Department of Economics
Working Paper No. 236

Productivity Growth and the General X-factor in Austria's Gas Distribution

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October 2016

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Abstract: We estimate cost functions to derive productivity growth using a unique database on costs and outputs of essentially all regulated Austrian gas distribution companies over the period 2002–2013, covering the times before and after the introduction of incentive regulation in 2008. We estimate a *concave* relation between total costs and time, and a significant one-off but permanent reduction in *real* costs after an imposed reduction in *granted* costs in the course of the introduction of incentive regulation. Our results imply that technological opportunities were higher in the early years of the sample than in later years, and that productivity growth grinded to a halt from 2008 on. We conclude that technological opportunities are exhausted (for the time being) in the Austrian gas distribution sector giving rise to an optimal general X factor (X-gen) of zero for the foreseeable future.

Keywords: X-gen; Productivity; Regulation; Gas distribution

JEL codes: L22, L25, L51, Q48

Acknowledgement: The data employed in this study were collected in the course of a project on behalf of the Austrian Association of Gas- and District Heating Supply Companies (FGW). These data have been gratefully provided for this academic study under the condition that individual firm observations are not made publicly available.

1. Introduction

Since the rise of *incentive based regulation* of network industries (see e.g., Baumol, 1982; Crew and Kleindorfer, 1986; Littlechild, 1983; Laffont and Tirole, 1993), many regulatory authorities across the world have applied a so called "general X-factor" (X-gen), which defines the annual rate at which output prices of regulated firms have to decrease. The underlying idea is that all factor efficient companies under regulation should pass-through cost savings to consumers to mimic a competitive outcome in the industry. In this regard, Bernstein and Sappington (1999) have developed a famous formula for the practical application of X-gen for regulatory authorities. Under the assumption that input price growth rates are equal between the regulated sector and the total economy, this factor in their formula essentially boils down to the projected general productivity growth differential between the regulated industry and the economy as a whole. A (natural) monopoly would not or only partially pass through implied cost savings to final consumers, whereas, in a competitive environment, firms are price takers and adjust prices according to cost variations. Thus, the goal of incentive regulation is to induce firm behavior as if regulated firms operated in a competitive environment where any changes in costs (from changes in input prices or productivity) are fully passed on to customers.[1] Hence, regulated firms' granted costs (or revenues) decline annually by the rate of X-gen. This system is intended to provide incentives for efficiency savings, as any cost savings beyond the predicted rate of X-gen enter as profits, since firms are "residual claimants" in incentive regulation, at least until the price caps are next reviewed (usually every four to five years).

However, this puts regulators on a tricky path. On the one hand, if X-gen is set *too large*, this risks that current consumers underpay for the services and that regulated companies are put under undue strain not being able to earn the opportunity cost of capital, with possible negative side effects such as under-investment, under-provision of quality or outright bankruptcy. On the other hand, if X-gen is set *too small*, current consumers overpay for the services and regulated companies earn excessive profits (market power rents), with additional possible negative side effects such as a general mistrust of the public in regulation. The "right" value of the X-factor is therefore essential for the well-functioning of the regulatory system.

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[1] In many jurisdictions (such as in Austria), this implies that for a pre-specified regulatory period (e.g. five years), the granted costs or revenues of regulated companies are reduced by the X-factor on an annual basis, after being valorized by a general price index, such as consumer prices. In this case, this form of regulation is called "CPI minus X" (or "RPI minus X") regulation going back to Stephen Littlechild in the 1980s.

Unfortunately, while economists have a good idea as to what the productivity growth rate for the economy as a whole looks like, there is much more controversy of how large productivity growth is for single segments of the economy, such as gas distribution.[2] To aggravate problems, it is not the past productivity growth differential that matters for setting X-gen but the projected productivity growth differential in the next regulatory period.

In this paper we first argue and then empirically show that for reaching the goals of efficiently estimating productivity growth and setting the X-gen it is essential (1) to obtain appropriate panel data on the specific regulated sector; (2) to take the specifics of the regulated segment, i.e. the development of its technological opportunities, into account; and (3) to control for the specific regulatory history of the segment. A distinct feature compared to other studies is our rich and unique database on costs and network characteristics of all Austrian gas distribution firms subject to incentive regulation over the twelve year period 2002–2013. Hence, our data are *specifically for the gas distribution segments of these companies* (since many firms also serve other segments, e.g. electricity). Although these data are confidential,[3] high data quality seems assured, as similar data are requested by the Austrian regulatory authority for its regulatory decisions (e.g. benchmarking analyses, determination of granted costs).

For 19 Austrian gas distribution companies over the period 2002–2013 we estimate log-linear multi-output cost functions. While time trend should capture technological advancement (often referred to as "frontier shift"), productivity growth also incorporates scale economies. We take the development of technological opportunities insofar into account in that we estimate *flexible functional forms* such as a quadratic relation between total costs and time. Finally, we also utilize information from the time *before the introduction of incentive regulation* in the Austrian gas distribution sector in 2008. This allows us to disentangle one-off events such as an imposed reduction of regulated utilities' *granted* costs[4] by around 8%[5] when entering incentive regulation in 2008. The intention for the required one-time cost reduction by the regulatory authority was to erode accumulated inefficiencies of the firms previous to the introduction of

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[2] This does not mean that there are no controversies in the literature over the magnitude of total factor productivity growth (see e.g. Gordon, 2012), but only that these controversies are much more intense for single industries, let alone single segments of industries, such as gas distribution.

[3] Actual cost data (as opposed to costs granted by the regulatory authority) are generally only available confidentially. To the best of our knowledge there is no other study that incorporates such panel data on costs and outputs at the firm level over such a long time period.

[4] As opposed to *actual* costs, *granted* costs refer to costs that the regulatory authority indeed recognizes as costs related to the subject of regulation (i.e. gas distribution activities).

[5] On average, the regulator cut 8% of granted costs. However, the cost reductions included firm specific components, so that the cuts varied across firms.

incentive regulation. Failing to address this one-time cost cut in our estimations would essentially attribute this one-off event to permanent productivity growth overestimating the appropriate X-gen.

Our main results can be summarized as follows. Including just a linear time trend and ignoring pre incentive regulation period information, we estimate an annual TFP growth rate of 1.83% in the Austrian gas distribution sector in the period 2002–2013. Since projected economy wide TFP growth is close to zero and input price growth rates are essentially equal, this would give rise to an optimal X-gen of more than 1% for the next regulatory period. This would however (1) ignore the development of technological opportunities in the sector and (2) mix up the one-off regulatory decision to reduce *granted* costs by approximately 8% (which indeed had an impact on *actual* costs) in 2008 with permanent productivity growth.

When we include a quadratic time trend in addition to the linear term, we estimate a significant *concave* relation between total costs and time. As we argue in more detail below, this polynomial specification of second order of the time trend is more adequate in mapping total costs. We find that high productivity growth rates in the early 2000s peter out in the last years of the sample and become statistically indistinguishable from zero for the period 2008–2013. This specification implies an optimal X-gen of zero.

Including an "incentive-regulation-dummy" (= 1 from 2008 on, zero else) instead of the quadratic time trend has the same effect of making our estimated TFP growth rate statistically indistinguishable from zero and implying a value of X-gen of zero, however, the interpretation differs. The interpretation of results using the polynomic specification of the time trend implies high technological opportunities in the early 2000s, and fading away of these technological opportunities in the course of time. Given the sunk cost nature of investments in the industry, this appears plausible. Grid investments (CAPEX), once undertaken, cannot be reversed, and ex post (after investments have been made) technological progress can only be achieved by reducing operating costs (OPEX). Since OPEX make up only around 65% of total costs (35% CAPEX), ex post technological opportunities are constrained. The interpretation of results using the "incentive-regulation-dummy" implies that technological opportunities have never (i.e. in the estimation sample) been so large after all, and any X-inefficiency and/or cost savings due to technological progress were passed through by the Austrian regulatory authority when entering incentive regulation in 2008 by the one-off reduction in *granted* costs of approximately 8%. These cost savings are, however, *not repeatable*.

Thus, finally in a "horse race" we estimate a specification including linear and quadratic time trends *and* the "incentive-regulation-dummy". The results point to a mixture of interpretations. Technological opportunities were higher in the early years of the sample than in later years, *and* the Austrian regulatory authority mandated a substantial pass through of potential cost savings to consumers in 2008 (and subsequent years), when incentive regulation was initiated in gas distribution in Austria. We conclude that technological opportunities are exhausted (for the time being) giving rise to an optimal X-gen of zero for the foreseeable future.[6]

The paper is structured as follows. Section 2 gives a short literature review and describes the regulatory environment in Austrian gas distribution. Section 3 derives the estimation equation from cost function theory and discusses productivity measurement. Section 4 presents the data set, the main results on the cost function estimates, and a variety of robustness checks. Section 5 reports the "building blocks" of the Bernstein/Sappington formula for X-gen and calculates various plausible values for X-gen. Section 6 concludes.

