Revisiting the returns of public infrastructure in Mexico: a limited information maximum likelihood estimation.

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This paper revisits the issue of accurately decomposing productivity growth to the impact of public infrastructure at firm level for Mexican industry whether the underlying functional form is a profit or a cost function. Our framework decomposes productivity growth into different components, and in particular the contribution of public infrastructure. We also propose a novel limited information maximum likelihood (LIML) estimation method that adequately deals with the issue of the endogeneity and model misspecification. The reported evidence shows that public infrastructure enhances productivity growth through profit gains and cost savings in all ten two-digit Mexican industries, though some variability across time exists, notably in the nineties and the 2000s when a shortage of infrastructure is observed.

JEL Codes : D21, D24, H54, E62.

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1. Introduction

Measuring productivity growth in an accurate way is by no means an easy task, let alone decomposing productivity growth into its underlying components (Barro, 1989; Shah, 1992; Morrison and Schwartz, 1994 and 1996; Becerril et al. 2009 and 2010; Hao and Huang, 2014; Diewert, et al. 2017; Moller et al., 2017). Yet after hefty recessions as the one towards the end of the last decade, productivity growth plays prominent role among academics and economic policy makers alike. It is not surprising, therefore, that in recent years there has been a resurgent of studies on productivity growth measurement such as Joumard et al. (2004), Genius et al. (2012), Lansink et al. (2015) and recently Diewert, et al. (2017).

Alas, as often encountered in the economic performance measurement, productivity growth measurement does not come as a straight forward exercise though it is rather simple to provide a definition. For example, Jorgenson (1995) defines productivity growth as "*the part of output growth that cannot be explained by an increase in the use of inputs*". The intricacies emerge during the stage of decomposing productivity growth to its contributing factors. Moreover, productivity growth has been attributed to a plethora of contributing factors like improvements in technology, scale effects, an increase in the efficiency of resource used (see Capalbo and Antle, 1988, and Majumdar 2010, Genius et al., 2012; Diewert, et al. 2017). Given the complexities involved in accurately decomposing productivity growth much controversy in operational research has emerged (Genius et al. 2012, Lansink et al. 2015). In a recent paper, Diewert, et al. (2017) highlight the complexities of correctly identifying the productivity growth components.[1]

[1] The authors propose to relax the underlying convexity assumptions of the technology and decompose a productivity index based on distance functions.

Herein, we propose a novel way to accurately decomposing productivity growth, opting for a flexible functional specification that nests both profit and cost function. By doing so, we also focus on the impact of infrastructure capital on productivity growth, a variable that has been rather neglected in recent years.[2] The theoretical framework of this paper is based on micro-foundations and complements previous studies opting for a parametric measure of productivity growth decomposition (see Genius et al. 2012; Lansink et al. 2015; Páez-Pérez and Sánchez-Silva, 2016). The starting point of our analysis focuses on solving the standard profit maximization problem that a firm is facing. We develop a framework that permits the identification of the impact of public infrastructure on both the profit and the cost function. The choice of the profit function is based on the earlier research of Genius et al. (2012), arguing that the profit function approach performs better than either the production function or the cost function approach. The profit function provides additional flexibility as the supply function is endogenous. In turn, profit optimization provides the base of a theoretical framework that allows the identification both of profit gains and of cost savings due to public infrastructure. In addition, we identify the effects of technological change on productivity growth. In the estimation phase, we introduce a novel local likelihood estimation method. The proposed local likelihood estimation corrects for issues related to endogeneity, whilst we account for heteroskedasticity in the covariance matrix of the error term.[3] We also extend out estimation method also by accounting a non-parametric estimation.

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[2] If we would like to trace the starting point we shall note Ashauer (1989) who argued that public infrastructure explained some of the productivity growth slowdown in US economy in the late seventies and it has elicited many papers thereafter. Despite the evidence provided by Aschauer (1989), some research reported estimates of an insignificant return to public infrastructure in US (Holtz-Eakin, 1994). Moreover, the high output elasticities of infrastructure reported by Aschauer (1989) raised criticism on issues such as the lack of flexibility of their underlying production function specification, the aggregation bias in the macroeconomic data sets used, and the possible endogeneity of output (see Vijverberg et al. 1997). Using duality theory, Morrison and Schwartz (1996) addressed some of these issues to find that public infrastructure was enhancing productivity in US.

[3] With reference to infrastructure investment, Hurlin and Minea (2013), using an aggregate production function and time series, show that traditional measures of returns could be biased due to endogeneity issues and the underlying data generating process. In addition, aggregation bias related to resorting to an aggregate production function is well documented (Zhang, 2014).

This paper comes in timely manner as global economy is continuing to face an uphill to restore growth many years after the financial meltdown in late 2000s. We argue that infrastructure investment would enhance productivity growth. However, infrastructure investment has been on a dramatic declining trend for over two decades across the world that is in advanced, emerging market, and developing economies (see Becerril et al. 2009 and 2010; IMF, 2014; Hao and Huang, 2014; Páez-Pérez and Sánchez-Silva, 2016; Moller et al., 2017). Moreover, in advanced economies infrastructure dropped, on average, to 3% of GDP in 2014 down from 5% in the eighties, whilst in advanced and emerging economies similar negative patterns are also observed.[4] In order to investigate the role of infrastructure we focus, in an empirical application, on two-digit Mexican industries. The return to infrastructure has been rarely investigated in Mexico, whereas public investment in infrastructure fell from 12% in the early eighties to bellow 5% in the nineties and in 2000s (Becerril et al. 2009 and 2010).[5] In a parallel process the growth also dramatically declined and major macroeconomic imbalances emerged. Besides the idiosyncratic characteristics of the Mexican economy and the uncertainties linked to the external economic environment, IMF (2014) emphasizes the importance of infrastructure.

This paper contributes to the literature in several ways. First, to the best of our knowledge, this is the first study to examine the profit gains and cost savings of public infrastructure, inferring a direct way

[4] Previous research shows that investing in infrastructure could be the key to economic recovery as most studies in the literature report evidence of positive returns to infrastructure (Gramlich, 1994; Vijverberg et al., 1997; Joumard et al. 2004; Becerril et al. 2009 and 2010; Hao and Huang, 2014; Zhang, 2014; Páez-Pérez and Sánchez-Silva, 2016; Moller et al., 2017), though there is much criticism on the exact magnitude of these returns (Hurlin and Minea, 2013, Zhang, 2014; Páez-Pérez and Sánchez-Silva, 2016). There is also some controversy regarding the funding of infrastructure investment with the importance of public private partnerships (PPPs) being prominent in recent years (see Páez-Pérez and Sánchez-Silva, 2016). Given this background, it is not surprising that there is strong interest on accurately measuring the return to infrastructure (Hurlin and Minea, 2013, Páez-Pérez and Sánchez-Silva, 2016).

[5]There are few studies that have attempted to measure the return to infrastructure in the case of Mexican industry, though Shah (1992), Feltestain and Ha (1995) and Feltestein and Shah (1995), and Becerril et al. 2009 and 2010 report that indeed public infrastructure investment is a productive input.

of decomposing productivity growth into the impact of public infrastructure. Second, we propose a local likelihood estimation method of a flexible functional form whether a translog profit or cost function, whilst we adequately deal with issues of endogeneity and account for non-parametric heteroskedasticity in the covariance matrix of the error term. In some detail, we employ a limited information maximum likelihood (LIML) estimation. Third, the proposed decomposition of productivity growth also takes into account technological change, strengthening the validity of our empirical results. Fourth, we use a large firm-specific dataset that represents most Mexican industrial output. A quick glimpse at the results shows that public infrastructure asserts a positive impact on the Mexican industry as measured by both profit gains and cost savings, albeit since late in the eighties this impact records a significant decline.

