Power Sector Regulation and Private Sector Participation in Africa

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Faced with financial constraints, most African countries have adopted the recommendations of the Bretton Woods institutions by opening up power generation to private actors in order to meet the challenges of universal access to electricity. The participation of these private actors takes place notably through independent power producers (IPPs) or through public-private partnerships (PPPs). However, capital markets remain limited on the continent and most of the inputs (fixed or variable) required for power generation are imported. This situation exposes private actors to currency and inflation risks (increased foreign currency debt burden and cost of imported inputs), which would act as obstacles on private investment in the sector. Using the theoretical framework of Nucci and Pozzolo (2001), followed by an empirical method that combines the local projection (LP) à la Jordà (2005) and the impact evaluation methodology (AIPW doubly robust estimator) proposed by Lunceford and Davidian (2004), we show that the adoption by the regulator of measures such as the automatic tariff adjustment mechanism or cost reflectivity allows the mitigation of currency and inflation risks on the evolution of installed capacity in the 54 African countries over the period 1990-2019.
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I. Introduction

Access to electricity in Africa is still weak, estimated at less than 54% in 2020. This means that almost 600 million Africans still do not have access to electricity.[1] This problem could essentially be attributed to the lack of adequate investment in the power sector. Indeed, African governments have not been able to provide the necessary public investment to boost the sector due to fiscal constraints (ERI 2020). These constraints are mainly explained by the recurrent difficulty of mobilising tax revenues (tax optimisation by multinationals, preponderance of the informal sector and the important share of the agricultural sector which is not easy to tax) and by the burden of public debt (debt services).

Faced with these financial constraints, throughout the continent, the recommendations of the Bretton Woods institutions (IMF and World Bank) have been adopted. This has led to the opening up of power generation to private actors in order to provide the capital needed to meet the challenges of universal access to electricity on the continent. The participation of these private actors takes place notably through IPPs or through PPPs. However, these private actors also face major challenges: local capital markets are weak and limited (debts essentially denominated in foreign currencies), and inputs are mostly imported. Indeed, sources of finance are scarce in the continent and even when they exist, financing is short term, which is not adapted to the long duration of most energy projects (NEPAD-OECD Investment Initiative). In addition, the cost of local credit remains quite high (exorbitant interest rates). Another difficulty for these actors remains the dependence on foreign markets for the import of fixed inputs (capital) and variable inputs (fuels).

These financial risks therefore expose private actors to currency and inflation shocks or crisis. Indeed, the weakness of domestic capital markets means that a large part of the debt of private actors is denominated in foreign currency. Therefore, a devaluation of the national currency leads to an increase in the debt burden for private

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[1] Population without access to electricity in Africa, 2000-2020, IEA

actors. Moreover, this devaluation will increase the cost of imported inputs. Also, as the electricity price is generally rigid, even when an inflation crisis does not lead to a depreciation of the exchange rate, it can contribute to the increase of the domestic cost of the projects (salaries for example when they are indexed to inflation).

Regulation of the sector is therefore desired, including tariff regulation, to reduce these various risks to which private actors are exposed. This essentially involves the establishment by the independent regulator of a tariff that reflects the real cost of supplying electricity, and an automatic tariff adjustment mechanism using a predetermined calculation to adjust tariffs in line with fluctuating costs on a periodic basis. Adequate quality regulation would therefore be essential to ensure the transparency and predictability necessary to attract and retain private investment to pursue the objectives of universal access to electricity.

However, the role of regulation on private investments remains rather contrasted in the literature. Broadly, numerous analyses have shown the favourable role of the regulation of a sector on the participation of private actors in investments (Pargal, 2003; Wallsten, 2002; Rubino and Cuomo, 2015). These potentially positive effects of independent regulators on private investments are also mentioned in the context of developing countries (Andres, Guasch and Straub, 2007; Cubbin and Stern, 2005; Gassner, Popov and Pushak, 2009), and more precisely in the context of the electricity sector (Bergara, Henisz and Spiller, 1998; Zhang, Parker and Kirkpatrick, 2008; Cubbin and Stern, 2006). However, for some authors, regulatory agencies do not guarantee an improvement in private investment due to political interference or measures not adapted to the reality of the sector (Bertoméu-Sánchez, Camos and Estache, 2018; Parker and Kirkpatrick, 2012; Andrés, Schwartz and Guasch, 2013; Carvalho, Marques and Berg, 2012; Estache et al., 2010).

Then, which role might tariff measures undertaken by independent regulators have on power sector investment in Africa? Could these tariff measures (cost reflectivity, automatic tariff adjustment mechanism) mitigate the currency and inflation shocks to the evolution of private investment in the sector?

The objective in this paper is therefore to analyse the impact of an increase in power generation costs on the participation of private actors in the investment of the power sector in Africa and especially to see if the implementation of tariff measures such as the cost reflectivity and the automatic tariff adjustment mechanism by an independent regulator of the sector would allow to mitigate this impact.

Our contribution to the existing literature is threefold. First, we are conducting for the first time such kind of analysis including all African countries. In order to take into account all 54 countries of the continent, we have carried out preliminary work to collect data on the establishment of independent regulators (for 16 countries out of 54) from official sources. This allowed us to complete the documentary research initiated by Eberhard et al. (2016), Foster et al. (2017) and Imam, Jamasb and Llorca (2019). Second, in order to deepen the previous works, beyond the analysis of the relationship between regulation and participation of private actors in a general way, we have mainly analysed the role of tariff regulation in a specific way, more precisely the cost reflectivity and the automatic tariff adjustment mechanism, on private participation. Finally, to compensate for the unavailability of data on the evolution of power generation costs, we have approached it through two factors (inflation shocks and currency shocks). Indeed, as cost is the key determinant of profitability, we assume that a currency devaluation would have an impact both on the cost of a project via imported inputs and via the cost of financing the project (mainly foreign currency debt). As for the participation of private actors in investments, it is approached by the evolution of the total installed capacity per country because investment in the sector has been undertaken mainly by private actors over the last decades. Indeed, in the case of Africa, over the period 1990-2019 that we are considering, investments in the sector are essentially made by private actors. Therefore, the evolution of installed capacity in Africa over this period is a fine proxy for private investments in the power generation.