2. Literature review and Austrian regulatory environment

2.1. Literature review

The empirical literature on productivity growth and/or technical change in (energy) network industries is mostly concerned with *non-parametric methods*, such as index number approaches (e.g. Malmquist index or Tornqvist index) or data envelopment analysis (DEA)[7], as large firm-level panel datasets necessary for parametric estimation are scarce. Price and Weyman-Jones (1996) apply non-parametric frontier analysis and Malmquist indices and show that productivity increased after privatization took place in the UK gas industry. Measuring productivity by a Malmquist index, Hjalmarsson and Veiderpass (1992) provide evidence for high annual productivity growth of 5% in Sweden’s electricity distribution during 1970–1986, while Førsund and Kittelsen (1998) estimate an annual growth of nearly 2% for Norway’s electricity distribution for the period 1983–1989. Hammond et al. (2002) investigate technical efficiency of firms subject to different forms of regulation in the UK gas sector by applying DEA. Firms under the basic price system are more efficient than those under the maximum price system or under the sliding scale. Arocena et al. (2002) utilize the Tornqvist index and

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[6] Of course, we cannot rule out technological breakthroughs in gas distribution in the future, which may justify positive optimal X-factors then.

[7] DEA is less data demanding as parametric estimation, thus requires only few firm observations over time.

show, among other findings, that Spain's electricity, oil and gas industries generally outperform the manufacturing sector in terms of TFP growth.

Studies that econometrically analyze productivity growth generally adopt a cost function in order to estimate cost savings over time unrelated to output or input price variation (and other control variables).[8] The advantage of a *parametric regression* is its possibility to control for confounding effects, such as control variables, fixed effects, or stochastic errors in order to determine "unbiased" productivity growth. However, the approach is "data hungry" since it requires firm-level panel data over a reasonable time period. There are only few relevant empirical studies that utilize firm-level panel data for parametric regression analysis in network industries to infer about productivity.

Rossi (2001) estimates a production function for Argentina's gas distribution sector for the period 1994–1997 and arrive at an average productivity growth of 2.8%, which can be decomposed into technical change of 2.4% and technical efficiency (catch-up) of 0.4%. Casarin (2014) also focuses on the Argentinian gas distribution industry for the period 1992–2001. He calculates negative (!) TFP growth from the estimates of a variable translog cost function based on both time-trend estimates and an index model[9] at the magnitudes of -0.19% and -0.83%, respectively. However, his findings show that pure technical change was positive, yet bad performance from capacity utilization led to a negative total TFP growth. Martínez-Budría et al. (2003) focus on Spain's electricity distribution between 1985 and 1996 and estimate an average productivity growth from a quadratic cost function of 5.3%, of which 2.4% attain to technical change and 2.9% to scale economies. In summary, the relevant studies that rely on parametric productivity estimation yield a wide array of results.

2.2. Austrian gas distribution sector and regulatory environment

Before the introduction of incentive regulation in 2008, the Austrian gas distribution sector was regulated on a cost+ basis. In 2008, an incentive regulatory regime was introduced in order to induce a more efficient behavior of the regulated natural monopoly firms, as if they operated in a competitive environment. Under competition, firms are price takers and thus pass on any cost savings from productivity growth and/or input price reductions directly to end-users via price adjustments. Hence, the *general X-factor (X-gen)* represents a price cap that makes sure that

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[8] Alternatively, it is possible to employ a production function, which represents the dual to a cost function, to measure productivity growth as the increase in output unrelated to changes in inputs. Cost functions bear the advantage over production functions that they allow for the inclusion of multiple outputs.

[9] The index model is based on Baltagi and Griffin (1988).

firms reduce their final prices (see Bernstein and Sappington, 1999).[10] Since February 2008, all 20 regulated gas distribution firms are subject to a general X-factor ("X-Gen") of 1.95% annually (see E-Control, 2008 and 2013), implying that granted costs are reduced by this percentage each year.[11] Firms are residual claimants on any additional cost savings over the regulatory period giving them an incentive to increase efficiency. Moreover, Austria's regulatory system exhibits other important features: regulation of total costs (TOTEX); regulatory period of five years[12]; elevation of granted costs by a "Network Input Price Index"[13]; benchmarking of all the 20 gas distribution companies to calculate individual efficiency factors ("X-Ind") with the aim to arrive at 100% efficiency within 10 years.

Since X-gen represents the crucial element in price cap regulation, its magnitude set by the regulatory authority is of utmost importance. If set too high, the financial viability of the regulated firms is in danger in the long run. If set too low, regulated firms achieve excessive rents while consumers suffer from high prices through exploitation of market power.[14] However, regulatory authorities often lack reliable firm-level panel data over long-enough time spans in order to derive "optimal" values for X-gen. Hence, its current value of 1.95% per year may have been set ad-hoc and, thus, is likely to depart from an optimal value as suggested by economic theory. It is therefore the goal of this paper, to deduct a rigorous measure for X-gen in Austria's gas distribution.

Upon the introduction of this incentive regulatory regime, in addition to X-Gen (and X-Ind for inefficient firms away from the frontier), the Austrian regulator mandated a *one-off but permanent reduction in granted costs* (see E-Control, 2008, p.8). Specifically, for the cost basis of 2008 the CAPEX of the year 2006 and the OPEX of the year 2005, reduced by 4.5%, were used. This cost basis of 2006 was additionally reduced by 3.8% to arrive at the cost basis 2007. Including the X-Gen of 1.95%, this amounted to a reduction in granted costs of approximately 8% for the year 2008 compared to the previous year.[15]

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[10] We refer to Section 5 where we provide a formal derivation of X-gen from the relevant literature.

[11] This holds for "100%-efficient" firms as determined in the benchmarking. "Inefficient" firms must in addition catch up and become "efficient" over a time period of 10 years. This is achieved by applying the so-called "X-Ind", i.e. an individual efficiency factor which depends on the efficiency score attained at the benchmarking.

[12] That is, the first regulatory period was February 2008 until December 2012, and the second regulatory period started in January 2013 and lasts until December 2017.

[13] In German, Netzbetreiberpreisindex (NPI) (E-Control, 2013, p.20).

[14] See Bernstein and Sappington (1999, 2000) for more details on this issue.

[15] Of course, input price inflation is granted via the *Netzbetreiberpreisindex (NPI)*. Thus, E-Control follows a "NPI-X"-regulation.

3. Cost functions and productivity growth

The starting point of our productivity analysis is a multi-output logarithmic cost function, where total costs (TOTEX, *C*) are explained by *n* input prices (*w*), *m* outputs (*Y*) and a time trend (*T*):

$$\ln C = f(\ln Y_1, \dots, \ln Y_n, \ln w_1, \dots, \ln w_m, T) \tag{1}$$

We apply a second order Taylor approximation of the true unknown cost function (see Berndt, 1991, chap. 9), which can be formulated as (see Christensen and Green, 1973; Martínez-Budría et al., 2003):

$$\ln C_{it} = \sum_{k=1}^{m} \alpha_k \ln Y_{k_{it}} + \sum_{i=1}^{m} \beta_i \ln w_{i_{it}} + 0.5 \sum_{k=1}^{n} \sum_{l=1}^{n} \delta_{ij} \ln Y_{k_{it}} \ln Y_{l_{it}} + 0.5 \sum_{i=1}^{m} \sum_{j=1}^{m} \gamma_{ij} \ln w_{i_{it}} \ln w_{j_{it}} + \sum_{k=1}^{n} \sum_{i=1}^{m} \rho_{ki} \ln Y_{k_{it}} \ln w_{i_{it}} + \mu_T T_{it} + \mu_{TT} {T_{it}}^2 + \upsilon_i + \varepsilon_{it} \tag{2}$$

where *i* and *t* denote firms and years respectively. Firm-fixed-effects (υ_i) capture time invariant firm-specific cost effects.[16] ε is the error term.

Unfortunately, our data are not well suited for calculating input prices that vary across firms and time. Labor input prices (*Pl*), defined as labor expenses divided by full time equivalent employees, suffer from the problem of outsourcing. Some companies partially or completely outsourced their employees. Thus, at least for those companies that completely outsourced their employees, it was not possible to calculate the labor input price.[17] The weighted average costs of capital (WACCs) –artificial capital prices set by the regulator –are almost equal across companies and do not vary a lot across time. Hence, fixed effects estimations take up most of the low variability. As an alternative proxy for the price of capital we divide capital expenditures (CAPES) by the regulatory asset base (RAB). However, given that our input price measures contain quite some potential problems, we do not include them in our main specifications (but only in the robustness regressions). We are confident that – since the labor price and WACC do not vary across time a lot – firm-fixed-effects capture many input price related effects on costs. The translog specification of our cost function without input prices is as follows:

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[16] That is, we include an individual constant for each firm in order to address firm-specific characteristics that do not vary much with time. Examples would be a firm's quality of management, geographic area, the topography of the service region, regionally varying political influence, etc.