The remainder of the paper is organised as follows; section 2 presents the theoretical framework of the total factor productivity growth decomposition, while section 3 discusses the data set. Section 4 provides the empirical specification, the estimation procedure, and the empirical findings, whereas the last section highlights some concluding remarks and economic policy implications derived from the empirical findings.

2. Decomposing productivity growth

In what follows we present a three-step approach: as a first step, we derive two measures of the return to public infrastructure, namely profit gains and cost savings. In the second step, we apply a decomposition of the productivity growth into the impact of public infrastructure and technological change. Finally, in the estimation phase we apply a novel flexible local likelihood estimation technique.

Consider the following production function, where *X, G, t* denotes production inputs, public infrastructure, and technological change respectively.

$$Y = f(X, G, t) \qquad (1)$$

The firm's objective is to maximise profits given the production function (1) is:

$$\pi\ (P, w, G, t) = \max_{X}\ [P\ f(X, G, t)-w\ X], \qquad (2)$$

where P is the output price, *w* is as nx1 vector of the price of private inputs. This profit function is strictly convex in *P* and *w*.

By applying the envelope theorem and partial differentiating with respect to infrastructure and time respectively (*t* is time accounting for technology change), we get:

$$\pi_G(P, w, G, t) = P\ f_G(X, G, t) \qquad (3)$$

$$\pi_t(P, w, G, t) = P\ f_t\ (X, G, t), \qquad (4)$$

where the subscripts *G, t* denote first partial derivatives with respect to infrastructure and technology respectively.

Equation (3) is the profit marginal shadow value of public infrastructure. This shadow value equals the marginal product value of public infrastructure. Equation (4) is the profit marginal shadow value of technology as depicted by a time trend and equals to its marginal product value.

Equivalently, the maximisation of profits (see equation 1) can be expressed in terms of maximising the difference between total revenues (see *PxY,* equation below) and the cost of producing (see *C,* equation below):

$$\pi\ (P, w, G, t) = \max_{w}\ [PxY - C(w, Y, G, t)] \quad (5)$$

This profit function is convex and linear homogenous in *P* and *w*.

We could then apply envelope theorem to obtain:

$$\pi_G\ (P, w, G, t) = -C_G\ (w, Y, G, t) \qquad (6)$$

$$\pi_t\ (P, w, G, t) = -\ C_t\ (w, Y, G, t) \qquad (7)$$

Equation (6) shows that the marginal shadow value of public infrastructure derived from the profit function is equal to the negative marginal shadow value of public infrastructure derived from the cost function, *C*. Equation (7) describes the effect of the technological change, that is the marginal shadow value of technological change derived from the cost function.

2.1. Profit gains and cost savings due to the impact of public infrastructure

Next, we use the above theoretical specification to quantify the effects of public infrastructure on productivity growth. In the case, that infrastructure capital is indeed a productive input it would induce profit gains.

To measure these profit gains, we start our analysis by total differentiating the profit function of equation (2):

$$\dot{\pi}(P,w,G,t) = \frac{\pi_P(P,w,G,t)P}{\pi(P,w,G,t)}\dot{P} + \Sigma\frac{\pi_{w_i}(P,w,G,t)w_i}{\pi(P,w,G,t)}\dot{w}_i + \frac{\pi_G(P,w,G,t)G}{\pi(P,w,G,t)}\dot{G} + \frac{\pi_t(P,w,G,t)}{\pi(P,w,G,t)} \quad (8)$$

, where dots above the variables denote percentage growth rates.

Now, taking the difference between the total derivative of the profit function of equation (8) and the weighted average of the growth rates of output price and input prices we get:

$$\eta_\pi = \dot{\pi}(P,w,G,t) - \xi(\dot{P},\dot{w}) \quad (9)$$

, where η_π denotes profit gains, ξ is the weighted average of the growth rates of output price and input prices with weights being the elasticities of the profit function with respect to P and w (see Ray and Segerson, 1990).

We can further analyze the second term of the right-hand side of equation (9) as:

$$\eta_\pi = \dot{\pi}(P,w,G,t) - \left[\frac{\pi_P(P,w,G,t)P}{\pi(P,w,G,t)}\dot{P} + \Sigma\frac{\pi_{w_i}(P,w,G,t)w_i}{\pi(P,w,G,t)}\dot{w}_i\right] \quad (10)$$

Combining equation (10) with (8) we finally get:

$$\eta_\pi = \frac{\pi_G(P,w,G,t)G}{\pi(P,w,G,t)}\dot{G} + \frac{\pi_t(P,w,G,t)}{\pi(P,w,G,t)} \quad (11)$$

In effect, the η_π is the sum of the impact of public infrastructure and technological change on profit over time. We shall call the first component of the right-hand side of the equation (11) profit gains due to public infrastructure, indicated as $\eta_{\pi G}$ thereafter. The second component of the right-hand side of the equation (11) is the profit gains due to technology, indicated as $\eta_{\pi t}$ thereafter.

Equivalently to profit gains, we could derive the cost savings due to public infrastructure and technology. By total differentiating the cost function *C(w, Y, G, t)* in equation (5) gives:

$$\dot{C}(w,Y,G,t) = \Sigma \frac{C_{wi}(w,Y,G,t)w_i}{C(w,Y,G,t)}\dot{w}_i + \frac{C_Y(w,Y,G,t)Y}{C(w,Y,G,t)}\dot{Y} + \frac{C_G(w,Y,G,t)G}{C(w,Y,G,t)}\dot{G} + \frac{C_t(w,Y,G,t)}{C(w,Y,G,t)} \quad (12)$$

The effect of public infrastructure, technology and scale effects is derived from the difference between the total derivative of the cost function of equation (12) and the weighted average of the growth rates of input prices:

$$\eta_C = \dot{C}(w,Y,G,t) - \theta(\dot{w}) \quad (13)$$

, where η_C denotes costs savings, θ is a function of the growth rate of *w*. θ is the weighted growth rates of input prices with weights being the elasticities of the cost function with respect to *w*.

Furthermore, substituting θ we derive:

$$\eta_C = \dot{C}(w,Y,G,t) - \left[\Sigma \frac{C_{Wi}(w,Y,G,t)w_i}{C(w,Y,G,t)}\dot{w}_i\right] \quad (14)$$

And combining equation (14) with (12) we get:

$$\eta_C = \sigma \dot{Y} + \frac{C_G(w,Y,G,t)G}{C(w,Y,G,t)}\dot{G} + \frac{C_t(w,Y,G,t)}{C(w,Y,G,t)} \qquad (15)$$

, where σ the cost elasticity with respect to output.

Equation (15), η_C, decomposes cost savings into the scale effect, the effect of public infrastructure, and the technical change effect.

However, a criticism that may arises from this decomposition of cost savings refers to the endogeneity of output growth (Hurlin and Minea, 2013) as the latter is subject to price changes. This is due to the underlying profit maximization theoretical specification. Therefore, as output is endogenous we should remove any effect stemming from changes in prices. To this end, we consider an adjusted output that is net of changes in prices.

As a first step of deriving the adjusted output, we proceed with total differentiating the production function, $Y = f(P, w, G, t)$[6]:

$$\dot{Y}(P,w,G,t) = \frac{Y_P(P,w,G,t)P}{Y(P,w,G,t)}\dot{P} + \Sigma \frac{Y_{wi}(P,w,G,t)w_i}{Y(P,w,G,t)}\dot{w}_i + \frac{Y_G(P,w,G,t)G}{Y(P,w,G,t)}\dot{G} + \frac{Y_t(P,w,G,t)}{Y(P,w,G,t)} \qquad (16)$$

[6] Note that the production function is given as $Y = f(X, G, t)$, while $X = X(P, w, G, t)$ as in the maximisation of Π. Thus, the production function becomes $Y = f(P, w, G, t)$.