Our main findings suggest that inflation and currency crises negatively affect private participation in power sector investment (proxied by changes in installed capacity) in the 54 African countries over the period 1990-2019. Moreover, currency crises appear to be much more severe than inflation crises over our period of analysis. Meanwhile, these negative effects of inflation and currency crises on private participation are mitigated for the group of countries that have established an independent power sector regulator compared to countries that have not yet done so.[2] This is especially true if regulators in these countries adopt automatic tariff adjustment mechanism and generation cost reflectivity for operators. Indeed, the empirical results show that cost reflectivity measures would be much more effective, followed by the automatic tariff adjustment mechanism, compared to a simple implementation of an independent power regulator (without these two types of policies).

The rest of the paper is subdivided as follows: Literature review in section II, Private actors and power sector in Africa in section III, Theoretical framework in section IV, Main data in section V, Estimation using Local Projection and AIPW Estimator in section VI, Results in section VII, and Concluding remarks in section VIII.

II. Literature review

The literature on this issue can be divided into three sub-sections, namely, private participation and performance, private participation and regulation, and the potential effects of the currency and inflation shocks on investment.

A. Private participation and performance

Opinions are still very divided as to the benefits or not of private participation in various sectors. Authors such as Koo et al. (2013) suggest that private participation is in fact negatively associated with the efficiency of the electricity service. In the same vein, and in general, Trujillo et al. (2002) estimate that private participation in infrastructure negatively influences the efficiency of the service due to the aggravation of the agency problem. Nevertheless, the results of these two studies show that the negative effects of private participation on efficiency are reduced with the quality of regulation. Other authors like Koo et al. (2013), assume that there is no effect of private sector participation on the level of performance. Using a meta-analysis, they show that the performance of public enterprises is not significantly different from that of private enterprises and that privatisation has no beneficial effects on public services in transition economies. On the other hand, the prevailing or dominant thought is rather in favour of a positive effect of private participation in infrastructure. In this line, Wallsten (2001) found, for example, that the performance of telecommunications at national level is positively related to regulation and private participation. As regards other relevant studies, Hawdon (1996), analysing the performance of electricity sectors supported by World Bank loans, found that countries that had adopted privatisation had significantly higher efficiency than the group that had not privatised.

B. Private participation and Regulation

In general, a large number of studies have shown the favourable role of the regulation of a sector and the participation of private actors. We are thinking in particular of the study by Pargal (2003) in which he shows that the absence of independent regulation can be a major obstacle to attract private sector investment in the infrastructures of developing countries. His results suggest that improving regulatory certainty and minimising the risk of expropriation through the establishment of independent regulatory bodies is a key determinant of the volume of private investment flows. In the same vein, Wallsten (2002) has shown that countries that have established independent regulatory agencies in the telecommunications sector have seen a faster increase in investment in the sector compared to countries that have not, and that investors are willing to pay more for these companies in countries that have undertaken reforms. Furthermore, Rubino and Cuomo (2015) show that the legal and regulatory framework adopted in the European Union (EU) favours the financing of the development of cross-border interconnections in the EU zone.

In the same vein, for Bertoméu-Sánchez, Camos and Estache (2018), regulatory agencies are basically supposed to reduce the risk of companies taking control of the regulatory process by trying to influence the government, ministries or other public actors and obtain favourable regulatory decisions. Such agencies would also reduce collusion between governments and private

[2]But a regulatory agency cannot, on its own and without appropriate measures, correct all the negative effects of currency shocks (the most severe in our case) for instance.

operators and political interference in prices, quantities, quality and profitability. They are therefore seen as sending a strong signal to the market that the government was taking regulation seriously, which should mitigate investment risks and thus make it easier to attract investors and private operators. These potentially positive effects of independent regulators on various types of private infrastructure investment in developing countries have also been described by Andres, Guasch and Straub (2007), Cubbin and Stern (2005) and Gassner, Popov and Pushak (2009). Evidence of the positive effect of regulatory agencies on investments has also been established in the electricity sector. This is notably the case in Bergara, Henisz and Spiller (1998) who found that well-defined and credible political institutions were positively and significantly correlated with overall power generation capacity. Indeed, power generation is characterised by massive investments, hence the need to offer all the guarantees to investors to boost investments that will increase the installed capacity and power generation (Zhang, Parker and Kirkpatrick, 2008; Laffont and Tirole, 1993).[3] Finally, Cubbin and Stern, 2006 estimate, for 28 developing countries over the period 1980-2001, that the existence of regulatory law and better regulatory governance is positively and significantly associated with higher levels of per capita generation capacity and that this positive effect increases over time with the development of regulatory experience and reputation.

However, for some authors such as Parker and Kirkpatrick (2012), there is growing uncertainty about the effectiveness of regulatory agencies and reforms in attracting PPPs. Indeed, the emerging picture of the relationship between regulatory agencies and PPPs is complicated by the fact that there are countries with regulatory agencies and no PPPs and countries with PPPs and no regulatory agencies (Bertoméu-Sánchez, Camos and Estache, 2018). They also show that an independent regulator is not necessarily a sufficient condition for increasing private participation in water services for instance. Finally, for developing countries, Andrés, Schwartz and Guasch (2013), Carvalho, Marques and Berg (2012) and Estache et al. (2010) suggest that, in general, regulatory agencies do not guarantee a major improvement in investment, access rates or efficiency in the water and sanitation sector. For this group of countries, this is largely due to the fact that institutional weaknesses make these agencies less independent and competent than they should be. In sum, the bias in favour of regulatory agencies may be positive in theory, but the practice seems to be quite different.

C. Currency and inflation crisis effects on investment

Conventional wisdom holds that an increase in price (inflation) or exchange rate (currency crisis) uncertainty reduces investment (Darby et al., 1999). For instance, if the expected net present value (NPV) of the project is positive, the company invests, otherwise it does not. This implies that if the investment is reversible, the company will simply disinvest if the NPV becomes negative. But if the investment is irreversible, then the company decides not to invest further.