[17] To check for robustness, we calculate the price of labor for those firms, where the data on labor expenses and the number of employees was available.

$$\ln C_{it} = \alpha_0 + \sum_{k=1}^{n} \alpha_k \ln Y_{k_{it}} + 0.5 \sum_{k=1}^{n} \sum_{l=1}^{n} \delta_{ij} \ln Y_{k_{it}} \ln Y_{l_{it}} + \mu_T T_{it} + \mu_{TT} {T_{it}}^2 + \upsilon_i + \varepsilon_{it} \tag{3}$$

We introduce symmetry for the δ-parameters ($\delta_{ij} = \delta_{ji}$).

Productivity growth is composed of technological change (TC) – cost shifts over time – and returns to scale (RTS) – the sum of the partial output productivities (e.g. Berndt, 1991, chap. 9; Caves et al., 1981; Martinez-Budria et al., 2011; Triebs et al., 2016):

$$\Delta TFP = \frac{TC}{RTS} = -\frac{\partial \ln C}{\partial T} * \frac{1}{\sum_{j=1}^{n} \partial \ln C / \partial Y_j} \tag{4}$$

RTS are increasing, constant or decreasing if the last term in equation (4) is smaller than one, equal to one or greater than one, respectively. Constant returns to scale would imply that TFP growth is equivalent to technological progress: $\Delta TFP = -\frac{\partial \ln C}{\partial T}$.

Due to data constraints (firm level panel data on specific segments), many studies cannot parametrically estimate TFP-growth (or technological change) and instead use so called index number approaches (e.g. Malmqvist-Index or Törnqvist-Index). The advantages of our parametric approach are on the one hand that we can derive the cost function from economic principles, e.g. decomposition of TFP growth in TC and RTS, and on the other hand that we can control for additional cost determinants, such as unobserved heterogeneity (firm fixed effects, υ_i), and stochastic errors (ε_{it}).

4. Data, main results and robustness

A key feature of our study is the availability of reliable panel data on essentially all Austrian gas distribution companies subject to incentive regulation. Moreover, the sample period 2002–2013 covers six years before and six years after the introduction of incentive regulation on February 1, 2008. This unique dataset allows for the empirical estimation of a cost function in order to obtain TFP growth estimates. Eventually, we utilize average annual TFP growth estimates as a predictor for TFP growth in the forthcoming regulatory period, which can be utilized to calculate the optimal value of X-gen based on the Bernstein–Sappington formula.

4.1. Data

We utilize data about costs, outputs, and inputs of 20 regulated gas distribution companies in Austria for the 12-year period 2002–2013. These data originate from a database developed in the course of a study on behalf of the Austrian Association of Gas and Heating Companies, which was gratefully provided for further academic research under the condition that individual data points about firms are not made publicly available. The database collects information from a survey of all 20 gas distribution firms that are subject to incentive regulation in Austria. This survey closely follows the data collection surveys of the Austrian regulatory authority in order to calculate *granted* costs from *real* costs and actual data on output characteristics related to the gas distribution activities.

We had to drop data on one relatively small company due to missing information, so that we perform the analysis on 19 regulated Austrian gas distribution companies, essentially covering the population of regulated gas distribution firms in Austria. Some data points are missing since some companies could not research long ago data points. This leaves us with an unbalanced panel of 205 observations. Due to data confidentiality we can only report means and standard deviations but no single observations (e.g. including minima or maxima) of specific companies.

The relevant literature is inconclusive regarding the optimal choice of output variables for the estimation of a multi-output cost function of utilities. Various measures are employed. Farsi et al. (2007) investigate 26 gas distribution companies in Switzerland and utilize delivered gas in MWh as their output measure (besides load factor, number of terminal blocks, customer density, and area size, which control for firm characteristics). Rossi (2001) analyses eight Argentinian gas distribution companies and employs the number of customers (which is similar to metering points, MP) as his primary output variable and network length (KM), distribution area, share of residential to total sales, and maximum load as “environmental variables”. Neuberg (1977) discusses different cost drivers in *electricity distribution*, which can also be related to *gas distribution*, namely the number of customers, distributed volumes (MWh), length of lines (KM), and distribution area. Burns and Weyman-Jones (1996) employ several outputs in electricity distribution: installed capacity (MW), MP, demand structure (type of customers, dispersion of customers), surface area, KM, MWh, transformer capacity. Besides, Triebs et al. (2016) utilize MWh and MW and Arocena et al. (2012) use MWh and MP as outputs for electricity distribution utilities.

Given our data availability and the suggestions from the literature, we apply three output measures in our main specifications, namely the length of distribution lines (KM), the number of metering points of households and small businesses (MP), and capacity of large businesses and industry (GW). The Austrian regulator also uses the same three outputs in its benchmarking (E-Control, 2008, p. 47). Also, according to industry conversations, these are the most plausible output related cost drivers, because these variables are under the immediate control of the firms, whereas the distributed volumes are determined by demand. However, to check for robustness, we additionally include distributed volumes (GWh) and run regressions for various output combinations.

Table 1: Descriptive Statistics

Variable		**Obs.**	**Mean**	**Std. Dev.**
TOTEX	Total expenditures related to distribution activities (tEUR)	205	31,630	48,758
KM	Network length weighted by grid layer and pipe dimension (KM)	205	3,375	5,544
MP	Metering points of households and small businesses (#)	205	75,166	163,864
GW	Installed capacity of industry and large businesses (GW)	205	927	1,336
GWh	Total distributed gas (GWh)	205	5,229	7,466
Pc	Price of capital (%)	205	14.24	4.41
Pl	Price of labor (tEUR)	183	70.98	21.43

*Notes: "Obs." are firm-year observations. "Std." is standard deviation. TOTEX are the sum of OPEX (material expenses, personal expenses, other expenses, cost allocations, Adjustment – internally produced and capitalized assets and higher upstream network costs) and CAPEX (financing costs = WACC * Regulatory Asset Base). Regulatory Asset Base is book value (immaterial and tangible fixed assets), adjustment of book values to 40 years (according to E-Control's calculations), subsidies for building costs, and adjustments of subsidies for building costs to 40 years (according to E-Control's calculations).*

As presented in Table 1, we calculate total costs as total expenditures (operating and capital expenditures) that are directly related to the *distribution operations of the firms*. As for the outputs, we follow the Austrian regulatory agency's output specification (E-Control, 2008, p. 38). The network length is weighted by different gas pressure levels and pipe dimensions to reflect their different costs per KM. [18] Metering points (MP) refer to residential and small business customers, whereas installed capacity refer to large business and industry customers.[19] The average sample firm has total costs (TOTEX) of 31.6 million Euro and operates on average 3,375 km weighted gas grid length (KM), 75,166 metering points of households and small

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[18] This is actually a weighted average grid length, where weights are chosen to reflect differential costs/km, which in turn depend on the grid layer (GL) (there are three GL; GL1: transmission grid; GL2: >6 bar pressure; GL3: <6 bar pressure) and on the pipe dimension (PD) (<300mm; >300&<600; and >600mm). The exact weighting factors are as follows: GL1 <300mm: 1.94, GL1 >300&<600: 3.17, GL1 >600: 4.22, GL2 <300mm: 1.00, GL2 >300&<600: 1.36, GL2 >600: 1.36 (E-Control, 2008, p. 38).

[19] However, when we include these outputs in total KM, total MP, and total GW, the empirical results regarding TFP growth stay fairly robust.

businesses (MP), and 927 gigawatts (GW) of installed capacity of large businesses and industry. Standard deviations are very large relative to mean values pointing to substantial heterogeneity across firms. This underlines the importance of including firm-fixed effects to account for unobserved firm level heterogeneity. Table 1 also presents additional variables (distributed volumes, input prices), which are employed in alternative specifications to check for robustness estimations (see Section 4.3.).

4.2. Main results

We begin by specifying a Cobb-Douglas-style cost function with three outputs, that we extend by a time trend and firm fixed-effects:

$$\ln C_{it} = \alpha_0 + \alpha_1 \ln KM_{it} + \alpha_2 \ln MP_{it} + \alpha_3 \ln GW_{it} + \mu_T T + v_i + \varepsilon_{it}. \tag{5}$$

KM indicates weighted grid length in km, *MP* the number of metering points of households and small businesses, and GW the installed capacity of industry and large businesses in gigawatt. T represents the time trend, which takes a value of one in 2002 and runs up to twelve in 2013. The firm fixed-effects (v_i) capture time-invariant unobservable heterogeneity. In what follows, we will expand equation (5) by introducing a dummy measuring the period of incentive regulation ($Incentive$) and a squared time trend. Our regressions include robust (heteroscedasticity consistent), firm-clustered standard errors.