The adjusted growth rate of output is the difference between equation (16) and the weighted average of the growth rates of output price and input prices, with weights being the elasticities of the production function with respect to *P* and *w* respectively. Thus, the adjusted output growth is:

$$\dot{Y}_{\alpha} = \dot{Y}(P,w,G,t) - \left[\frac{Y_P(P,w,G,t)P}{Y(P,w,G,t)}\dot{P} + \Sigma \frac{Y_{wi}(P,w,G,t)w_i}{Y(P,w,G,t)}\dot{w}_i \right] \tag{17}$$

, where subscript α counts for the adjusted profit maximized growth of output.

By combining (16) and (17) we get:

$$\dot{Y}_{\alpha} = \frac{Y_G(P,w,G,t)G}{Y(P,w,G,t)}\dot{G} + \frac{Y_t(P,w,G,t)}{Y(P,w,G,t)} \tag{18}$$

, that is the corrected growth rate of output net of changes in prices.[7]

Thus, the adjusted cost savings, $\eta_{C\alpha}$, are:

$$\eta_{C\alpha} = \sigma \dot{Y}_{\alpha} + \frac{C_G(w,Y,G,t)G}{C(w,Y,G,t)}\dot{G} + \frac{C_t(w,Y,G,t)}{C(w,Y,G,t)} \tag{19}$$

The cost savings in equation (19) indicate: i) the scale effect induced by the response of output to changes both in public infrastructure and technology, where σ is the output elasticity, ii) the direct cost impact of public infrastructure, that is the contribution of public infrastructure to the firm's cost savings over time holding output constant, and iii) the technical change effect.

[7] This adjustment is necessary to isolate, and therefore to be able to identify, the supply side impact of public infrastructure. Thus, any demand side effects are purged of.

Now, by substituting equations (6) and (7) into (19), multiplying and dividing the last two terms on the right-hand side of equation (19) by profit, and using $\frac{\Pi}{C} = \frac{(R-C)}{C} = \sigma - 1$, where R is total revenue, we get:

$$\eta_{C\alpha} = \sigma \dot{Y}_{\alpha} + (1\text{-}\sigma)\, \eta_{\pi} \tag{20}$$

$$\eta_{C\alpha} = \sigma \dot{Y}_{\alpha} + (1\text{-}\sigma) \left(\frac{\pi_G(P,w,G,t)G}{\pi(P,w,G,t)} \dot{G} + \frac{\pi_t(P,w,G,t)}{\pi(P,w,G,t)} \right),$$

where the first term, $\sigma \dot{Y}_{\alpha}$, is the scale effect, the second term is the public infrastructure effect, and the last term is the technological change.

Moreover, to conceptualize the impact of public infrastructure on productivity growth we could further formulate productivity growth (with dots implying growth rate) from equations (16) and (17) as:

$$\dot{Y} = \frac{f_G(X,G,t)G}{f(X,G,t)} \dot{G} + \frac{f_t(X,G,t)}{f(X,G,t)} , \tag{21}$$

where the first term is the product of the output elasticity with respect to public infrastructure, which is the primal rate of return to public infrastructure, and the growth rate of public infrastructure. The second term is the primal rate of technical change, as *t* is time accounting for the technology change.

Note that if the growth rate of infrastructure is zero or the output elasticity with respect to infrastructure is zero then equation (21) reduces to the traditional Sollow's residual measure of total factor productivity. Essentially, equation (21) depicts total factor productivity.

We can further formulate TFP growth in terms of profit gains due to infrastructure and technological change using equation (11) as follows:

$$\dot{TFP} = \left(1 - \frac{1}{\sigma}\right)\Pi_{\text{Gains}} \tag{22}$$

or

$$\dot{TFP} = \left(1 - \frac{1}{\sigma}\right)\left(\frac{\pi_G(P,w,G,t)G}{\pi(P,w,G,t)}\dot{G} + \frac{\pi_t(P,w,G,t)}{\pi(P,w,G,t)}\right) \tag{23}$$

Equation (23) shows that the total factor productivity depends on: the scale economies, $1-\frac{1}{\sigma}$, the profit impact of public infrastructure, and the technological change. Low economies of scale in parallel with a small profit impact of public infrastructure and technological change would result to low levels of total factor productivity.

2.2 The local likelihood estimation of productivity growth

The starting point of the estimation of the productivity growth is to specify a translog profit function as follows:

$$\begin{aligned} ln\pi = \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln w_i + \beta_p \ln P + \alpha_t t + \beta_G \ln G + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{m} a_{ij} \ln w_i \ln w_j + \frac{1}{2}\beta_{GG} \ln G^2 + \frac{1}{2}\beta_{pp} \ln P^2 \\ + \sum_{i=1}^{n} \gamma_{ip} \ln w_i \ln P + \sum_{i=1}^{n} \gamma_{iG} \ln w_i \ln \mathrm{G} + \beta_{pG} \ln P \ln G + \frac{1}{2}\beta_{tt} \ln t^2 + \sum_{i=1}^{n} \gamma_{it} \ln w_i t + \gamma_{pt} \ln P t + \gamma_{Gt} \\ \ln G t, \end{aligned} \tag{24}$$

where π is total profit, w_i are input prices, P is the output price, G is the public infrastructure, and t is the technology.

We apply the usual monotonicity conditions. That is the profit function is non-decreasing in the price of output, and non-increasing in the prices of inputs, whilst it is non-decreasing in public infrastructure capital.[8] At the point of approximation the profit shares of output and inputs are positive and negative respectively. Sufficient conditions, therefore, are that $\beta_p \geq 0$, $\alpha_t \geq 0$, and $\alpha_i \leq 0$, for all i. We also employ linear homogeneity with respect to output and input prices, namely $\sum_{i=1}^{n} \alpha_i + \beta_p = 1$, $\sum_{i=1}^{n} \gamma_{it} + \gamma_{pt} = 0$, and $\sum_{i=1}^{n} \alpha_{ij} + \sum_{i=1}^{n} \gamma_{ip} = 0$ and impose the symmetry condition $\alpha_{ij} = a_{j.i}$[9].

To estimate the translog profit function with the underlying shares of outputs, inputs and public infrastructure, we build on the local likelihood estimation method of Kumbhakar and Sun (2012) who propose a non-parametrical estimation using kernel-based functions. In detail, we extend Kumbhakar and Sun (2012) estimation by treating for endogeneity in output, inputs and public infrastructure (see P, w_i and G in equation 24 respectively). To this end, we employ a limited information maximum likelihood (LIML) estimation based on the following reduced form:

[8]Applying Hotelling's Lemma to equation (24), we obtain the shares of profit attributed to output, inputs, and public infrastructure as:

$$R_P = \frac{dln\pi}{dlnP} = \beta_{ps} + \beta_{PP} lnP + \sum_{i=1}^{n} \gamma_{iP} \ln w_i + \beta_{PG} \ln G + \gamma_{Pt}\, t,$$

$$S_i = \frac{dln\pi}{dlnw_i} = \alpha_{is} + \sum_{i=1}^{n} \alpha_{ij} \ln w_j + \sum_{i=1}^{n} \gamma_{ip} lnP + \sum_{i=1}^{n} \gamma_{iG} lnG + \sum_{i=1}^{n} \gamma_{it} t,$$

$$R_G = \frac{dln\pi}{dlnG} = \beta_G + \beta_{GG} lnG + \sum_{i=1}^{n} \gamma_{iG} \ln w_i + \beta_{pG} lnP + \gamma_{Gt} t.$$

The R_G is of our interest as it shows the shadow share of public infrastructure.

[9] In addition, we test for convexity with respect to price. We confirm that the Hessian matrix of second- order partial derivatives of the restricted profit function is positive semi definite. Also, the profit function is concave with respect to the quasi fixed input, that is public infrastructure. This implies that the Hessian matrix of the profit function is negative semi-definite with respect to public infrastructure.

$$\Psi = \Pi\left(z,t\right) + U_{*}, \tag{25}$$

where $\Psi = [P', w_i', G', t']$, $\Pi(\;)$ is a non-parametric functional form, z is a vector of instruments[10], and U_{*} is a vector error term.