Inflation shocks and investment

Using panel data for OECD countries and arguing that inflation affects investment because it increases the cost of capital, Madsen (2003) shows that investment in non-residential buildings and structures and in machinery and equipment is strongly negatively related to inflation, suggesting that the low-inflation environment of the 1990s was an important contributor to the strong investment activity of the last decade in OECD countries. As for Hochman and Palmon (1983), they show that when the "Fisher effect" is assumed to exist, the cut-off rate of return on investment decreases with expected inflation, independently of the type of financing. However, if the real interest rate increases with inflation, inflation may increase the cut-off rate of return on investment. Finally, using data from about 100 countries between 1960 and 1990 to assess the effects of inflation on economic performance, Barro (2013) indicate that the effects of an average inflation increase of 10 percentage points per year are a reduction in the growth

[3] Installed capacity is the maximum level of electrical power (electricity) that a power plant can deliver at a given time under certain conditions. In other words, it is the amount of electricity a generator can produce when operating at full capacity. This maximum amount of power is usually measured in megawatts (MW) or kilowatts and helps utilities predict how much electrical load a generator can handle.

rate of real GDP per capita by 0.2 to 0.3 percentage points per year and a decrease in the investment/GDP ratio by 0.4 to 0.6 percentage points.

DEPRECIATION AND INVESTMENT

For Harchaoui, Tarkhani and Yuen (2005), in theory and globally, exchange rate variations have two opposite effects on investment. When the national currency depreciates, the marginal benefit of investing an additional unit of capital is likely to increase, because the revenue from domestic and foreign sales is higher. In other words, a depreciation will therefore have a positive impact on investment due to higher demand in domestic and export markets.[4] However, this positive effect is offset by the increase in variable costs and the price of imported capital. Since theoretical models do not give a clear indication of which effect dominates, the overall effect of exchange rates on investment remains an empirical question. Therefore, an exchange rate depreciation stimulates investment by increasing demand in the domestic and export markets, but reduces investment because of the increased cost of imported intermediate goods and the user cost of capital. In the very specific case of an electricity producer in Africa, with a high import of inputs and almost no export of electricity, we will most likely have an overall negative effect of depreciation on investment. Meanwhile, using industry-level data for 22 Canadian manufacturing industries over the period 1981-1997, Harchaoui, Tarkhani and Yuen (2005) show that the overall effect of exchange rates on total investment is shown to be statistically insignificant.

Moreover, many studies have also analysed the role of the change regime on the dynamics of investment. This is especially the case with the analysis of Aizenman (1992), which shows that overall investment is higher under a fixed change regime than under a flexible change regime, both for productivity shocks and for monetary shocks. However, welfare is not necessarily higher under either regime. Meanwhile, a flexible change regime is one of the means to stabilise employment during shocks. Also, the issue of exchange rate volatility and its link with investment is widely analysed. Indeed, Servén (2003) examines the link between real exchange rate volatility and private investment in developing countries using a large cross-country time series data set. He develops a GARCH-based measure of real exchange rate volatility and finds that it has a negative and significant effect on investment. Moreover, this negative effect of real exchange rate volatility on investment is significantly larger in very open economies and in those with less developed financial systems.

Through this literature review, we can see that previous studies have been rather limited to a broad analysis of the role of regulation on the attraction of private investment, without detailing the type of regulation in question. Also the studies analysing the effect of currency or inflation shocks are rather general. This suggests that the impact of currency shocks, for example, could have both beneficial and detrimental effects on investment. Our contribution will therefore be, first, to target a specific regulation measure, the tariff regulation in the power sector through the cost reflectivity and the automatic tariff adjustment mechanism. Second, we will analyse the effects of currency and inflation shocks in a specific sector (power generation) within African countries. This helps to clarify the adverse effect of, for example, currency shocks given the specific characteristics of the power sector in this part of the world (low electricity exports, dependence on imported inputs, foreign currency debts). Finally, we show how this tariff regulation plays a fundamental role in mitigating currency and inflation shocks and allows the attraction and the maintaining of private investments.

III. Private actors and power sector in Africa

As shown in Figure 1, global electricity generation across the African continent stood at 870.1 TWh in 2019. However, almost 80% of this electricity generation in Africa still comes from fossil fuels, while wind and solar account for just over 4% of the continent's electricity mix (over 15% for hydro). This dependence on fossil fuels increases vulnerability to depreciation shocks, especially for countries that are net importers of gas, oil, and/or coal. Moreover, the last decade has been marked by the constant evolution of power generation as we can see on the right side of the figure, and this despite the bud-

[4] Another illustration with Japan's FDI by industry, Kiyota and Urata (2004) find that the depreciation of the host country's currency attracts FDI. Their results suggest the need to avoid overvaluing the national currency.

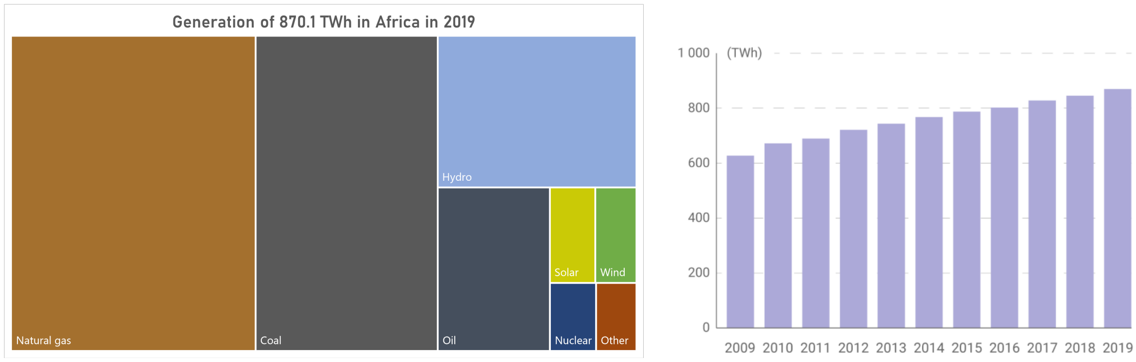

FIGURE 1. *Energy mix and evolution of power generation in Africa*

getary difficulties of the Governments.

This increase in power generation across the continent has been achieved mainly through the involvement of private actors, notably through PPPs and IPPs.[5] IPPs have indeed become widespread across Africa and are now present in more than 30 countries. According to the African Development Bank, there are over 270 IPPs in operation or under construction in Africa (MIRA database, AfDB 2019). This represents approximately USD 51.7 billion in investments and 27.1 GW of installed generation capacity. Already in 2016, a report by Proparco (AFD) reported 77,800 MW due to IPPs in 20 selected countries on the continent, representing a 25.6% share of total generation (Tbale A1, Appendix A). This share is close to 50% for the countries like Gambia (43%), Togo (49%) and Uganda (49%). In Côte d'Ivoire for instance, this share represents more than 50% (52% exactly).