Table 2 provides regression results of the main specifications (1)–(4), which represent variations of the basic specification as presented in Equation (5). Specification (1) includes only a linear time trend, which attains a negative but statistically insignificant coefficient of $\hat{\mu}_T = -0.012$. This would give rise to a constant (but insignificant) TC estimate of 1.2% per year. The estimates suggest increasing RTS ($\hat{\alpha}_1 + \hat{\alpha}_2 + \hat{\alpha}_3 = 0.66$), meaning that if all outputs are increased by 10%, costs disproportionately increase by only 6.6%. This seems plausible for the distribution network representing the natural monopoly part of the gas industry. However, RTS are statistically not distinguishable from unity (i.e. constant returns to scale). In combination, this results in a constant and statistically significant annual TFP growth rate of 1.83%. As argued above, however, this would (1) ignore the development of technological opportunities in the sector and (2) mix up the one-off regulatory decision to reduce granted costs by approximately 8% in 2008 with permanent TFP growth.

Table 2. Regression results of main specifications

Variable	Coefficient	(1)	(2)	(3)	(4)
$ln\,KM$	α_1	0.531***	0.535***	0.616***	0.609***
		(3.25)	(3.27)	(3.87)	(3.87)
$ln\,MP$	α_2	-0.009	-0.004	0.001	0.004
		(-0.08)	(-0.04)	(0.01)	(0.04)
$ln\,GW$	α_3	0.137**	0.127**	0.125**	0.117**
		(2.76)	(2.80)	(2.40)	(2.47)
T	μ_T	-0.012	-0.002	-0.036*	-0.024
		(-1.44)	(-0.22)	(-1.97)	(-1.03)
T^2	μ_{TT}			0.002	0.001
				(1.25)	(1.03)
$Incentive$	μ_{Inc}		-0.075		-0.069
			(-1.63)		(-1.40)
Firm FE		yes	yes	yes	yes
Obs.		205	205	205	205
Overall R^2		0.943	0.949	0.949	0.950
Ø RTS		0.66	0.66	0.74	0.73
Ø TC 2002–2013 (%)		1.21	0.20	1.45*	0.50
Ø TC 2008–2013 (%)		1.21	0.20	0.44	-0.38
Ø ΔTFP 2002–2013 (%)		1.83**	0.31	1.95***	0.68
Ø ΔTFP 2008–2013 (%)		1.83**	0.31	0.59	-0.53

*Notes: Dependent variable is ln(TOTEX). T is the time trend. Incentive is a dummy for the incentive regulation period 2008–2013. Robust clustered (by firm) t-values in brackets. ***, **, * represent significance at the 99%, 95% and 90% levels, respectively. We apply a linear test if RTS=1. We apply a non-linear test for ΔTFP=0 based on the Stata command "testnl".*

For these reasons, specification (2) shows the effect of introducing the dummy variable for the incentive regulation period "*Incentive*" (i.e. zero until 2007, one from 2008 on). Its estimated coefficient is $\hat{\mu}_{Inc} = -0.075$ (i.e. decline in *actual* costs of 7.5%) capturing fairly well the imposed ceteris paribus one-off but permanent reduction in *granted* costs in 2008. The inclusion of this dummy renders the coefficient of the time trend and therefore TC statistically and economically indistinguishable from zero. It should be stressed that we use *actual* (and not officially granted) cost data. Thus, our results also imply that regulatory interventions (i.e. significantly reducing *granted* costs) have an effect on *real actual* costs of firms. Together with RTS of 0.66 we estimate a constant annual TFP growth of 0.31%, statistically not distinguishable from zero.

When we include a *quadratic time trend* instead of the *"Incentive"-dummy*, as in specification (3), we estimate a significant concave relation between total costs and time. *This captures the declining technological opportunities in the sector over time.* In this case, TFP growth calculates as:

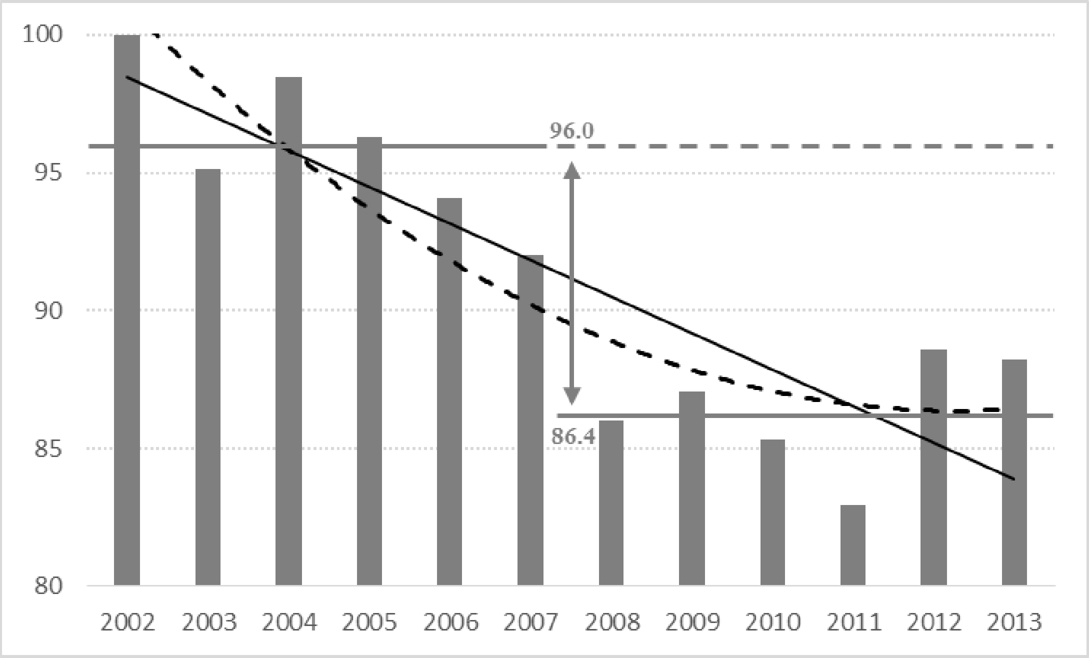
$$\Delta TFP = -(\hat{\mu}_T + 2\hat{\mu}_{TT}T)/(\hat{\alpha}_1 + \hat{\alpha}_2 + \hat{\alpha}_3), \tag{6}$$

The polynomic specification of the time trend shows high values of technical change (i.e. high technological opportunities) in the early years of the sample period, but low TC values for later years (see Figure 1). Thus, for the entire period 2002–2013, the annual rate of TC is statistically significant at 1.45%, whereas TC becomes statistically insignificant at an annual rate of 0.44% for the period 2008–2013. We estimate RTS of 0.74. This results in a statistically significant annual TFP growth rate of 1.95% for 2002–2013, yet in a statistically insignificant rate of 0.59% for the period 2008–2013. If we want to control for the limited potential for TFP growth (or TC growth) in recent years, it seems reasonable to focus on the recent sample period 2008–2013 when projecting TFP growth.

Finally in a "horse race", our *most preferred* specification (4) controls for both limited potential for productivity growth in recent years (non-linear time trend effects) and for the one-off reduction in granted costs in the year 2008 (*"Incentive"*-dummy). The linear and quadratic terms of the time trend become statistically insignificant but qualitatively retain a concave relation between costs and time. The *"Incentive"*-dummy remains negative with a coefficient value of -0.069 (-6.7%). This shows that the one-off decrease in granted costs cannot be repeatedly applied, since estimated TC (i.e. permanently annually repeated cost reductions) is essentially zero. RTS are 0.73, but statistically not different from one. This totals in an annual TFP growth of 0.68 for 2002–2013 and -0.53% for 2008–2013, both statistically indistinguishable from zero.

Figure 1 visualizes our main results by plotting estimated cost changes for the years 2002–2013. The grey bars represent changes in total costs relative to the base year 2002 (=100%), as estimated by time fixed effects. Moreover, the figure addresses the different specifications presented above: the linear time trend (continuous black line) corresponds to specification (1), the polynomic time trend of second order (dotted black line) corresponds to specification (3), the *"Incentive"*-dummy effect, as presented in specification (2), is shown by the difference in the grey lines (i.e. difference in costs before and after the introduction of incentive regulation in 2008). As we can observe, there is indeed a strong cost effect in the year 2008 (and thereafter) as also visualized by the bars indicating individual year effects. The quadratic relation much better captures the evolution of total costs over time than the linear time trend, and clearly there is a strong average difference in costs between the period 2002–2007 and 2008–2013.

Figure 1. Changes in costs (%, base = 2002)



The bars represent time fixed effects (base = 2002). The solid black line represents a linear time trend, the dashed black line corresponds to a second order polynomic time trend. The grey lines represent average costs before and after the introduction of incentive regulation in 2008, their difference relates to the "Incentive"-dummy capturing the one-off cost cut.

The interpretation of results using the quadratic specification (3) implies high technological opportunities in the early 2000s, however, these technological opportunities (TC) faded away in the course of time. Given the sunk cost nature of investments in the industry, this appears plausible. Grid investments (CAPEX), once undertaken, cannot be reversed, and ex post (after investments have been made) technological progress can only be achieved by reducing operating costs (OPEX). Since OPEX make up only around 65% of total costs (35% CAPEX), ex post technological opportunities are constrained. The interpretation of results using specification (4) implies that technological opportunities have never (i.e. in the estimation sample) been so large after all, and any X-inefficiency and/or cost savings due to technological progress have been passed through by the Austrian regulatory authority when entering incentive regulation in 2008. These cost savings are, however, not repeatable. In our opinion, the results point to a mixture of interpretations. Technological opportunities were higher in the early years of the sample (before incentive regulation was implemented) than in later years, *and* the Austrian regulatory authority managed to fully pass through potential cost savings to consumers in the year 2008 (and subsequent years), when incentive regulation was initiated in Austria's gas distribution sector. Altogether, specification (4) suggests that annual TFP growth is close to zero (0.68 for 2002–2013 and -0.53% for 2008–2013) and statistically insignificant throughout.