The estimation of the reduced form is flexible as it nests all possible functional forms, whether we are dealing with a production, cost or profit function, whilst the use of instruments treat for endogeneity problems. Therefore, our estimations would be bias free.

We also propose to account for heteroskedasticity in the covariance matrix of the error term $U = \left[u, U_{*}'\right]'$. To this end, we model variances and covariances according to a certain pre-determined (and thus exogenous) variable, namely public infrastructure, which is present in the local likelihood estimation. All other techniques, to our knowledge, simply assume that the covariance matrix is an IID component.

For simplicity in presentation, we focus on productivity growth, suppressing the dependence on public infrastructure, *G.* That is, we consider that public infrastructure as exogenous and outside the control of the firm. This is plausible as we are dealing with micro data at firm level that would be impossible to input the decision making of building public infrastructure at least in the short term as in our case here in where public infrastructure is quasi fixed input. Similarly, we treat the time trend, t.

Suppose $\mathbb{Z} = \left[z', t\right]'$, so that we can write the reduced form in (25) as:

[10] As instruments, we shall consider all available relative prices of private inputs.

$$\tilde{Y} \triangleq \left[\tilde{Y}_1,\ldots,\tilde{Y}_{M'}\right] = \begin{bmatrix} \mathrm{Z} & & & \\ & \mathrm{Z} & & \\ \cdots & & \ddots & \\ & & & \mathrm{Z} \end{bmatrix} \begin{bmatrix} \pi_1(\mathrm{Z}) \\ \pi_2(\mathrm{Z}) \\ \vdots \\ \pi_{M'}(\mathrm{Z}) \end{bmatrix} + \begin{bmatrix} U_{*,1} \\ U_{*,2} \\ \vdots \\ U_{*,M'} \end{bmatrix}, \quad (26)$$

where $\tilde{Y}$ represents productivity growth (in the simple case $\tilde{Y} = \tilde{Y}_1 = y_1 = \dot{TFP}$), $\pi_{m'}(\mathbb{Z})$ is the vector of functional coefficients corresponding to the m' th equation ($m' = 1,\ldots,M'$).

Alternatively, we can write (26) for simplicity as:

$$\tilde{Y} = \left(I_{M'} \otimes \mathrm{Z}\right)\pi\left(\mathrm{Z}\right) + U_{*}. \quad (27)$$

Regarding the error term, U, it follows:

$$U \triangleq \left[u', U_{*}'\right]' \sim N_M\left(O,\ \Sigma(\Psi,\mathrm{Z})\right). \quad (28)$$

Note that as shown above the covariance matrix is dependent on all endogenous and pre-determined variables and this provides greater flexibility. Indeed, we suggest to model this dependence as follows:

$$\Sigma(\Psi,\mathrm{Z}) = C(\Psi,\mathrm{Z})' C(\Psi,\mathrm{Z}). \quad (29)$$

Where $c(\Psi,\mathrm{Z}) = vec\left[C(\Psi,\mathrm{Z})\right],$ that is the vector consisting of the upper diagonal elements of $C(\Psi,\mathbb{Z})$. For simplification, we also note $W = \left[\Psi', \mathrm{Z}'\right]',$ that we then employ in a local linear model $c_j(\Psi,\mathbb{Z}) = \mathbb{W}\delta_j\left(\mathbb{W}\right), j = 1,\ldots,\frac{M(M+1)}{2}.$

In a vector notation, we have: $c(W) = \left(I_{\frac{M(M+1)}{2}} \otimes W\right)\delta(W).$

Thus, we can present all equations of our estimation model as follows:

$$
\begin{aligned}
& y_1 = \mathrm{B}\beta(\Psi) + u, \\
& \tilde{Y} = \left(I_{M'} \otimes \mathrm{Z}\right)\pi(\mathrm{Z}) + U_*, \\
& U = \left[u', U_*'\right]' \sim N_M\left(O,\ \Sigma(\Psi,\mathrm{Z})\right), \\
& \Sigma(\Psi,\mathrm{Z}) = C(\Psi,\mathrm{Z})'C(\Psi,\mathrm{Z}),\ c(W) = \left(I_{\frac{M(M+1)}{2}} \otimes W\right)\delta(W).
\end{aligned} \tag{30}
$$

From where, we can estimate all local coefficients as follows:[11]

$$
\beta_{m'}(\Psi) = \beta_{m',0} + \beta_{m',1}'\left(\Psi_i - \Psi\right), m' = 1,\ldots,M', \tag{31}
$$

or collectively

$$
\beta(\Psi) = \beta_0 + B_1\left(\Psi_i - \Psi\right).
$$

3. Measuring the impact of public infrastructure for the two-digit Mexican industry

To apply our productivity growth decomposition, we opt for the case of Mexico. This is of interest because Mexico has one of the lowest among OECD countries investment in core public infrastructure defined as capital stock in electricity, transport, and communication. Moreover, OECD (2005) argues that there has been a chronic underinvestment of infrastructure investment caused mainly by the lack of fiscal consolidation and prioritisation of public expenditure towards investment rather than consumption expenditure.[12] One of the latest episodes of heavy curtailment in infrastructure

[11] As an extension of this parametric estimation we present the case of non-parametric estimation method of our model in Appendix. Note that in the empirical application, we estimate with the parametric method. Results of non-parametric method are available under request.

[12] In the case of Mexico, other factors, besides infrastructure, could be held accountable for the observed underperformance of the industry. Specifically, in the nineties, the businesses in Mexico faced a major financial crisis that led to severe macroeconomic imbalances, which coupled with rising world uncertainties posed by high volatility in oil prices and high interest rates curbed economic activity. Another factor could be the globalization that appears to have stressed the economy triggered by the intensified competition of low labour cost countries, such as China (see OECD, 2003a). However, globalization should not be seen as posing only threats to the economy, as globalization could have been beneficial if producers and policy makers alike had swiftly responded towards restructuring traditional labour intensive production procedures and adopting the necessary policy reforms, in particular in labour markets (see Bergoeing et al. 2002). Moreover, the low skilled manufacturing sector of Mexico is difficult to compete against China or with other low-income countries, including in Central America. Based on data reported in the IMD World Competitiveness Yearbook (2004) the hourly compensation in the manufacturing sector in Mexico is \$2.45 compared to \$0.66 in China.

investment took place during the financial crisis in 2009 followed by fiscal consolidation efforts that heavily relied on reducing public investment expenditures. In addition, public investment projects are crucially dependent on changes in oil revenue and thus subject to uncertainties of high volatility in oil markets. In a parallel process, and despite the economic recovery in the second half of the nineties brought by the fiscal consolidation, the productivity growth followed a declining path. Based on the country economic review of OECD (2003a, 2007), the inadequate public investment has created shortages in core infrastructure such as communications, transportation, electricity, sanitation and water.[13] In turn, an inadequate provision of core infrastructure deters further investment and acts as an impediment to business (Shah, 1992; Feltestain and Ha, 1995; Feltestain and Ha, 1999; Moller et al., 2017). Inadequacies in transportation and communication infrastructure have prevented Mexico from getting the most out of its proximity to the US (OECD 2007).

Table 1 presents the percentage change compared to previous year of the real fixed capital formation. There is much variability, as real fixed capital formation takes as low values as -9.3 in 2009 down from 8.7% in 2006. This shows the erratic underlying cycle of boom and busts that could have severely affected the growth performance. It is worth mentioning that following the extensive privatization operations of the early 1990s, the public-sector share of investment declined. However, private sector appears not to cover the shortage of infrastructure created by the public underinvestment as it has mainly directed resources to the commercial sector. It is worth noting that prior to 1994 infrastructure was entirely provided by the government, which had monopolies in many sectors, notably electricity

[13] According to OECD Environmental Performance Review (2003b) in Mexico, the water and wastewater sector would require $2.2 billion of investment funds, twice the annual budget of the National Water Commission (CNA), which is responsible for producing and regulating water.

and transportation, though since the mid-nineties there has been also private provision.[14] In addition, there is also evidence of inadequate quality of investment (OECD, 2005 and 2007).

