, but the output are not; either investment at time t does not respond to productivity at time t, or capital at time t is not function of investment at time, t; the productivity shock, ω, is observed before the choice of labor and intermediate material is made. Under these assumptions, if

$$\frac{\partial F}{\partial ET \partial L}\frac{\partial F}{\partial ET \partial \omega^B_{it}} - \frac{\partial F}{\partial ET \partial \omega^B_{it}}\frac{\partial F}{\partial L^2} + \frac{1}{\eta F}\left(\frac{dF}{dET}\frac{\partial F}{\partial \omega^B_{it}}\frac{\partial F}{\partial L^2} - \frac{\partial F}{\partial ET \partial \omega^B_{it}}\frac{d^2 F}{dL} - \frac{\partial F}{\partial L \partial ET}\frac{\partial F}{\partial L}\frac{\partial F}{\partial \omega^B_{it}} - \frac{\partial F}{\partial L}\frac{dF}{dET}\frac{\partial F}{\partial L \partial \omega^B_{it}}\right) > 0$$

everywhere, then $ET(\omega;\, p^{et}\, p^l\, p^c\, k)$, the intermediate input demand function, is strictly increasing in ω.

Proof. A profit maximizing DH firm solves the following optimization problem with respect to its free variable input L and ET:

$$\max_{et_{it},\, l_{it},} \, P(ed) \cdot ed - P^{et} \cdot et - P^c \cdot k - P^l \cdot l$$

$$s.t. \; ed_{it} = F(k,\, et,\, l,\, \omega^B)$$

Where $P(ed)$ is the inverse demand function and P^J the respective prices of the inputs. First order conditions of these problem are:

$$P(F)\frac{dF}{dj} + F\frac{dP}{dF}\frac{dF}{dj} = P^J \; with \; j = et,\, l$$

Multiplying and dividing by P the second member of the lhs and substituting $1/\eta = -\frac{F}{\partial F}\frac{\partial P}{P}$.

$$P(F)\frac{dF}{dj} - \frac{dF}{dj}\frac{P}{\eta} = P^J \Rightarrow P(F)\frac{dF}{dj}(1 - \frac{1}{\eta}) = P^J \Rightarrow$$

$$\Rightarrow P(F)\frac{dF}{dj} = \frac{P^J}{(1 - \frac{1}{\eta})} \; with \; j = et,\, l$$

Both $P(F(k_{it},\, et_{it},\, l_{it},\, \omega^B_{it}|\mathbf{x_{it}}))$ and $\frac{dF(k_{it},\, et_{it},\, l_{it},\, \omega^B_{it}|\mathbf{x_{it}})}{dj}$ are function of productivity ω^B_{it}. Taking derivatives of both sides with respect to ω^B_{it}, you obtain:

$$\frac{dP(F)}{dF}\frac{dF}{d\omega^B_{it}}\frac{dF}{dj} + P(F)\frac{dF}{dj d\omega^B_{it}} = 0 \; with \; j = et,\, l$$

Divide equation by P and total differentiate $dF(k_{it},\, et_{it},\, l_{it},\, \omega^B_{it}|\mathbf{x_{it}})$ and $\frac{dF(k_{it},\, et_{it},\, l_{it},\, \omega^B_{it}|\mathbf{x_{it}})}{dj}$:

$$\frac{dP(F)}{dF}\frac{1}{P}\frac{dF}{dj}\left(\frac{\partial F}{\partial ET}\frac{dET}{d\omega_{it}^{B}}+\frac{\partial F}{\partial L}\frac{dL}{d\omega_{it}^{B}}+\frac{\partial F}{\partial\omega_{it}^{B}}\right)+\left(\frac{\partial F}{\partial j\partial ET}\frac{dET}{d\omega_{it}^{B}}+\frac{\partial F}{\partial j\partial L}\frac{dL}{d\omega_{it}^{B}}+\frac{\partial F}{\partial j\partial\omega_{it}^{B}}\right)=0\ with\ j=et,\,l$$

Which can be equivalently rewritten as:

$$\left(\frac{\partial F}{\partial j\partial ET}\frac{dET}{d\omega_{it}^{B}}+\frac{\partial F}{\partial j\partial L}\frac{dL}{d\omega_{it}^{B}}+\frac{\partial F}{\partial j\partial\omega_{it}^{B}}\right)-\frac{1}{\eta F}\frac{dF}{dj}\left(\frac{\partial F}{\partial ET}\frac{dET}{d\omega_{it}^{B}}+\frac{\partial F}{\partial L}\frac{dL}{d\omega_{it}^{B}}+\frac{\partial F}{\partial\omega_{it}^{B}}\right)=0\ with\ j=et,\,l$$