If the conditions for profitable investment are met, the private sector will participate fully in power sector investments in Africa in the same way that private mobile phone operators have participated massively in financing.[6] For example, Côte d'Ivoire has attracted more than 1 billion USD in investment in 18 months to increase the country's generation capacity by 30%. Uganda has halved the cost of electricity and tripled its electricity access rate, largely through privatisation of the service. Kenya is massively increasing its generation capacity, both thermal and renewable, through a series of new private producers, and South Africa has used the private sector to rapidly increase its solar and wind generation capacity. This shows that if countries put in place the required conditions to invest in private power generation, investors and financiers will respond. So, after establishing the theoretical link, from an empirical point of view we will also test the hypothesis that the required tariff conditions will attract and retain these private investors.

IV. Theoretical framework

First, the frequency of episodes of interaction between inflation and depreciation in many countries has raised concerns about the possibility of inflation-depreciation vicious circles. According to this vicious circle hypothesis, a higher domestic inflation rate than that prevailing abroad could trigger a cumulative and self-reinforcing process leading to a vicious circle between inflation and currency depreciation (Ahmad, 1984). Indeed, a low inflation rate generally leads to an increase in the value of the currency, as its purchasing power increases relative to other currencies. Conversely, countries with higher inflation tend to see their currencies depreciate against those of their trading partners.[7] More precisely, a depreciation of the domestic currency initially aggravates the rate of domestic price inflation through an immediate increase in the price of traded goods expressed in domestic currency, which quickly feeds through to the

[5] As a reminder, IPPs are producers that are usually not owned by the national state-owned electricity company. IPPs generate electricity for sale to the national, usually public, operator.

[6] Source: Les producteurs privés d'électricité : une solution pour l'Afrique ? Proparco (AFD), 2017

[7] Source: OFX team, 6 factors influencing exchange rates and what you can do about it, 2019

domestic price level. This inflation, in turn, requires a depreciation of the exchange rate, which causes further inflation.

Then, by assuming the precedent hypothesis of a vicious circle between inflation and currency depreciation, we develop a theoretical framework based on that of Nucci and Pozzolo (2001) in order to highlight theoretically the mitigating role of regulation with regard to the link between inflation shocks, followed by currency shocks on the dynamics of private investment in power generation in Africa. As the power sector investment is driven by expected returns in the light of a range of risks related to both costs and revenues (Gross, Blyth and Heptonstall, 2010), in this analysis we will specifically formalise the effect of an exchange rate depreciation on private participation in the sector's investments by focusing mainly on the cost channel (rather negative effect due mainly to the dependence on imported inputs).[8,9] We refer to input costs and credit costs. The idea is that the impact of currency depreciation would increase, for example, with a dependence on imports of inputs and the share of private actors' debt denominated in foreign currency.

Let $\pi(K_t, e_t)$ be the profit function of an IPP or under a PPP, where K_t is its capital stock (turbines, generators) at time t and e_t is the real exchange rate calculated in units of domestic currency per unit of foreign currency.[10] The producer chooses his optimal level of investment I_t at date t. Given the adjustment costs associated with a change in the quantity of the capital factor, we assume that the accumulation process is subject to an adjustment cost, $C(I_t)$, which is increasing and convex in I_t.

We can therefore estimate the value of a representative power generation company as the maximum expected present value of its cash flows using the discounted cash flows (DCF) method which is the fundamental valuation method expressed as follows:[11]

(1)
$$V_t(K_{t-1}) = \max_{I_t}\Big([\pi(K_t, e_t) - I_t - C(I_t)] + \beta^t_{t+1}\mathrm{E}_t[V_{t+1}(K_t)]\Big)$$

where the cash flow in each period is expressed as $\pi(\cdot)$ net of aggregate capital expenditure, β^t_{t+1} denotes the producer's discount factor between periods t and $t+1$, E_t is the expectation operator conditional on all information available at time t and the price of capital goods is normalised to 1. The capital stock K_t is governed by the standard accumulation equation $K_t = K_{t-1} + I_t$, where depreciation is ignored for reasons of simplicity. The first-order condition for maximising Equation (1) with respect to the capital stock provides the following expression:

$$(2)\quad \frac{\partial V_t(K_{t-1})}{\partial K_{t-1}} = \left[\frac{\partial \pi(K_t, e_t)}{\partial K_t}\right] + \beta^t_{t+1}\mathrm{E}_t\frac{V_{t+1}(K_t)}{\partial K_t}$$

$$(3)\quad q_t = \left[\frac{\partial \pi(K_t, e_t)}{\partial K_t}\right] + \beta^t_{t+1}\mathrm{E}_t(q_{t+1})$$

where the variable q_t is the marginal valuation of capital: $\partial V_t/\partial K_{t-1}$.[12] Equation (3) gives us the following expression for q_t:

$$(4)\quad q_t = \frac{\partial \pi(K_t, e_t)}{\partial K_t} + B^t_{t+1}E_t \times \left[\frac{\partial \pi(K_{t+1}, e_{t+1})}{\partial K_{t+1}}\right] + \beta^t_{t+2}E_t(q_{t+2})$$

[8]The revenue channel (positive effect) is not relevant enough in this case because there are very few interconnections between the power networks of African countries.

[9]Goldberg (1993) had observed, for example, that a real depreciation of the dollar had generated an expansion in commands for American capital goods.

[10]The turbine and the generator are the two main components of the power generation. With the exception of photovoltaic plants, power is generated by an alternator driven by a turbine or, for certain isolated systems, by an internal combustion engine (diesel generator with a power of a few MW to several tens of MW). Several turbine technologies are available depending on the fluid used to drive them: vapor turbine, combustion turbine or hydraulic turbine.