Table 1: Real total gross fixed capital formation (Percentage change from previous year).

	1990-00	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Australia	4.1	-3.3	14.6	8.8	7.2	9.0	4.7	9.2	7.8	-1.4	4.3	7.0	9.0	-2.2	-2.0	-1.3
Austria	2.8	-1.3	-2.9	3.8	0.8	0.2	1.2	4.6	1.3	-7.3	-2.3	6.8	0.6	-1.4	0.4	-1.9
Belgium	1.7	1.8	-3.7	0.2	8.3	6.5	3.5	6.3	2.9	-7.3	-0.1	4.1	0.0	-2.1	5.1	1.2
Brazil	..	1.1	-1.6	-3.8	8.4	2.3	6.0	11.9	12.7	-1.9	18.1	6.7	-0.6	6.0	-4.3	-3.7
Canada	2.7	4.8	1.0	5.2	8.4	9.2	6.3	3.2	1.6	-11.5	11.5	4.8	4.8	0.4	0.3	-1.5
Chile	8.1	3.5	2.2	6.5	11.3	23.5	4.3	10.8	17.9	-12.1	11.6	15.0	11.6	2.1	-6.1	1.2
Colombia	..	9.7	11.1	11.5	11.1	13.2	18.1	14.4	9.9	-1.3	4.9	19.0	4.7	6.0	10.9	3.0
France	1.7	2.3	-0.9	1.9	3.1	2.9	4.0	5.5	0.7	-9.0	1.9	2.1	0.3	-0.4	-1.2	-0.6
Germany	1.9	-2.1	-5.8	-1.4	-1.0	0.5	7.6	4.6	0.6	-9.9	4.6	7.5	0.0	-0.4	3.3	2.5
Greece	4.0	1.3	-1.0	15.5	5.4	-12.8	17.0	17.6	-6.5	-13.3	-20.8	-17.0	-28.5	-9.5	3.0	0.6
India	..	3.0	8.2	10.7	18.4	16.9	13.9	17.4	9.1	-0.4	15.1	11.5	0.3	5.1	2.6	7.0
Israel	7.4	-3.1	-5.8	-5.5	1.9	3.5	6.5	10.5	5.5	-3.3	10.3	14.5	3.2	1.1	-2.9	0.7
Italy	1.3	2.8	4.2	-0.2	1.7	2.0	3.4	1.3	-3.2	-10.0	-0.6	-1.7	-9.4	-5.8	-3.2	1.6
Japan	-0.6	-2.1	-4.9	0.2	0.4	0.8	1.5	0.3	-4.1	-10.6	-0.2	1.4	3.4	3.2	2.6	-0.6
Korea	5.4	1.5	6.9	4.8	2.9	2.0	3.6	5.0	-0.9	0.3	5.5	0.8	-0.5	3.3	3.1	4.0
Mexico	5.9	-3.3	0.6	3.0	7.4	5.8	8.7	5.9	5.1	-9.3	1.2	7.8	4.8	-1.5	2.2	4.9
Norway	3.8	-0.6	-0.4	0.4	10.0	12.0	9.1	11.7	0.9	-6.8	-6.6	7.4	7.6	6.8	0.6	-3.6
Russia	..	10.9	3.1	13.9	12.0	10.2	17.9	21.1	9.7	-14.7	6.4	9.2	7.0	0.6	-2.1	-18.5
South Africa	..	2.8	3.5	10.2	12.9	11.0	12.1	13.8	12.8	-6.7	-3.9	5.7	3.6	7.6	-0.4	2.6
Spain	3.2	4.9	4.6	7.0	5.1	7.5	7.4	4.4	-3.9	-16.9	-4.9	-6.3	-8.1	-3.8	3.4	5.4
Turkey	4.4	-30.0	14.7	14.2	28.4	17.4	13.3	3.1	-6.2	-19.0	30.5	18.0	-2.7	4.4	-1.3	2.6
United Kingdom	0.7	-1.3	2.5	3.1	3.2	1.6	3.3	5.3	-4.7	-14.4	5.9	2.3	0.7	3.4	7.8	4.7
US	5.7	-0.5	-1.8	3.9	5.8	5.6	2.2	-1.2	-4.8	-13.1	1.1	3.7	5.3	2.7	3.9	3.0
Euro area	2.1	1.1	-1.2	1.2	2.2	2.7	5.6	4.8	-0.8	-11.1	-0.5	1.7	-3.5	-2.3	1.2	2.0
Total OECD	3.2	-0.7	-0.6	2.9	4.5	4.5	4.2	2.7	-2.0	-11.0	2.0	3.5	1.6	1.0	2.7	2.3

[14] To this day, the state has a dominant position in the electricity industry with two companies, the *Comision Federal de Electridad* (CFE) and a smaller company for the Mexico City area, the *Luz y Fuerza del Centro* (LFC) (see OECD, 2007). These companies own the entire transmission network. Since 1992 the Electricity Public Service Law allows private independent power producers that they must sell to CFE and LFC under 25-year contract. This Law has resulted to limited private investment as a mere $3.7 million have been invested in energy from 1992 to 2000. Similarly, the private provision of transportation infrastructure, despite the apparent necessity to build and maintain roads, railways and ports, was limited to $12.5 million for the period 1990-2000. On the other hand, private investment funds to telecommunications have been significant, amounting to $27.8 million for the period 1990-2000, insinuating the strong presence of private funds in the sector.

Source: OECD 2015, Economic Outlook.

For purposes of the present analysis, infrastructure investment excludes private investment funds so as to identify the net public infrastructure impact on private sector productivity. This hypothesis may not seem as strong as in a first sight given that state-owned firms still dominate infrastructure investment, and as a result its potential impact merits an investigation given that the efficiency and the quality of state's infrastructure services could prove to be an important determinant of the competitiveness, in terms of productivity gains, of Mexican firms.

Our sample covers the period from 1970-2013.[15] The data set is mainly derived from the Annual Industrial Survey (AIS) from the Mexican Institute for Statistics, Geography and Informatics (INEGI), which provides adequate information regarding: output measured as value added, that is net of intermediate inputs, employment measured as number of employees, wages, investment, capital stocks, and expenditures in electricity, communications, and transport.

The focus on micro data allows employing disaggregation into our empirical application justifying the theoretical specification of the present analysis that focuses on the firm's profit optimization and thus departs from a demand side analysis.[16] In addition, our estimations do not suffer from aggregation bias (Hurlin and Minea, 2013). In detail, the following ten Mexican two-digit industries are included in our sample: mining, food, beverages & tobacco, wood and wood products, paper, chemicals, plastics &

[15] The sample is from the annual industrial survey of Mexico (Censo Industrial of the INEGI). The sample has been corrected for missing data and methodological changes, e.g. in 2001.

[16] It is worth noting that a demand side analysis is warranted at an aggregate macroeconomic level as in Aschauer (1999) or within a general equilibrium framework and it would have, therefore, assisted the identification of the impact of public infrastructure. However, such an analysis is beyond the scope of the present study that relies on profit optimization and industry data.

rubber, metal products, machinery & equipment, construction.[17] According to the classification of industries in Mexico (Sistema de Clasificacion Industrial de America del Norte, SCIAN), the industries including in the sample represent around 80% of the total industrial production over the sample period.