Which can be restated in matrix form as:

$$\begin{pmatrix}\frac{\partial F}{\partial ET^2}-\frac{1}{\eta F}(\frac{dF}{dET})^2 & \frac{\partial F}{\partial ET\partial L}-\frac{1}{\eta F}\frac{\partial F}{\partial L}\frac{dF}{dET}\\ \frac{\partial F}{\partial L\partial ET}-\frac{1}{\eta F}\frac{dF}{dL}\frac{\partial F}{\partial ET} & \frac{\partial F}{\partial L^2}-\frac{1}{\eta F}(\frac{dF}{dL})^2\end{pmatrix}\begin{pmatrix}\frac{dET}{d\omega_{it}^{B}}\\ \frac{dL}{d\omega_{it}^{B}}\end{pmatrix}=\begin{pmatrix}\frac{1}{\eta F}\frac{dF}{dET}\frac{\partial F}{\partial\omega_{it}^{B}}-\frac{\partial F}{\partial ET\partial\omega_{it}^{B}}\\ \frac{1}{\eta F}\frac{dF}{dL}\frac{\partial F}{\partial\omega_{it}^{B}}-\frac{\partial F}{\partial L\partial\omega_{it}^{B}}\end{pmatrix}$$

Applying the Cramer's rule

$$\frac{dET}{d\omega_{it}^{B}}=\frac{\begin{Vmatrix}\frac{1}{\eta F}\frac{dF}{dET}\frac{\partial F}{\partial\omega_{it}^{B}}-\frac{\partial F}{\partial ET\partial\omega_{it}^{B}} & \frac{\partial F}{\partial ET\partial L}-\frac{1}{\eta F}\frac{\partial F}{\partial L}\frac{dF}{dET}\\ \frac{1}{\eta F}\frac{dF}{dL}\frac{\partial F}{\partial\omega_{it}^{B}}-\frac{\partial F}{\partial L\partial\omega_{it}^{B}} & \frac{\partial F}{\partial L^2}-\frac{1}{\eta F}(\frac{dF}{dL})^2\end{Vmatrix}}{\begin{Vmatrix}\frac{\partial F}{\partial ET^2}-\frac{1}{\eta F}(\frac{dF}{dET})^2 & \frac{\partial F}{\partial ET\partial L}-\frac{1}{\eta F}\frac{\partial F}{\partial L}\frac{dF}{dET}\\ \frac{\partial F}{\partial L\partial ET}-\frac{1}{\eta F}\frac{dF}{dL}\frac{\partial F}{\partial ET} & \frac{\partial F}{\partial L^2}-\frac{1}{\eta F}\frac{(\frac{dF}{dL})^2}{dL^2}\end{Vmatrix}}$$

Note that the denominator is the Hessian matrix. Stated assumptions imply that this matrix is negative semidefinite, i.e. the determinant of the Hessian is positive. Consequently, a profit maximizing DH firm has intermediate input demand such that the following is verified:

$$sign\left(\frac{\partial ET}{\partial\omega_{it}^{B}}\right)=sign\begin{Vmatrix}\frac{1}{\eta F}\frac{dF}{dET}\frac{\partial F}{\partial\omega_{it}^{B}}-\frac{\partial F}{\partial ET\partial\omega_{it}^{B}} & \frac{\partial F}{\partial ET\partial L}-\frac{1}{\eta F}\frac{\partial F}{\partial L}\frac{dF}{dET}\\ \frac{1}{\eta F}\frac{dF}{dL}\frac{\partial F}{\partial\omega_{it}^{B}}-\frac{\partial F}{\partial L\partial\omega_{it}^{B}} & \frac{\partial F}{\partial L^2}-\frac{1}{\eta F}(\frac{dF}{dL})^2\end{Vmatrix}$$

Under mild regularity conditions on $F(\cdot)$ such that the Fundamental Theorem of Calculus holds for $ET(\cdot)$, the following is true:

$$ET(\omega_2;\,p^{et}\,p^{l}\,p^{c}\,k\,\mathbf{x})-ET(\omega_1;\,p^{et}\,p^{l}\,p^{c}\,k\,\mathbf{x})=\int_{\omega_1}^{\omega_2}\frac{\partial ET(\omega;\,p^{et}\,p^{l}\,p^{c}\,k\,\mathbf{x})}{\partial\omega}P(d\omega)$$

Where $\omega_2>\omega_1$. If the following condition holds everywhere:

$$\frac{\partial F}{\partial ET\partial L}\frac{\partial F}{\partial ET\partial\omega_{it}^{B}}-\frac{\partial F}{\partial ET\partial\omega_{it}^{B}}\frac{\partial F}{\partial L^2}+\frac{1}{\eta F}\left(\frac{dF}{dET}\frac{\partial F}{\partial\omega_{it}^{B}}\frac{\partial F}{\partial L^2}-\frac{\partial F}{\partial ET\partial\omega_{it}^{B}}\frac{d^2F}{dL}-\frac{\partial F}{\partial L\partial ET}\frac{\partial F}{\partial L}\frac{\partial F}{\partial\omega_{it}^{B}}-\frac{\partial F}{\partial L}\frac{dF}{dET}\frac{\partial F}{\partial L\partial\omega_{it}^{B}}\right)>0$$

It follows that

$$\int_{\omega_1}^{\omega_2}\frac{\partial et(\omega;\,p^{et}\,p^{l}\,p^{c}\,k\,\mathbf{x})}{\partial\omega}P(d\omega)>\int_{\omega_1}^{\omega_2}0P(d\omega)=0$$

Finally, you obtain

$$ET(\omega_2;\, p^{et}\, p^{l}\, p^{c}\, k\, \mathbf{x}) > ET(\omega_1;\, p^{et}\, p^{l}\, p^{c}\, k\, \mathbf{x})$$

$\square$