4.3. Robustness

This section presents alternative regression estimates to provide evidence of robustness of our main results. First, we change our outputs to total KM (instead of weighted KM), total MP (instead of MP for households and small businesses), and total GW (instead of GW for large businesses and industry). Second, we run regressions for different output combinations and include an additional output measure (GWh). Third, we control for the prices of labor and capital. Fourth, we allow for interaction terms in a translog specification.

Alternative output measures

Table 3 presents the main specifications (as in Table 2) with alternative output measures, namely total KM, total MP, and total GW. Evidently, our conclusions regarding the estimated annual TFP growth stay robust. The inclusion of the *"Incentive"*-dummy in specification (AO2) results in an economically and statistically insignificant estimate of constant TC of 0.3%, which in turn renders TFP growth statistically insignificant at 0.5% annually. The coefficient estimate of "*Incentive*", although insignificant, points to a one-off cut in actual costs of 7.2%. When we control for limited technological opportunities in later sample years by a polynomic specification of the time trend (AO3), TFP growth is statistically significant at an annual rate of 2.22% for the entire period 2002–2013, however becomes statistically and economically insignificant at 0.49% for the period 2008–2013. Once controlling for both, the one-off cost cut (*"Incentive"*, 6.3%) and limited potential for technical change (T and T^2), TC and ΔTFP become statistically insignificant for the whole sample period. For the second period 2008–2013, the estimated TFP growth rate becomes even negative but statistically insignificant at -0.55%.

Table 3. Robustness - alternative output measures

Variable	Coef.	AO1	AO2	AO3	AO4
$ln\, total\, KM$	α_1	0.472***	0.458***	0.595***	0.570***
		(3.55)	(3.41)	(4.66)	(4.31)
$ln\, total\, MP$	α_2	0.021	0.036	0.037	0.048
		(0.24)	(0.37)	(0.51)	(0.62)
$ln\, total\, GW$	α_3	0.129**	0.120**	0.111*	0.105*
		(2.46)	(2.45)	(1.91)	(1.93)
T	μ_T	-0.013	-0.003	-0.044**	-0.033
		(-1.69)	(-0.36)	(-2.12)	(-1.25)
T^2	μ_{TT}			0.002	0.002
				(1.36)	(1.16)
$Incentive$	μ_{Inc}		-0.072		-0.063
			(-1.54)		(-1.24)
Firm FE		yes	yes	yes	yes
Obs.		205	205	205	205
R2 within		0.134	0.155	0.158	0.173
R2 between		0.931	0.933	0.93	0.932
R2 overall		0.915	0.917	0.914	0.916
Ø RTS		0.62*	0.61*	0.74*	0.72*
Ø TC 2002–2013 (%)		1.28	0.30	1.65**	0.76
Ø TC 2008–2013 (%)		1.28	0.30	0.36	-0.40
Ø ΔTFP 2002–2013 (%)		2.10***	0.50	2.22***	1.05
Ø ΔTFP 2008–2013 (%)		2.10***	0.50	0.49	-0.55

*Notes: Dependent variable is ln(TOTEX). T is the time trend. Incentive is a dummy for the incentive regulation period 2008–2013. Robust clustered (by firm) t-values in brackets. ***, **, * represent significance at the 99%, 95% and 90% levels, respectively. We apply a linear test if RTS=1. We apply a non-linear test for ΔTFP=0 based on the Stata command "testnl".*

Different output combinations

In Table 4 we present different output combinations, to check for the sensitivity of our results to the inclusion of different outputs. In specifications (OC1)–(OC6) we include various combinations of any two outputs with and without including the *"Incentive"*-dummy. In specifications (OC7) and (OC8) we add distributed volumes (GWh) to the other three output variables, and in specifications (OC9) and (OC10) we reduce our outputs to KM and KWh only. We get a consistent picture in so far as *once we include the "Incentive"-dummy to capture the one-off cost cut, estimated annual TFP growth*[20] *becomes statistically insignificant throughout and enters negative in many cases.* Besides, we find evidence for one-off reductions in actual costs in 2008 (*"Incentive"*-dummy) in the magnitude of 7.4%–8.7%, which is consistent with previous findings.

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[20] As the time trend enters only linearly, TFP growth it is a linear projection and we do not have to distinguish between sample periods.

Input prices

As mentioned above, our data are not well suited for calculating input prices. The price of capital (Pc) would be best reflected by the Weighted Average Cost of Capital (WACC) – an artificial capital rate for regulated firms, which is exogenously set by the regulatory authority. However, the WACCs hardly vary across firms in a given year and the variation across years is low as well. For this fact, our fixed effects absorb most of WACCs' variation. Alternatively, we proxy for the price of capital by dividing capital expenditures by the regulatory asset base ($Pl = CAPEX/RAB$). We are well aware of the problems using such a measure for the price of capital (such as possible endogeneity with total costs and possible inconsistencies across firms due to different investment strategies, etc.), and use it only as a robustness check. With respect to the price of labor (Pl), calculated as labor expenses divided by the number of employees ($Pl = labor\ expenses/employees$), we face the caveat that some firms partly, other firms entirely outsourced their staff. At least for the latter it is not possible to calculate a labor price. Hence, two firms drop from the sample, so we end up with a reduced number of observations (183 compared to 205 observations). Table 1 summarizes both variables.

To check for sensitivity, we estimate our main specifications with input prices, as presented in Table 5. Specifications (IP1)–(IP4) include both the price of capital and the price of labor, which reduces our number of observations to 183, whereas specifications (IP5)–(IP8) include only the price of capital, to keep the full range of sample observations.

Again, we find that the inclusion of "*Incentive*" (IP2) renders the TC and ΔTFP statistically insignificant. Nonetheless, the coefficient of "*Incentive*" indicates a much smaller (2.9%) cut in actual costs in 2008. It is possible that this finding is somewhat biased from firms that partly outsourced their staff. A polynomic specification of second order of the time trend (IP3) gives a statistically insignificant TFP growth rate for the later sample period 2008–2013 of 0.23%. In specification (IP4) the inclusion of both "*Incentive*" and a polynomic time trend (T, T^2) gives an estimated, statistically insignificant, annual TFP growth rate of 0.58% for the period 2008–2013.

Table 4. Robustness - different output combinations

Variable	Coef.	OC1	OC2	OC3	OC4	OC5	OC6	OC7	OC8	OC9	OC10
$ln\,KM$	α_1	0.523**	0.531**			0.638**	0.634**	0.409*	0.407*	0.276	0.272
		(2.74)	(2.76)			(2.34)	(2.35)	(1.95)	(1.93)	(1.05)	(1.02)
$ln\,MP$	α_2	0.137**	0.126**	0.155**	0.145**			0.027	0.009		
		(2.70)	(2.73)	(2.70)	(2.64)			(0.48)	(0.14)		
$ln\,GW$	α_3			0.169	0.175	0.029	0.031	-0.189	-0.196		
				(1.15)	(1.18)	(0.16)	(0.17)	(-1.20)	(-1.25)		
$ln\,GWh$	α_4							0.261**	0.278**	0.251***	0.252***
								(2.70)	(2.69)	(5.20)	(5.54)
T	μ_T	-0.012	-0.002	-0.006	0.004	-0.009	0.002	-0.005	0.007	-0.005	0.007
		(-1.44)	(-0.22)	(-0.92)	(0.45)	(-1.17)	(0.21)	(-0.58)	(0.57)	(-0.66)	(0.67)
$Incentive$	μ_{Inc}		-0.075		-0.074		-0.086		-0.086*		-0.087*
			(-1.64)		(-1.63)		(-1.71)		(-1.73)		(-1.80)
Firm FE		yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Obs.		205	205	205	205	205	205	205	205	205	205
R2 within		0.128	0.150	0.096	0.118	0.079	0.109	0.183	0.212	0.172	0.202
R2 between		0.959	0.959	0.960	0.960	0.956	0.956	0.842	0.826	0.874	0.873
R2 overall		0.949	0.950	0.947	0.947	0.947	0.948	0.835	0.821	0.870	0.869
Ø ΔTFP (%)		1.83**	0.31	1.95	-1.14	1.41*	-0.29	1.03	-1.34	0.944	-1.24

*Notes: Dependent variable is ln(TOTEX). T is the time trend. Incentive is a dummy for the incentive regulation period 2008–2013. Robust clustered (by firm) t-values in brackets. ***, **, * represent significance at the 99%, 95% and 90% levels, respectively. We apply a non-linear test for ΔTFP=0 based on the Stata command "testnl".*