Time series for infrastructure and industry capital stock is constructed using series for total Gross Fixed Capital Formation (GFCF) and investment. The capital stock series for both totals and disaggregated components were built up via a Perpetual Inventory Method (PIM) applied to a benchmark capital stock for the year 1970, which is the standard OECD method. A PIM adds GFCF to benchmark capital and subtracts the depreciated capital in each year. The depreciation pattern can be linear or non-linear. We used a linear depreciation pattern, which is the normal choice when information about actual depreciation is not available (see Albala-Bertrand, 2003).[18] The benchmark for total capital stock was based on Hofman (2000 a, b). The proportion of core infrastructure of the total stock is based on the methodology proposed by Arellano and Braun (1999). In turn, the proportion of infrastructure components of total infrastructure was based on actual investment patterns. The depreciation rates used were the ones suggested in these sources. The price indexes used to deflate the nominal series came mostly from the GDP deflator, but we also used PPI and CPI as

[17] Based on the classification of industries in Mexico (Sistema de Clasificacion Industrial de America del Norte, SCIAN) there are twenty sectors. Given that the aim of the present analysis is to examine the impact of public infrastructure on private sector productivity, the focus is on the manufacturing production where the private sector dominates, in particular sectors 31-33. These sectors are then divided into ten sub-sectors according to the Censo Industrial of 1999. Due to data availability issues textile products, clothes and shoes industry (*productos textiles, cuero y piel*) were not included in the sample, as well as electrical, electronic and communication industry (*aparatos electricos, computacion y communicacion*). Also, note that the sample covers registered firms. Despite the importance of the informal sector for the Mexican economy, data are not available.

[18] Note that according to the PIM method the usefulness of an asset is assumed to decline monotonically with age and is approximated by a rectangular hyperbola, whilst the curvature parameter describes the form of depreciation. It is assumed that the efficiency of machinery and equipment declines over a larger portion of a service life and with less severity than the depreciation of buildings. Hence, as proposed by OECD methodology (see Ball et al., 2004) the value of the curvature parameter is taken as 0.75, 0.6, and 0.5 for buildings, construction and machinery respectively, whereas the mean service live of buildings, construction and machinery is 38, 20 and 9 years respectively.

deflators when the formers were unavailable.[19] These series were available from the National Income and Product Accounts (NIPA) of the Banco de Mexico.

4. Empirical findings

We estimate the translog profit function and derive productivity growth using the local likelihood estimation method. Note that in the estimation of the profit function equation we employ a panel of inter industry time series data. By doing so we deal with the problem of multicolinearity frequently associated with data of a single industry. The inter industry data set provides the necessary variability, and therefore allows a more rigorous statistically analysis of the parameter estimates and the correspondent elasticities.[20] In order to capture cross-industry variability, we introduce dummy variables on the constant term of the profit function for each industry. We have assumed that the intercept $\alpha_0 = \alpha_0 + \sum_s \alpha_{0s} D_s$, where D_s refers to the industry dummies taking values 1 and 0, s is the industry identification index, and the α_{js} are normalized with respect to the *k* industry ($\alpha_{jk} = 0$). Further, in order to take into account the heterogeneity across different industries in terms of technology we also introduce in our analysis intercepts in the share equations as follows: $\beta_{ps} = \beta_p + \sum_s \beta_{ps} D_s$ and $\alpha_{is} = \alpha_{is} + \sum_s \alpha_{is} D_s$, where D_s refers to the industry dummies taking values 1 and 0, s is the industry identification index, and the β_{ps} and α_{is} are normalized with respect to the *k* industry.

[19] All series are expressed in constant terms.

[20] Given that our data set has time series dimension, in addition to the cross-section dimension across industries, it could be the case that there exist unit-roots and stochastic trends. Preliminary tests show that the despite some non-stationary variables into our sample the residuals from the estimated equations were found to be stationary indicating the existence of long-run relationships in terms of cointegration (results are available under request).

Empirical results suggest that the estimated translog profit function is well behaved, as the signs on the coefficients of the profit function are reported to be consistent with curvature conditions, while the magnitudes of the estimated elasticities are plausible and statistically significant for most industries.[21] Table 2 reports parameter estimates for intercepts, input and output prices for all industries in the sample in order to account for possible heterogeneity across different industries in terms of technology. The empirical evidence suggests that indeed there is some heterogeneity across industries.

TABLE 2: Parameter estimates of the tranlsog profit function for input and output prices

Industry	Intercept, α_{0s}	Coeff. α_{Ks}	Coeff. α_{Ls}	Coeff. β_{Ps}
Mining	1.15**	-0.64*	-0.212**	0.031*
Food	4.35**	-0.73**	-0.171**	0.096**
Beverages & Tobacco	6.17*	-0.93**	-0.086**	0.081**
Wood	4.23**	-0.25*	-0.762*	0.024*
Paper	3.11*	-0.13*	-0.825*	0.081**
Chemical	-0.12*	-0.31	-0.781*	0.128**
Plastics and Rubber	2.150	-0.53*	-0.581*	0.311**
Metal Products	3.01**	-0.67**	-0.473	0.244*
Machinery & Equip.	2.20*	-0.72*	-0.251*	0.121**
Construction	1.83*	-0.73*	-0.127*	0.132**

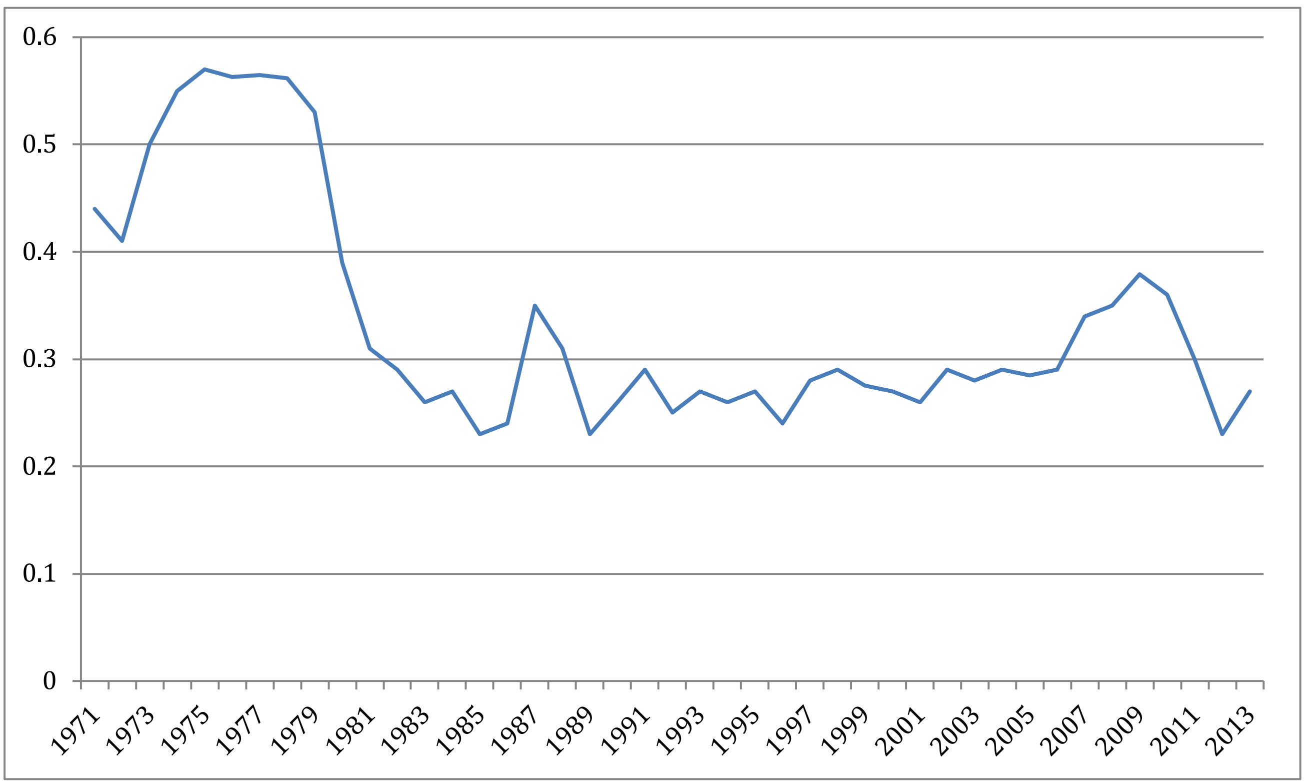
Where Coeff. means coefficient. *** p<0.01; ** p<0.05, while * p<0.1.