[11]K_{t-1} is due to the assumption that more than one time period is required for the construction of new productive capital or the notion of "Time to build". So, a delay for the installation of equipment is introduced (Kydland and Prescott, 1982)

[12]So $q_{t+1} = \partial V_{t+1}/\partial K_t$

$$q_t = \frac{\partial \pi (K_t, e_t)}{\partial K_t} + B_{t+1}^t E_t \times \left[\frac{\partial \pi (K_{t+1}, e_{t+1})}{\partial K_{t+1}}\right] + B_{t+2}^t E_t \times \left[\frac{\partial \pi (K_{t+2}, e_{t+2})}{\partial K_{t+2}}\right] + \cdots + \beta_{t+j-1}^t E_t \left(q_{t+j-1}\right) \tag{5}$$

$$q_t = \mathrm{E}_t \sum_{j=0}^{\infty} \beta_{t+j}^t \left[\frac{\partial \pi (K_{t+j}, e_{t+j})}{\partial K_{t+j}}\right] \tag{6}$$

which implies that q_t is equal to the present value of the future net returns of marginal capital income. The discount factor at period j is $\beta_{t+j}^t = \prod_{i=1}^{j} (1 + r_{t+i-1})^{-1}$ with r_t being the nominal rate of return required by the producer between periods t and $t+1$. Moreover, the first-order condition for maximising Equation (1) with respect to investment gives the following expression:

$$1 + \left[\frac{\partial C (I_t)}{\partial I_t}\right] = q_t \tag{7}$$

Assuming that the adjustment cost is increasing and convex with the level of investment, the term appearing on the left side of Equation (7), which is the marginal cost of investment, is a positive and increasing function of I_t. Therefore, by reciprocal or inverse bijection, investment can be expressed as an increasing function of q_t. Substituting from Equation (3) we then have:

$$I_t = \phi \left\{ \mathrm{E}_t \sum_{j=0}^{\infty} \beta_{t+j}^t \left[\frac{\partial \pi (K_{t+j}, e_{t+j})}{\partial K_{t+j}}\right] \right\} \tag{8}$$

where $\phi(\cdot)$ is an increasing function due to the properties of the adjustment cost function $C(I_t)$.

Now, to characterize the effect of an currency shock or depreciation on private sector participation in power generation investment, we will determine an explicit expression for the marginal return on fixed capital. In each period, the producer maximizes its profit by choosing the level of fixed capital K^* (assumed to be entirely imported for producers based in Africa) and its variable capital acquired at home L or imported L^*.[13]

$$\pi (K_t^*, e_t) = \max_{K^*, L, L^*} x (p_t)\, p (e_t) + e_t x^* (p_t^*)\, p^* (e_t) - w_t L_t - e_t w_t^* L_t^* \quad \text{s.t. } x_t + x_t^* = F (K_t^*, L_t, L_t^*) \tag{9}$$

where $x(p_t)$ and $x^*(p_t^*)$ denote the electricity demand functions faced by the producer on the domestic and foreign markets, with p_t and p_t^* being the price levels of the KWh on these markets; $w_t L_t$ and $e_t w_t^* L_t^*$ are the expenditures on locally produced and imported inputs, L_t and L_t^*, respectively. The power generation function, $F(\cdot)$, is homogeneous of degree 1, or monetary neutrality as defined by Leontief.

The first-order conditions in Equation (9) give the following expression for the marginal return on capital:

$$\frac{\partial \pi(\cdot)}{\partial K_t^*} = \frac{1}{K_t^*} \left[p_t x_t \frac{1}{\mu_t} + e_t p_t^* x_t^* \frac{1}{\mu_t^*} - w_t L_t - e_t w_t^* L_t^* \right] \tag{10}$$

where μ_t et μ_t^* are the producer's price-cost margins on the domestic and foreign markets; they can also be expressed in terms of the price elasticity of demand ($\vartheta_{t,x}$ and ϑ_{t,x^*}), such $\mu_t = (1 + 1/\vartheta_{t,x})^{-1}$ and $\mu_t^* = (1 + 1/\vartheta_{t,x^*})^{-1}$, respectively.

In this model, we assume that a potential imbalance arises from the start of the inflation-depreciation vicious circle. In other words, an inflation shock i_t at date t, through the decline in domestic competitivity, leads to a depreciation of the exchange rate e_t. Let us also assume that private operators perceive this change in the value of money as permanent. Therefore, the level of the exchange rate in future periods is expected to be equal to today's exchange rate, i.e. $\mathrm{E}_t \left(e_{t+1+j} - e_t\right) = 0,\ \forall j \geq 0$.

By differentiating Equation (8) with respect to the exchange rate e_t and, for simplicity, the firm's discount factor is assumed to be constant over time in Equation (3) such as $\beta_{t+1}^t = \beta,\ \forall t$,

[13] Here, the variable capital or inputs include mainly fuel and labour. The producer can therefore increase the number of KWh produced by only increasing the amount of variable inputs. However, only an increase in fixed capital could lead to an increase in installed capacity in MW.

we have:

$$(11)\quad \frac{\partial I_t}{\partial e_t}=\frac{\partial \phi}{\partial e_t}\Leftrightarrow\frac{\partial I_t}{\partial e_t}=\frac{\partial \phi}{\partial q_t}\times\frac{\partial q_t}{\partial e_t}=\phi_q(\cdot)\times\frac{\partial q_t}{\partial e_t}\ \text{ with }\ q_t=\frac{1}{1-\beta}\left[\frac{\partial\pi\left(K_t^*,e_t\right)}{\partial K_t^*}\right]$$

And using Equation (10), we can derive an expression for the effect of exchange rate changes on private sector investment or participation in power generation:

$$(12)\quad \frac{\partial I_t}{\partial e_t}=\phi_q(\cdot)\frac{1}{1-\beta}\times\left[\frac{\partial K_t^{-1}\left(p_tx_t\mu_t^{-1}+e_tp_t^*x_t^*\mu_t^{*-1}\right)}{\partial e_t}\right]-\phi_q(\cdot)\frac{1}{1-\beta}\left[\frac{\partial K_t^{-1}\left(w_tL_t+e_tw_t^*L_t^*\right)}{\partial e_t}\right]$$

where $\phi_q(\cdot)$ is non-negative as previously indicated. Rearranging, we obtain :

$$(13)\quad \frac{\partial I_t}{\partial e_t}=\frac{\phi(\cdot)}{(1-\beta)\partial K_t^*\partial e_t}\times\left(\frac{p_tx_t}{\mu_t}+\frac{e_tp_t^*x_t^*}{\mu_t^*}-w_tL_t-e_tw_t^\star L_t^*\right)$$

$$(14)\quad \frac{\partial I_t}{\partial e_t}=\frac{\phi(\cdot)}{(1-\beta)\partial K_t^*\partial e_t}\times\left[\left(\frac{p_tx_t}{\mu_t}-w_tL_t\right)-e_t\left(w_t^*L_t^*-\frac{p_t^*x_t^*}{\mu_t^*}\right)\right]$$