Table 5. Robustness - input prices

Variable	Coef.	IP1	IP2	IP3	IP4	IP5	IP6	IP7	IP8
$ln\,KM$	α_1	0.432**	0.437**	0.552**	0.551**	0.490**	0.491**	0.564***	0.550**
		(2.13)	(2.17)	(2.60)	(2.60)	(2.70)	(2.70)	(2.94)	(2.86)
$ln\,MP$	α_2	-0.008	-0.014	0.002	-0.002	0.031	0.038	0.032	0.039
		(-0.03)	(-0.05)	(0.01)	(-0.01)	(0.30)	(0.37)	(0.34)	(0.40)
$ln\,GW$	α_3	0.073	0.070	0.062	0.060	0.117**	0.105**	0.111**	0.101**
		(1.49)	(1.43)	(1.39)	(1.35)	(2.36)	(2.37)	(2.17)	(2.21)
$ln\ Pc$	β_1	0.096	0.100	0.069	0.072	0.108*	0.116*	0.092	0.102
		(1.51)	(1.59)	(1.18)	(1.23)	(1.75)	(1.96)	(1.53)	(1.72)
$ln\ Pl$	β_2	0.119**	0.116**	0.123**	0.122**				
		(2.53)	(2.55)	(2.52)	(2.55)				
T	μ_T	-0.008	-0.004	-0.041*	-0.037	-0.010	0.001	-0.029	-0.015
		(-0.87)	(-0.43)	(-1.88)	(-1.66)	(-1.03)	(0.10)	(-1.34)	(-0.58)
T^2	μ_{TT}			0.002	0.002			0.001	0.001
				(1.65)	(1.59)			(0.94)	(0.70)
$Incentive$	μ_{Inc}		-0.029		-0.018		-0.080*		-0.074
			(-1.34)		(-0.86)		(-1.75)		(-1.52)
Firm FE		yes	yes	yes	yes	yes	yes	yes	yes
Obs.		183	183	183	183	205	205	205	205
R2 within		0.157	0.162	0.192	0.194	0.147	0.172	0.157	0.178
R2 between		0.953	0.952	0.955	0.954	0.956	0.956	0.957	0.957
R2 overall		0.941	0.94	0.944	0.944	0.947	0.947	0.948	0.948
Ø RTS		0.50	0.49	0.62	0.61	0.64	0.63	0.71	0.69
Ø TC 2002–2013 (%)		0.83	0.43	1.19	0.93	0.98	0.10	1.21	0.15
Ø TC 2008–2013 (%)		0.83	0.43	-0.14	-0.35	0.98	0.10	0.40	-0.49
Ø ΔTFP 2002–2013 (%)		1.66	0.88	1.93**	1.53	1.54	-0.16	1.71**	0.22
Ø ΔTFP 2008–2013 (%)		1.66	0.88	0.23	0.58	1.54	-0.16	0.59	-0.71

*Notes: Dependent variable is ln(TOTEX). T is the time trend. Incentive is a dummy for the incentive regulation period 2008–2013. Robust clustered (by firm) t-values in brackets. ***, **, * represent significance at the 99%, 95% and 90% levels, respectively. We apply a linear test if RTS=1. We apply a non-linear test for ΔTFP=0 based on the Stata command "testnl".*

In the specifications (IP5)–(IP8) we only include *Pc* (but omit the *Pl*). Again, our results stay in line with our main conclusions. Controlling for "*Incentive*" (IP6) renders both TC and ΔTFP economically and statistically insignificant (0.10% and -0.16%, respectively). In the polynomic specification of the time trend (IP7), we get a statistically significant TFP estimate of 1.17% for the whole sample period 2002–2013, whereas low limited opportunities in later years result in a positive but statistically insignificant TFP growth rate of 0.59% for the later period 2008–2013. Finally, specification (IP8) corroborates our main findings that allowing for a non-linear behavior of the time trend *and* controlling for the one-off cost cut gives a negative but insignificant prediction of annual TFP growth of -0.71% for 2008–2013.

Translog specifications

Table 6 presents estimates from translog specifications that include output interaction terms. In the translog specification, RTS depend on firms' output levels, which are thus evaluated at their sample means ($\bar{Y}_1$, $\bar{Y}_2$, $\bar{Y}_3$): $RTS = \sum_{j=1}^{n} \partial \ln C / \partial Y_j = \hat{\alpha}_1 + \hat{\alpha}_{11}\bar{Y}_1 + \hat{\alpha}_{12}\bar{Y}_2 + \hat{\alpha}_{13}\bar{Y}_3 + \hat{\alpha}_2 + \hat{\alpha}_{22}\bar{Y}_2 + \hat{\alpha}_{12}\bar{Y}_1 + \hat{\alpha}_{23}\bar{Y}_3 + \hat{\alpha}_3 + \hat{\alpha}_{33}\bar{Y}_3 + \hat{\alpha}_{13}\bar{Y}_1 + \hat{\alpha}_{23}\bar{Y}_2$. Hence, RTS and the resulting TFP growth rates have to be interpreted with caution as (1) our sample is skewed and (2) results are not directly comparable. Moreover, the estimates may suffer from decreased estimation efficiency (lower degrees of freedom) and multi-collinearity issues given the many parameters to be estimated.[21] Despite these econometric issues, the results of the translog specifications prove the robustness of the above findings with respect to ΔTFP.

Only including a linear time trend (TL1) would imply a statistically insignificant and constant TC of 1.14% annually ($\hat{\mu}_T = -0.0114$). Together with RTS for the mean sized firm of 0.37 (statistically different from unity), we estimate a statistically significant annual TFP growth rate of 3.11%. Again, this would mix up TFP growth with the one-off reduction in granted costs in 2008 (which cannot be repeated over time) and decreasing technological opportunities in the industry in recent years.

The inclusion of the "*Incentive*"-dummy (TL2) renders TC statistically and economically insignificant (0.23%), pointing to a one-off cut in real costs of 7% ($\hat{\mu}_{Inc} = -0.069$). Together

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[21] The exclusion of firm fixed-effects results in many significant coefficient estimates regarding the outputs and their interaction terms. Nevertheless, the interpretation of ΔTFP remains robust and stays statistically insignificant for the period 2008–2013 based on specifications (6)–(8).

with statistically significant RTS evaluated at the sample mean of 0.38, (constant) TFP growth is statistically insignificant at 0.61%.

Table 6. Robustness – translog specifications

Variable	Coef.	TL1	TL2	TL3	TL4
$ln\,KM$	α_1	-1.538	-1.405	-1.716	-1.550
		(-1.18)	(-1.11)	(-1.19)	(-1.08)
$ln\,MP$	α_2	-0.566	-0.508	-0.192	-0.220
		(-0.32)	(-0.31)	(-0.08)	(-0.10)
$ln\,GW$	α_3	1.062*	1.025*	0.900	0.901
		(1.94)	(2.06)	(1.10)	(1.17)
$0.5\,ln\,KM^2$	α_{11}	-0.656	-0.677	-0.621	-0.648
		(-1.15)	(-1.22)	(-1.04)	(-1.11)
$0.5\,ln\,MP^2$	α_{22}	-0.199	-0.212	-0.269	-0.266
		(-0.60)	(-0.70)	(-0.65)	(-0.68)
$0.5\,ln\,GW^2$	α_{33}	-0.026	-0.015	-0.026	-0.016
		(-0.31)	(-0.19)	(-0.31)	(-0.20)
$ln\,KM\,ln\,MP$	α_{12}	0.530	0.538	0.547	0.551
		(1.49)	(1.58)	(1.61)	(1.68)
$ln\,MP\,ln\,GW$	α_{23}	-0.247	-0.245	-0.207	-0.213
		(-1.25)	(-1.33)	(-0.78)	(-0.85)
$ln\,KM\,ln\,GW$	α_{13}	0.239	0.230	0.204	0.204
		(0.91)	(0.94)	(0.64)	(0.68)
T	μ_T	-0.011	-0.002	-0.027	-0.015
		(-1.25)	(-0.24)	(-0.98)	(-0.45)
T^2	μ_{TT}			0.001	0.001
				(0.54)	(0.40)
$Incentive$	μ_{Inc}		-0.069*		-0.066
			(-1.79)		(-1.47)
Firm-FE		yes	yes	yes	yes
Obs.		205	205	205	205
R2 within		0.184	0.202	0.189	0.205
R2 between		0.779	0.808	0.796	0.817
R2 overall		0.802	0.824	0.818	0.833
Ø RTS		(SM) 0.37*	(SM) 0.38*	(SM) 0.42	(SM) 0.42
Ø TC 2002–2013 (%)		1.14	0.23	1.32	0.42
Ø TC 2008–2013 (%)		1.14	0.23	0.68	-0.08
Ø ΔTFP 2002–2013 (%)		(SM) 3.11**	(SM) 0.61	(SM) 3.16**	(SM) 0.99
Ø ΔTFP 2008–2013 (%)		(SM) 3.11**	(SM) 0.61	(SM) 1.64	(SM) -0.19

*Notes: Dependent variable is ln(TOTEX). T is the time trend. Incentive is a dummy for the incentive regulation period 2008–2013. Robust clustered (by firm) t-values in brackets. ***, **, * represent significance at the 99%, 95% and 90% levels, respectively. We apply a linear test if RTS=1. We apply a non-linear test for ΔTFP=0 based on the Stata command "testnl". (SM) indicates that values are evaluated at "sample mean" output levels.*

In the polynomic specification of second order of the time trend (TL3), both the linear and the quadratic time trend become statistically insignificant implying that TC is indistinguishable from zero over the sample period. RTS for the mean sized firm are 0.42. This results in a statistically significant TFP growth rate of 3.16%, whereas annual TFP growth becomes statistically insignificant at annually 1.64% for the later period 2008–2013.