Note that the major macroeconomic instability caused by financial crisis in the mid-1990s could potentially bias our empirical estimation of the system of equations. To take into account this event, we include a dummy-variable for the year of pesos' crisis, 1995, and the credit crunch in 2009, in the translog profit function specification. The dummy variable is found to be significant and carries a negative sign, insinuating the detrimental effect of crises on the profitability of the Mexican industry.

[21] For presentation purposes, we opt not present here parameter estimates of the local likelihood. Results are available under request. Moreover, the fitted profit function satisfies the monotonicity property at all data points as the output shares are found to be positive and the variable input shares negative, while the profit shares of infrastructure capital is estimated to be positive.

Diagram 1 presents the elasticity of profit with respect to public infrastructure. It is positive across all sample points. This finding implies that public infrastructure asserts a positive externality to the Mexican industry. However, note that it follows a negative trend till mid-nineties, whereas in 1995 the financial crisis led to major macroeconomic instability that resulted also to a sharp decline on the return to public infrastructure as measured by the elasticity of profits with respect to public infrastructure. Similarly, there is a sharp decline during the recent credit crunch.

DIAGRAM 1: The elasticity of profit with respect to public infrastructure.



Source: Authors' estimations.

4.2 Profit gains, cost savings, $\dot{TFP}$ contribution of public infrastructure

The profit gains of public infrastructure depend crucially on the elasticity of profits with respect to public infrastructure, but also the actual growth rate of public infrastructure (see equation 7). Table 3 presents the profit gains as derived from equation (7), augmented with the technical change effect, over the sample period 1970-2013. The results show that the effect of infrastructure is positive in all years albeit declining over time (see 3rd column in Table 3). The average value of the profit gains over the period due to infrastructure is around 0.7% compared to 1% of technical change. As investment in infrastructure fell over the years, and in particular during the financial and macroeconomic crisis in 1990-1995, gains in profits due to infrastructure also fell. There is some recovery in Π_{Gains} in the late nineties and 2000s, though its trend remains on a negative trajectory compared to the seventies. Chronic underinvestment in infrastructure appears to impended productivity growth.

TABLE 3: Estimates of the rate of gains in profit due to infrastructure and technology.

	$\frac{\pi_G(P,w,G,t)G}{\pi(P,w,G,t)}$	$\dot{G}$	$\frac{\pi_G(P,w,G,t)G}{\pi(P,w,G,t)}\dot{G}$	$\frac{\pi_t(P,w,G,t)}{\pi(P,w,G,t)}$	Π_{Gains}
1970-75	0.235	5.49	1.290	1.239	2.529
1975-80	0.332	5.4	1.793	1.293	3.086
1980-85	0.225	4.88	1.098	1.263	2.361
1985-90	0.222	2.42	0.537	0.849	1.386
1990-95	0.218	1.48	0.323	0.838	1.161
1995-00	0.223	2.1	0.468	1.134	1.602
2000-05	0.221	2.01	0.444	0.940	1.384
2005-13	0.222	2.012	0.447	1.037	1.484
average	0.237	3.24	0.768	1.074	1.842

Note: Profit gains, Π_{Gains}, is the sum of the impact of public infrastructure, $\frac{\pi_G(P,w,G,t)G}{\pi(P,w,G,t)}\dot{G}$, and technological change, $\frac{\pi_t(P,w,G,t)}{\pi(P,w,G,t)}$.

Clearly, the profit gains due to infrastructure have been declining over time. The average Π_{Gains} during the period 1970-80 is around 3.4%, whereas a marked decline is observed in the 1980s, followed by a sharp deterioration thereafter reaching an all-time low at around 1.1% in the first half of the 1990s. There was a partial recovery in late nineties, but it dropped thereafter. This development is mainly explained by both the decline in the profit elasticity with respect to public infrastructure but also by the downward trend observed in the growth rate of public infrastructure since the mid 1980s. In particular, due to the dramatic collapse of infrastructure investment in the 1990s, whereas it has not been recovered thereafter, the profit gains due to infrastructure lacked persistently behind the profit gains due to technology, halving the value of Π_{Gains} compared to the 1970s.

Table 4 presents the cost savings due to scale effects (1st column), infrastructure capital (2nd column) and technology (3rd column). The average cost saving due to infrastructure is -0.2% over the sample period, though it steadily declines over time to reach its lowest value in the period 1970-75 of -0.45% to -0.02% in 2005-13 period. Moreover, given that the scale and the technological effect remain relatively stable over the sample period, despite some observed decline in the 1990s, it is the infrastructure effect that curbs the magnitude of cost savings. Note that $C_{Savings}$ are the lowest during the period of financial crisis in 1991-95 and in general in the nineties. We reveal herein that despite the negative effect of financial crisis the Mexican industry was particularly hit by the underinvestment in public infrastructure. It is further worth to note that the $C_{Savings}$ due to infrastructure has never been recovered ever since.

TABLE 4: Cost savings due to infrastructure, scale effect and technology.

	$\sigma \dot{Y}_{\alpha}$	$(1\text{-}\sigma)\left(\frac{\pi_G(P,w,G,t)G}{\pi(P,w,G,t)}\dot{G}\right)$	$(1\text{-}\sigma)\left(\frac{\dot{\pi}(P,w,G,t)}{\pi(P,w,G,t)}\right)$	$C_{Savings}$
1970-75	1.38	-0.44	-1.16	-0.22
1976-80	1.22	-0.38	-1.01	-0.17
1981-85	1.23	-0.33	-1.02	-0.12
1986-90	1.22	-0.33	-1.01	-0.12
1991-95	0.98	-0.02	-0.99	-0.03
1996-00	0.91	-0.03	-0.89	-0.01
2000-05	0.94	-0.02	-0.94	-0.02
2005-13	0.93	-0.02	-0.92	-0.01
average	1.10	-0.20	-0.99	-0.09

Note: The cost savings are due to: the scale effect, $\sigma \dot{Y}_{\alpha}$, the direct impact of public infrastructure (1-σ) $\left(\frac{\pi_G(P,w,G,t)G}{\pi(P,w,G,t)}\dot{G}\right)$, and the technical change (1-σ) $\left(\frac{\dot{\pi}(P,w,G,t)}{\pi(P,w,G,t)}\right)$.

Cole et al (2005) show that Latin America in general has been less productive than main industrialised economies with the average $\dot{TFP}$ levels in Mexico corresponded to roughly 50% of US productivity between 1950 and 2000. There are many arguments put forward as possible explanations for this trend among others; macroeconomic instability due to widespread governmental economic intervention, corruption, income inequality, and lack of competition due to monopolies and barriers to entry (see Cole et al, 2005). Equation (12) provides a specification of $\dot{TFP}$ growth decomposition into the direct impact of public infrastructure and the primal rate of technical change so as to investigate whether these two factors could explain the decline of $\dot{TFP}$ growth over the years.