Equation (14) shows the dependence of investment on a one-period change in the level of the exchange rate, isolating the effect on the revenue side from that on the cost side. The value $(w_t^*L_t^*-p_t^*x_t^*/\mu_t^*)$ tends towards its maximum value $w_t^*L_t^*$ when there is no power exports ($x_t^*=0$). Indeed, with the lack of integration of inter-country power networks, the producers cannot benefit from the positive effects of depreciation linked to the sale of electricity abroad. To mitigate this negative effect of depreciation on private participation in investments, the role of an independent regulator would be to act here on the p_tx_t value, more precisely on the p_t pricing of electricity sold in the country, notably through the automatic tariff adjustment mechanism or through the cost reflectivity following the variation of the cost of power generation relative to a currency fluctuation. This must be clear in the tariff methodology in order to mitigate the risk for private actors, especially in countries facing recurrent currency crises.

A transformation of Equation (12) allows us to go further and to highlight the role of some relevant factors in the evolution of the effect described above.[14] Also, to simplify the notation, the temporal indices have been ignored for the rest of the framework:

$$(15)\quad \frac{\partial I}{\partial e}=\phi_q(\cdot)\frac{1}{1-\beta}\frac{TR}{K^*e}\left(\frac{1}{1+\mu^*}\chi\times\left[\eta_{p^*,e}\left(1+\vartheta_{x^*}\right)+1-\varepsilon_{\mu^*,e}\right]+\frac{1}{1+\mu}(1-\chi)\times\left[\eta_{p,e}\left(1+\vartheta_x\right)-\varepsilon_{\mu,e}\right]-\frac{1}{\bar{\mu}}\left(1+\eta_{w^*,e}\right)\alpha\right)$$

Where $TR=p_tx_t+e_tp_t^*x_t^*;\quad \chi=\dfrac{e_tp_t^*x_t^*}{TR};$

$$\eta_{p,e}=\frac{\partial p_t}{\partial e_t}\times\frac{e_t}{p_t};\quad n_{p^*,e}=\frac{\partial p_t^*}{\partial e_t}\times\frac{et}{p_t^*};$$

$$\varepsilon_{\mu,e}=\frac{\partial\mu_t}{\partial e_t}\times\frac{e_t}{\mu_t};\quad \varepsilon_{\mu^*,e}=\frac{\partial u_t^*}{\partial e_t}\times\frac{e_t}{\mu_t^*};$$

$$\alpha=\frac{e_t\omega_t^*L_t^*}{\omega_tL_t+e_t\omega_t^*L_t^*};\quad \eta_{w^*,e}=\frac{\partial w_t^*}{\partial e_t}\times\frac{e_t}{w_t^*}$$

χ is the representative producer's share of foreign sales (share of exported electricity) with respect to total revenues (TR) or total sales; $\eta_{p,e}$ and $\eta_{p^*,e}$ are the exchange rate elasticities of prices in the domestic and foreign markets respectively; $\varepsilon_{\mu,e}$ and $\varepsilon_{\mu^*,e}$ are the elasticities of the mark-up with respect to the exchange rate, respectively, in the domestic and external markets; α is the share of imported input costs in total variable costs; $\eta_{w^*,e}$ is the price elasticity of imported inputs (in foreign currency units) with respect to the exchange rate and $\bar{\mu}=\mu_t+\mu_t^*$ represents the producer's cost-price margin obtained without distinction between the domestic and foreign markets.

Equation (15) provides a useful framework for isolating the main determinants of the change in profitability, and hence investment, induced

[14] See appendix Nucci and Pozzolo (2001) for more details on the transformation.

by exchange rate depreciation. Through this equation, we see that the share of revenues from power exports χ mitigates the effect of depreciation on the producer's investment (a factor favourable to private participation) when $\frac{\eta_{p^*,e}}{1+\mu^*}(1+\vartheta_{x^*}) > \frac{\eta_{p,e}}{1+\mu}(1+\vartheta_x)$. However, a producer benefits little from this potential improvement in competitiveness due to currency depreciation when interconnection with other countries does not exist or is quite weak (low level of electricity exports).

As indicated just before, χ is negligible in our application, so $(1-\chi)$ tends almost to 1. So, in our case, Equation (15) can be rewritten as follows:

$$(16) \quad \frac{\partial I}{\partial e} = \phi_q(\cdot)\frac{1}{1-\beta}\frac{TR}{K^*e}\frac{1}{1+\mu}\times \left\{\left[\eta_{p,e}(1+\vartheta_x)-\varepsilon_{\mu,e}\right]-\frac{1}{\bar{\mu}}(1+\eta_{w^*,e})\,\alpha\right\}$$

Let us now turn to the elasticity of the domestic power price with respect to a variation in the exchange rate, $\eta_{p,e}$. In a regulated electricity sector, this variable could represent the automatic tariff adjustment mechanism. Indeed, the regulator can define in its tariff methodology an automatic tariff adjustment mechanism or a cost reflectivity measure in response to an exchange rate shock impacting producer's power generation costs (imported inputs and foreign credit costs). Thus, this positive elasticity helps to mitigate the negative effect of depreciation on investment. Also, since domestic demand for electricity is inelastic ($\vartheta_x = 0$), the increase in the price of electricity on the domestic market induced by a depreciation of the currency has no effect on the quantity of electricity sold.[15] This leaves the regulator with the choice of either subsidising the tariff difference (in the case of an automatic tariff adjustment mechanism) or allowing the producers to increase the tariff (in the case of cost reflectivity measure) to compensate the depreciation shock. In this configuration, it is also assumed that the elasticity of the mark-up with respect to the exchange rate is zero (favorable to the investment). However, in the context of a regulated sector and in the absence of an automatic tariff adjustment mechanism or a cost reflectivity measure following an exchange rate shock, $\eta_{p,e}(1+\vartheta_x) = 0$. That increases the negative effect of depreciation on power generation investment or private participation. Meanwhile, the elasticity of the mark-up with respect to the exchange rate $\varepsilon_{\mu,e}$ is negative and represents paradoxically a source of incentive for private actors. This seemingly counter-intuitive result has an economic explanation. Indeed, the actors who decide to remain on the market in this configuration will make investment decisions in order to restore part of their lost margin. These actors could, for example, decide either to invest in renewable energy (to limit imports of fuels that are highly dependent on exchange rate fluctuations) or to invest in more efficient equipment in order to reduce their energy bill. Finally, the elasticity of input prices with respect to the exchange rate $\eta_{w^*,e}$ and the share of imported input costs in total variable costs α reinforce the harmful effect of a depreciation for a national electricity producer. Indeed, we will assume that the elasticity of input prices with respect to the exchange rate $\eta_{w^*,e}$ is positive and that this share of imported input costs on total variable costs α is quite close to 1 when there is a high dependence of local producers on imported fuels. In general, in countries without an independent regulator with all appropriate measures in place, inflation or exchange rate shocks are likely to slow down the evolution of total installed capacity. However, this negative effect should be mitigated depending on the country's integration into a regional electricity market, independence from imported inputs (e.g. fuel) and the ability to raise domestic funds.