Finally, specification (TL4) corroborates our main findings that when we allow for a non-linear behavior of the time trend *and* control for the one-off cost cut, ΔTFP is statistically and economically insignificant, based on a TC estimate that is very close to zero between 2008 and 2013. The only coefficient that is close to statistical significance[22] is $\hat{\mu}_{Inc} = -0.066$. Thus, we estimate a significant reduction in costs after the introduction of incentive regulation in 2008 of 6.6% but no significant productivity growth at the end of the sample period.

Summarizing our robustness checks we obtain robust results that TC follows a *concave* pattern during our sample period 2002–2013. This yields a productivity growth of essentially zero from 2008 on. Moreover, we find supportive evidence that the imposed one-off but permanent cut of *granted* costs by the regulator in 2008 led to a one-off but permanent cut in *actual* costs.

5. Calculation of the general X-factor in Austria's gas distribution

The basic idea of incentive regulation is to eradicate potential X-inefficiencies of natural monopoly firms in the regulated sector compared to the competitive economy.[23] The ultimate target is therefore to induce regulated companies to pass on cost reductions from realized productivity gains and/or declines in input prices to final customers through price reductions. X-gen represents a price (or revenue) cap set by the regulatory authority in order to enforce such end-use price reductions. The "incentive" for firms subject to regulation is thus to realize cost reductions beyond X-gen, which can be attained as rents.

Bernstein and Sappington (1999) show that in a *competitive* economy (E), any changes in costs induced by changes in productivity (ΔTFP) and/or variations in input prices (Δw) directly lead to changes in prices (ΔP):[24]

$$\Delta P^E = \Delta w^E - \Delta TFP^E \tag{6}$$

Price developments in the regulated sector (R) have to be adjusted by X-gen in order to accord with the competitive economy:

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[22] The fact that we also do not get significant coefficients for the outputs nor the output interactions is most likely due to multicollinearity.

[23] See Bernstein and Sappington (1999) for a critical acclaim of X-gen.

[24] In a competitive environment, firms have no market power and are, thus, price takers.

$$\Delta P^R = \Delta P^E - X_{gen} = \Delta P^E - [(\Delta TFP^R - \Delta TFP^E) + (\Delta w^E - \Delta w^R)], \tag{7}$$

from which we get Bernstein and Sappington (1999)'s differential formula for X-gen:

$$\boldsymbol{X_{gen} = (\Delta TFP^R - \Delta TFP^E) + (\Delta w^E - \Delta w^R).} \tag{8}$$

This formula represents our *preferred method* to calculate X-gen.

However, in regulatory practice, alternative versions of the Bernstein and Sappington formula appear, mostly due to simplifying procedures and limiting data requirements. Substituting equation (6) into equation (8) yields the reduced formula:

$$X_{gen} = \Delta P^E - \Delta w^R + \Delta TFP^R, \tag{9}$$

which only requires three instead of four terms, and ΔP^E can easily be measured by the output inflation rate. Moreover, some regulatory authorities (e.g. the Austrian regulator) set the X-gen equal to the "frontier shift":

$$X_{gen} = \Delta TFP^R, \tag{10}$$

and simultaneously compensate firms by a Network Input Price Index (NPI) instead of an output price index.

To calculate X-gen, we utilize external data sources and suggestions from the related literature to create measures for ΔTFP^E, Δw^E, and Δw^R (see Table 7) and combine these data with our empirical estimates of ΔTFP^R. Based on our argumentation that we do not only have to account for the one-off but permanent cost shift in 2008, but also for limited potential for technological opportunities in the later years of our sample, we believe that *TFP growth is most adequately estimated for the second period of our sample, 2008–2013*. Moreover, it is not the past estimates that matter for setting X-gen but the projected values for the next regulatory period. Hence, recent sample years much better predict the coming regulatory period than long ago data points. In turn, X-gen is best calculated based on measures for the period 2008–2013 (after the one-off cost cut was imposed). However, to provide additional evidence, we also calculate X-gen based on values for the period 2002–2013. In case of alternating measures, we will utilize the most conservative, i.e. the one that gives the highest value of X-gen.

OECD provides yearly measures for Austria's productivity growth rate, which yields an average rate of $\boldsymbol{\Delta TFP^E = 0.07}\%$ for 2008–2013 (and $TFP^E = 0.64\%$ for 2002–2013).[25] In order to calculate the growth in input prices in the regulated gas distribution sector (Δw^R), we follow the regulatory authority (E-Control, 2013, p. 25) and calculate the (yearly change of the) Network Input Price Index (NPI), which calculates as $\Delta \mathrm{w}_t{}^R = \Delta NPI_t = 0.4 * \Delta BPI_t + 0.3 * \Delta BWI_t + 0.3 * \Delta CPI_t$, where BPI is the Building Price Index, BWI is the Index for Basic Wages, CPI is the Consumer Price Index, and t represents the respective year of obersvation.[26] For the period 2008–2013, we calculate an input price growth rate of $\boldsymbol{\Delta w^R = 2.74}\%$ ($\Delta w^R = 2.40\%$ for 2002–2013).

There is no standardized measure for growth rate of input prices in the total economy. We follow Stronzik and Wissner (2013) and utilize two input factors, labor and capital, for which we utilize the measures of the Index for Basic Wages (*BWI*) and the Deflator for Gross Fixed Capital Formation (DGFCF). We weight these measures by the Wage Ratio (*l*), which measures the share of labor income (including social expenditures by the employers) relative to the primary income of the total economy (Δw^E):[27] $\Delta \mathrm{w}_t{}^E = l * \Delta BWI_t + (1 - l) * \Delta DGFCF_t$. This yields an average annual input price growth rate for Austria's economy of $\boldsymbol{\Delta w^E = 2.55}\%$ for the period 2008–2013 ($\Delta w^E = 2.46\%$ for 2002–2013) [28]. We utilize the change in the CPI to measure Austria's output price inflation (ΔP^E): $\boldsymbol{\Delta CPI = 2.21}\%$ for the period 2008–2013 ($\Delta CPI = 2.04\%$ for 2002–2013).

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[25] http://stats.oecd.org/Index.aspx?DataSetCode=PDB_GR, September 26, 2016; Alternatively, Conference Board (https://www.conference-board.org/data/economydatabase/index.cfm?id=27762) states an average annual ΔTFP of -0.12% for 2008–2013.

[26] BPI, BWI, and CPI are obtained from Statistics Austria: https://www.statistik.at/web_en/statistics/Economy/Prices/consumer_price_index_cpi_hcpi/index.html, September 26, 2016.

[27] We gratefully acknowledge that Statistics Austria provided the data for the wage ratio and the DGFCF upon email request on August 4, 2015.

[28] Please note data for the wage rate and DGFCF are only available for the years 2008 onwards. Thus, we proxy for the years prior to 2008 by their means over 2008–2013.

Table 7. Index numbers

	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**02−13**	**08−13**
ΔTFP^E (%)	0.80	-0.30	1.30	1.50	2.10	1.90	-0.30	-1.60	1.10	0.60	0.40	0.20	**0.64**	**0.07**
Δw^R (%)	1.54	1.44	2.03	2.10	2.31	2.91	3.84	2.50	2.56	2.87	2.72	1.92	**2.40**	**2.74**
Δw^E (%)	2.45	2.24	2.11	2.31	2.58	2.45	3.14	2.99	1.87	2.08	2.90	2.36	**2.46**	**2.55**
ΔBWI (%)	2.50	2.20	2.00	2.30	2.70	2.50	3.00	3.40	1.60	2.00	3.30	2.60	2.51	2.65
ΔCPI (%)	1.76	1.36	2.06	2.37	1.46	2.12	3.23	0.56	1.76	3.30	2.43	2.00	2.04	2.21
ΔBPI (%)	0.67	0.93	2.03	1.74	2.65	3.82	4.92	3.28	3.89	3.21	2.50	1.34	2.58	3.19
ΔDGFCF (%)	2.34[a]	2.34[a]	2.34[a]	2.34[a]	2.34[a]	2.34[a]	3.40	2.08	2.42	2.23	2.09	1.81	2.34	2.34
Wage ratio (*l*)	0.68[a]	0.68[a]	0.68[a]	0.68[a]	0.68[a]	0.68[a]	0.65	0.69	0.67	0.67	0.67	0.70	0.68	0.67

Notes: [a] *mean value of 2008−2013 because data prior to 2008 were not available.* $\Delta w_t{}^R = \Delta NPI_t = 0.4 * \Delta BPI_t + 0.3 * \Delta BWI_t + 0.3 * \Delta CPI_t$. $\Delta w_t{}^E = l * \Delta BWI_t + (1 - l) * \Delta DGFCF_t$.