Table 5 reports the dramatic decline of $\dot{TFP}$ growth in manufacturing that more than halved over the sample period from around 3% in the 1970s to around 1.2% in the early 1990s (as in Lopez-Cordova 2003), recovering in 2000-05 to 2.3% and thereafter dropping again to 1.7%. Moreover, as in the case of Π_{Gains} and $C_{Savings}$, the contribution of public infrastructure to $\dot{TFP}$ growth exhibits a downward trend. The average contribution of the effect of public infrastructure on $\dot{TFP}$ growth is 0.9%, and follows a negative trajectory over time from around 1.85% in the 1970s to 1.28% in 1981-85, to 0.5% in 1986-90, and, then, further declines to 0.27% in the period 1991-95, recording some recovery thereafter to 0.5% in 2000-05 before declining thereafter. This observed decline is mainly due to chronic under investment in infrastructure OECD (2005, 2007) and IMF (2014).

TABLE 5: The effect of public infrastructure and technology on total factor productivity growth.

	$\left(1-\frac{1}{\sigma}\right)\left(\frac{\pi_G(P,w,G,t)G}{\pi(P,w,G,t)}\dot{G}\right)$	$\left(1-\frac{1}{\sigma}\right)\left(\frac{\pi_t(P,w,G,t)}{\pi(P,w,G,t)}\right)$	$\dot{TFP}_G$
1970-75	1.864	1.111	2.975
1976-80	1.890	1.027	2.917
1981-85	1.282	1.056	2.338
1986-90	0.516	1.056	1.572
1991-95	0.273	0.880	1.153
1996-00	0.321	0.890	1.211
2000-05	0.594	1.770	2.364
2005-13	0.458	1.330	1.788
average	0.900	1.140	2.040

Note: The effect of infrastructure is given by the first column, $\left(1-\frac{1}{\sigma}\right)\left(\frac{\pi_G(P,w,G,t)G}{\pi(P,w,G,t)}\dot{G}\right)$, the effect of technology by the second column, $\left(1-\frac{1}{\sigma}\right)\left(\frac{\pi_t(P,w,G,t)}{\pi(P,w,G,t)}\right)$.

6. CONCLUSION

This paper develops a new theoretical framework based on a flexible profit function that allows measuring productivity and the impact of infrastructure. It also provides a theoretical specification of $\dot{TFP}$ decomposition, whilst we propose a novel local likelihood estimation that takes into account model misspecification, endogeneity and heteroscedasticity. It follows from a literature that demonstrates the importance of investing in infrastructure for economic growth (Gramlich, 1994; Vijverberg et al., 1997; Becerril et al. 2009 and 2010; Hao and Huang, 2014; Zhang, 2014; Páez-Pérez and Sánchez-Silva, 2016; Moller et al., 2017). Alas, the exact return to infrastructure investment has been a matter of dispute (Hurlin and Minea, 2013, Zhang, 2014; Páez-Pérez and Sánchez-Silva, 2016). Overall though, most studies seem to provide evidence of positive returns to infrastructure (see for a review Gramlich, 1994; Vijverberg et al., 1997; Páez-Pérez and Sánchez-Silva, 2016; Moller et al., 2017).

In this paper we shed new light into the impact of infrastructure for an economy that has been limited evidence that is the case the case of Mexican industry (Feltestein and Shah 1995; Becerril et al. 2009 and 2010). Our findings are line with previous literature and we report that indeed public infrastructure investment is a productive input. In some detail, we provide a new duality theory modelling that it is flexible enough to decompose the impact of infrastructure into profit gains and cost savings for the Mexican industry. We report that both profit gains and cost savings due to infrastructure show some variability with a recorded decline in the nineties and in late 2000s. As a result, the slowdown in $\dot{TFP}$ shows that is partly due to under investment in infrastructure. Building infrastructure, we argue will boost productivity growth of Mexican industry and would enhance economic growth.

We believe our findings come in timely manner as productivity growth is low in many countries in the west and Latin America. The low productivity growth persists despite financial conditions have improved since the meltdown in the late 2000s. We argue that infrastructure investment would be the missing link as we provide evidence that infrastructure would enhance productivity growth. However, one should also take note that in terms of economic policy providing the necessary funding for infrastructure is of importance, in particular for countries like Mexico where macroeconomic imbalances could persist. It might be the case that the way forward is to enhance partnerships between the public and the private sector that in turn could share the cost of building infrastructure. We leave this research for the future.

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Appendix: non-parametric estimation

We can easily extend our likelihood estimation method to a non-parametric estimation. Suppose a parametric likelihood $L = L(\mathrm{y};\theta) = \prod_{i=1}^{N} f(\mathrm{y}_i;\theta)$. This likelihood can be made non-parametric through a local linearization.

The local linearization gives a new conditional log-likelihood at y is:

$$l(\theta_0,\Theta_1) = \sum_{i=1}^{N} \log f\left(\mathrm{y}_i;\ \theta_0 + \Theta_1 \cdot (\mathrm{y}_i - y)\right) \cdot K_H\left(\mathrm{y}_i - y\right), \quad \text{(A1)}$$

where $K_H(u) = |H|^{-1} K\left(H^{-1}u\right),$ for some bandwidth matrix and kernel $K(z) = \left[K_1(z_1),...,K_d(z_d)\right]'$, where d is the dimensionality of the parameter vector.

The kernels satisfy the standard property that they are symmetric, univariate density functions. In this case, we have $\int uu'K(u)du = \left(\int z_1^2 K_1(z_1)dz_1\right) I_d$.

Then the local linear estimator, say of $\pi(\mathrm{Z})$ is $\hat{\pi}(\mathrm{Z}) = \pi_0(\mathrm{Z})$ where parameter estimates are obtained by maximizing the conditional local log-likelihood:

$$\hat{\theta}_0(y) = \underset{\theta_0(y),\Theta_1(y)}{\arg\max} : \sum_{i=1}^{N} \log f\left(\mathrm{y}_i;\ \theta_0 + \Theta_1 \cdot (\mathrm{y}_i - y)\right) \cdot K_H\left(\mathrm{y}_i - y\right). \quad \text{(A2)}$$

In our case the parameter vector

$$\hat{\theta}_0(y) = \left[\beta_0(\Psi)', \pi_0(\mathrm{Z})', \delta_0(W)'\right]' \quad \text{(A3)}$$

and $y \triangleq \left[\Psi', Z', W'\right]'$.

To construct the local likelihood, we use seemingly-unrelated-regression (SUR) interpretation of LIML. Specifically, for a single observation, we can write:

$$f\left(y_1, \Psi \mid Z, \theta\right) = \left(2\pi\right)^{-M/2} \mid \Sigma\left(\Psi, Z\right) \mid^{-1/2} \exp\left\{-\tfrac{1}{2} S\left(\theta\right)\right\}, \quad \text{(A4)}$$

where $S\left(\theta\right) \triangleq U\left(\theta\right)' \Sigma\left(\Psi, Z\right)^{-1} U\left(\theta\right)$, $U\left(\theta\right) \triangleq \begin{bmatrix} y_1 - B\beta\left(\Psi\right) \\ \tilde{Y} = \left(I_{M'} \otimes Z\right)\pi\left(Z\right) \end{bmatrix}$.

We use a normal kernel for $K_j\left(z_j\right), j = 1, \ldots, d$ and a diagonal bandwidth matrix, H, with different bandwidth parameters for β, π, δ but common for the entire vector β, then π and then δ. So, we have three different bandwidth parameters $h = \left[h_\beta, h_\pi, h_\delta\right]'$, which are selected through cross-validation. Since the sample size is rather large, the bandwidth parameters are selected using all observations for all selected firms.

To maximize each localized likelihood, we use a standard Gauss-Newton algorithm with analytic first and second derivatives, which can be computed easily for this model. This guaranteed convergence in many cases where a standard conjugate-gradients algorithm has failed to converge starting from a variety of reasonable starting values.[22]

[22] The conjugate-gradients algorithm we use is a Fortran 77 implementation of Liu and Nocedal (1989). It is available as lbfgs in netlib. Our Gauss-Newton version is SNOPT and is based on http://www.ccom.ucsd.edu/~peg/papers/snpaper.pdf