The next section will be devoted to the presentation of the data essential for the empirical testing of the main hypotheses developed in this theoretical framework.

V. Main data and statistics

In this section we present all our main data sources for this analysis. These include mainly data on regulation and the quality of regulation and data on installed capacity.

[15] In the same vein, using unique data on Swedish households, Lanot and Vesterberg (2021) find that the price elasticity is smaller than what many previous studies on electricity demand have found. More precisely, the response to prices is very small.

TABLE 1—ESTABLISHMENT OF ELECTRICITY SECTOR REGULATORS IN AFRICA

Eberhard et al. (2016) and updated with data from Foster et al. (2017) and Imam, Jamasb and Llorca (2019)	
South Africa	1994
Egypt, Zambia	1997
Cameroon, Côte d'Ivoire, Senegal	1998
Madagascar, Niger, Uganda	1999
Ghana, Mali, Namibia, Togo	2000
Gambia, Mauritania, Rwanda, Tanzania	2001
Algeria	2002
Cabo Verde, Rep. Of Congo, Zimbabwe	2003
Lesotho, Mozambique	2004
Central African Republic, Nigeria, São Tomé and Príncipe	2005
Kenya	2006
Angola, Eswatini, Malawi	2007
Benin	2009
Burkina, Gabon	2010
Burundi, Sierra Leone, Sudan	2011
Seychelles	2012
Ethiopia	2014
Our update	
Liberia	2015
Dem. Rep. Of Congo, Mauritius, Morocco	2016
Botswana, Guinea	2017
Chad	2019
Comoros, Djibouti, Equatorial Guinea, Eritrea, Guinea-Bissau, Libya, Somalia, South Sudan, Tunisia	No IRA

A. *Establishment of Regulators in Africa*

Data on the years of establishment of an independent electricity regulator in Africa is crucial for our analysis. Indeed, we are able to track the establishment by country over our study period (1990-2019). As the existing source of data is limited to the year 2014, we completed this database with a large collection of official sources from different governments and institutions as shown in Table 1. As Zhang, Parker and Kirkpatrick (2008), we use a dummy variable to indicate whether a country has established an Independent Regulatory Agency (IRA) in the power sector that is not directly under the control of a ministry.

B. *Electricity Regulatory Index by AfDB*

To approximate the quality of regulation, we exploit the Electricity Regulatory Index (ERI) data source which is a publication of the African Development Bank (AfDB) and aims to provide an overview of regulatory developments and issues in the electricity sector on the African continent. The first edition of the ERI was published in 2018 and has been updated and published annually since then, with the third edition being published in November 2020. Beginning with a review of regulatory and capacity developments in 15 countries in 2018, the 2020 edition includes data for 36 participating African countries.[16]

The ERI 2020 report shows that the average score in Africa for economic regulation is 0.534, while the average score for technical regulation is 0.506.[17] The ERI reports provide a number of recommendations on how these indicators can be improved. Beyond the concrete strategies for implementing the recommendations and other interventions in line with international best practice to improve the regulation of the electricity sector in Africa that the ERI report proposes to policymakers, our analysis aims to highlight the need to implement these strategies to make the sector more attractive to private investors.

The ERI studies only started in 2018, so we made some assumptions to extend the information to earlier years and to account for the quality of regulation for different countries: (H1) If

[16]Guidelines for Advancing Economic and QoS Regulation in Africa's Electricity Sector, USAID, August 2021

[17]African Development Bank, "Electricity Regulatory Index for Africa, 2020"

the study indicates that a country has, for example, not yet implemented an automatic tariff adjustment mechanism, we assume that the country has never implemented it before; (H2) If the study indicates that a country has already implemented this measure, we assume that the country has always implemented it starting from the year of the independent regulator's establishment.

C. Private Participation in the Electricity Sector

To capture the flow of private investment in the power sector, the World Bank's Private Participation in Infrastructure (PPI) database remains the most widely used in this literature. However, this database represents only a compilation of publicly available information on private sector investment in infrastructure in developing countries, and should not be considered as an exhaustive resource. Some projects - particularly those involving local and small-scale operators - tend to be omitted as they are generally not reported by the main information sources, databases, government websites and other sources used by the PPI Projects database authors.

Therefore, as in Zhang, Parker and Kirkpatrick (2008), we use installed capacity provided by U.S. Energy Information Administration (EIA) as a proxy for private investment. Indeed, according to Izaguirre (1998), the participation of private actors in the electricity sector has been most evident in power generation, with three quarters of private investment concentrated in power plants.