Table 8. Calculation of X-gen

Specif.	**ΔTFP^R (%)**		**Method**	**X-gen**	
	02-13	**08-13**		**02-13**	**08-13**
Main Specifications					
baseline (preferred)	**0.00**	**0.00**	$\boldsymbol{X_{gen} = (\Delta TFP^R - \Delta TFP^E) + (\Delta w^E - \Delta w^R)}$	**-0.58**	**-0.25**
baseline	0.00	0.00	$X_{gen} = \Delta P^E - \Delta w^R + \Delta TFP^R$	-0.36	-0.52
baseline	0.00	0.00	$X_{gen} = \Delta TFP^R$	0.00	0.00
(2)	0.31	0.31	$X_{gen} = (\Delta TFP^R - \Delta TFP^E) + (\Delta w^E - \Delta w^R)$	-0.27	0.06
(2)	0.31	0.31	$X_{gen} = \Delta P^E - \Delta w^R + \Delta TFP^R$	-0.05	-0.21
(2)	0.31	0.31	$X_{gen} = \Delta TFP^R$	0.31	0.31
(4)	0.68	-0.53	$X_{gen} = (\Delta TFP^R - \Delta TFP^E) + (\Delta w^E - \Delta w^R)$	0.10	-0.78
(4)	0.68	-0.53	$X_{gen} = \Delta P^E - \Delta w^R + \Delta TFP^R$	0.32	-1.05
(4)	0.68	-0.53	$X_{gen} = \Delta TFP^R$	0.68	-0.53
Robustness Specifications					
(AO2)	0.50	0.50	$X_{gen} = (\Delta TFP^R - \Delta TFP^E) + (\Delta w^E - \Delta w^R)$	-0.08	-0.08
(AO4)	1.05	-0.55	$X_{gen} = (\Delta TFP^R - \Delta TFP^E) + (\Delta w^E - \Delta w^R)$	0.47	-1.13
(OC2)	0.31	0.31	$X_{gen} = (\Delta TFP^R - \Delta TFP^E) + (\Delta w^E - \Delta w^R)$	-0.27	-0.27
(OC4)	-1.14	-1.14	$X_{gen} = (\Delta TFP^R - \Delta TFP^E) + (\Delta w^E - \Delta w^R)$	-1.72	-1.72
(OC6)	-0.29	-0.29	$X_{gen} = (\Delta TFP^R - \Delta TFP^E) + (\Delta w^E - \Delta w^R)$	-0.87	-0.87
(OC8)	-1.34	-1.34	$X_{gen} = (\Delta TFP^R - \Delta TFP^E) + (\Delta w^E - \Delta w^R)$	-1.92	-1.92
(OC10)	-1.24	-1.24	$X_{gen} = (\Delta TFP^R - \Delta TFP^E) + (\Delta w^E - \Delta w^R)$	-1.82	-1.82
(IP2)	0.88	0.88	$X_{gen} = (\Delta TFP^R - \Delta TFP^E) + (\Delta w^E - \Delta w^R)$	0.30	0.30
(IP4)	1.53	0.58	$X_{gen} = (\Delta TFP^R - \Delta TFP^E) + (\Delta w^E - \Delta w^R)$	0.95	0.00
(IP6)	-0.16	-0.16	$X_{gen} = (\Delta TFP^R - \Delta TFP^E) + (\Delta w^E - \Delta w^R)$	-0.74	-0.74
(IP8)	0.22	-0.71	$X_{gen} = (\Delta TFP^R - \Delta TFP^E) + (\Delta w^E - \Delta w^R)$	-0.36	-1.29
(TL2)	(SM) 0.61	(SM) 0.61	$X_{gen} = (\Delta TFP^R - \Delta TFP^E) + (\Delta w^E - \Delta w^R)$	0.03	0.03
(TL4)	(SM) 0.99	(SM) -0.19	$X_{gen} = (\Delta TFP^R - \Delta TFP^E) + (\Delta w^E - \Delta w^R)$	0.41	-0.77

Note: None of the presented values of ΔTFP^R is statistically different from zero at conventional confidence levels. "Specif." refers to the respective regression specification. "(SM)" refers to sample mean output levels.

From our empirical results above, we show that TFP growth is close to zero and statistically insignificant when we control for the specifics in Austria's gas distribution (decreasing opportunities for technological progress; one-off cost reduction in 2008) in our specifications of the cost function. This result holds for many robustness checks. Hence, we set $\boldsymbol{\Delta TFP^R = 0\%}$ for the period 2008–2013. Nonetheless, even when relying on the estimates for whole sample period 2002–2013, TFP growth is statistically not different from zero in our preferred specification. Hence, $\Delta TFP^R = 0\%$ for the period 2002–2013 seems most adequate.

The first row of Table 8 calculates X-gen according to the Bernstein and Sappington (1999) formula as presented in equation (8) based on index numbers for ΔTFP^E, Δw^E, and Δw^R and the estimate for ΔTFP^R for the period 2008–2013 (and on the period 2002–2013). We get a value of X-gen of $\boldsymbol{X_{gen}} = (0.00\% - 0.07\%) + (2.55\% - 2.74\%) = \boldsymbol{-0.25\%}$ (and -0.58% for 2002–2013). Since there are no t-values available for the respective index numbers, we cannot make a more precise qualification of this number, however, it seems plausible that the value of *X-gen may not be statistically different from zero*.

To check for sensitivity, in Table 8 we provide additional calculations of X-gen based on alternative methods (as in equations (9) or (10)), on various regression specifications, and on point estimates for ΔTFP ignoring their statistical (in)significances. Evidently, the calculated values of X-gen, based on 2008–2013 numbers, range between -1.92% and 0.31, whereas most values are close to zero. Again, we cannot provide statistical significance levels, but these values are likely to be statistically not to distinguish from zero.

In summary, we calculate X-gen according to Bernstein and Sappington's differential formula for Austria's regulated gas distribution sector at a *most credible value of zero percent*. One major task in this event was to empirically estimate the productivity growth in the sector. Given the specifics in Austrian's gas distribution (declining opportunities for technological progress; one-off reduction in granted costs in 2008), we show that productivity growth was essentially zero since the implementation of incentive regulation in 2008. This finding is robust to a set of sensitivity tests (alternative output measures, different output combinations, inclusion of input prices, alternative regression specifications). For the remaining variables in the differential formula, we applied external and credible index numbers. A value of X-gen close to zero corroborates our assumption that potentials for cost reductions of regulated firms have been largely exhausted.

6. Conclusions

We focus on Austria's gas distribution industry to estimate productivity growth from a unique panel data set of all (but one minor) firms subject to incentive regulation. We utilize the productivity estimate and combine it with other external data to derive an adequate value of the general X factor (X-gen) for the regulated gas distribution industry.

The sample covers the years 2002–2013 and, thus, allows for inference of the periods before and after the introduction of incentive regulation in 2008. A key benefit of this study is that we do not derive productivity growth relying on index number approaches but we parametrically estimate cost functions for this purpose. Hence we are able to control for unique events – such as the one-off but permanent reduction in granted costs in the year 2008 – when measuring productivity growth in the sector. Failing to do so would essentially attribute this one-off event to permanent efficiency improvements overestimating the appropriate X-gen. Moreover, besides a linear specification of the time trend, we allow for a more flexible functional form by including a polynomic specification of second order. This approach seems to correspond much better with actual cost changes as it takes the specifics of the regulated segment (i.e. the development of its technological opportunities) into account. In addition, parametric panel estimations allow for the inclusion of firm fixed effects (capturing many time-invariant unobserved variation) and a stochastic error term. We therefore assert that this study is the first to measure productivity growth (and X-Gen) consistently for the gas distribution sector in Austria.

Our results imply that technological opportunities were higher in the early years of the sample than in later years, and that productivity growth grinded to a halt from 2008 on. We estimate a *concave* relation between total costs and time, and a significant one-off but permanent reduction in *real* costs after an imposed reduction in *granted* costs in the course of the introduction of incentive regulation. This cut seems to have brought about a substantial productivity shift that cannot be repeated in subsequent years. Our estimations suggest that annual *productivity growth is statistically indistinguishable from zero and thus most credibly set at a rate of zero percent*. Several alternative specifications of the cost function and sensitivity tests (e.g. alternating output measures, inclusion of input prices) support our estimates and yield robust conclusions. We conclude that technological opportunities are exhausted (for the time being), and this gives rise to an *optimal X-gen of zero for the foreseeable future*.

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