D. Data summary and statistics

Table 2 below gives an overview of most of the variables we use. Regarding installed capacity, the average value over the period 1990-2019 is 2.45 million kW per country. However, we could see, through the Std. Dev. or through the gap between the Min Value and the Max value, a strong heterogeneity between countries in terms of installed capacity. While the minimum value is 0.002 million kW for Liberia in the early 2000s, the maximum value is 58.22 million kW for South Africa (the continent's leading economic power) in 2019. Also, some of the averages, such as that for inflation (over 15,000%), which is mainly driven by Zimbabwe's hyperinflation of about 22 million percent in 2008, can be confusing. Over the same period, the depreciation rate of the LCU against the dollar averaged 7.21% per annual. This rate fluctuates between -100% (maximum depreciation) and 39.34% (maximum appreciation). Currency crises are declared based on Frankel and Rose (1996) who define an currency crisis as a significant variation in the nominal exchange rate, i.e. a nominal depreciation of a currency of at least 25%. Then, we declared an inflation crisis for an annual inflation rate of more than 10%.[18] Inflation Crises are more frequent than Currency ones. And Cost reflectivity measure remains more frequent than the Automatic tariff adjustment.

VI. Estimation: Local Projection and AIPW Estimator

Following Jordà and Taylor (2016) in estimating the time of austerity and Atsebi, Combes and Minea (2019) in assessing the trade costs of financial crises, we use a combined method of local projections (LP) à la Jordà (2005) and an impact assessment methodology.[19] This analysis consists of three steps: (i) estimating the probability of inflation or currency shocks (crises), i.e. estimating the propensity score of each type of shock according to their determinants, (ii) fitting an outcome model in which changes in our outcome variables (installed capacity) are explained by their determinants, (iii) and implementing a semi-parametric estimator of the average treatment effect (ATE), namely the Augmented Inverse Propensity Weighted (AIPW), using the predicted propensity scores obtained in the first step, as well as the observed and potential values (predicted in the second step) of the change in installed capacity.[20] See our Appendix B for more details on how we use the AIPW estimator in this analysis. The typical LP equation we estimate has the following form:

[18]Data on inflation and exchange rate are provided by World Development Indicators (WDI) which is the primary World Bank collection of development indicators, compiled from officially recognized international sources.

[19]Blagrave and Furceri (2021) also applied Impulse Response Functions (IRFs) or LP to assess the macroeconomic effects of electricity sector privatization.

[20]For instance, Imam, Jamasb and Llorca (2019) used total installed capacity as performance indicator in the power sector. Also, Jamil et al. (2022) have shown that the main benefit of private sector participation in Pakistan came from the timely expansion of installed capacity.

TABLE 2— SUMMARY STATISTICS

	Obs	Mean	Std. Dev.	Min	Max
Installed capacity (million kW)	1,594	2.45	7.16	0.002	58.22
Inflation, consumer prices (annual %)	1,407	15,719.55	586236.18	-11.69	2.20e+07
Official exchange rate (LCU per USD)	1,565	4.30e+06	1.70e+08	2.39e-09	6.72e+09
Currency depreciation (against USD)	1,509	-7.21	16.53	-100	39.34
Independent Regulation (Yes=1, No=0)	1,620	0.46	0.50	0	1
Auto. Tariff Adjustment (Yes=1, No=0)	1,620	0.09	0.28	0	1
Tariff Cost Reflectivity (Yes=1, No=0)	1,620	0.12	0.32	0	1
Inflation Crises (Yes=1, No=0)	1,408	0.23	0.42	0	1
Currency Crises (Yes=1, No=0)	1,531	0.11	0.31	0	1

$$y_{i,t+h} - y_{i,t} = \alpha_i^h + \Lambda^h D_{i,t} + \beta_{L1}^h \Delta y_{i,t-1} + \beta_{L2}^h \Delta y_{i,t-2} + \beta_C^h y_{i,t}^C + v_{i,t+h} \quad (17)$$

for $h = 1, \ldots, 5$, and where $y_{i,t+h} - y_{i,t}$ represents the cumulative change between time t and $t+h$ in private participation in the electricity sector (installed capacity), the α_i^h are country fixed effects, and $D_{i,t}$ represents the interest variable (a dummy variable indicating the presence or absence of an inflation or currency shock).[21] Furthermore, in order to control for the return to the potential trend in private participation, the term $y_{i,t}^C$ is the participation gap, denoting the cyclical component of the participation flows (installed capacity), and is represented here by the deviations of log Capacity from an estimated HP trend with a smoothing parameter of $\lambda = 100$.[22] We use the indices $L1$ and $L2$ for the parameters β associated with $\Delta y_{i,t-l}$ for $l = 1, 2$.[23] Finally, $v_{i,t+h}$ is the error term.

[21] We approach private participation through the evolution of installed capacity because over the last few decades, since the beginning of the liberalisation of the electricity sector in Africa in order to cope with the budgetary difficulties of the States in financing new power plants, most of the investments on the continent have been made by private actors, notably through the PPPs or IPPs.

[22] The Hodrick-Prescott filter (the so-called ”HP filter”), developed by economists Edward C. Prescott and Robert J. Hodrick, is used to separate business cycles (short-term fluctuations or trends) from the long-term trend.

[23] $\Delta y_{i,t-1}$ and $\Delta y_{i,t-2}$ are respectively the change in the investment flows one and two years prior to the crisis.

VII. Results

In line with standard procedures, the propensity score used here is based on a probit model. The Figures C1 and C2 (Appendix C) provide smooth kernel density estimates of the propensity score distribution for the treated and control units to check for overlap. According to Jordà and Taylor (2016), one way to think about overlap is to consider what the overlap would be in an ideal RCT. In this case, the empirical distributions of the propensity score for the treated and control units would be uniform and identical to each other. At the other extreme, suppose that treatment is allocated mechanically on the basis of controls. In this case, the distribution of treated units would peak at one and be zero elsewhere, and the distribution of control units would peak at zero and be zero elsewhere. In our case, both figures show considerable overlap between the distributions, indicating that we have a satisfactory first-stage model for correctly identifying ATE using the AIPW method. However, both figures also indicate that some observations are likely to have very high weights. Specifically, there are (treated) control units with propensity scores close to zero (one). The AIPW estimator has the property that high weights are compensated at the same rate by the augmentation term, which makes truncation unnecessary in our case.

We then estimate the cumulative responses and their sum at the five-year horizon.[24] The

[24] Barro (2001) and Park, Lee et al. (2003) suggest that the persistence of the effects of the currency crises on growth is no more than five years for instance.

crisis dummies (inflation and currency) are our treatment variables, so we estimate only the average treatment effects. As illustrated through the Table 3, our main results show that the effects of inflation and currency crises on private participation (installed capacity) are mitigated for the group of countries that have established an independent electricity regulator compared to the countries that have not yet done so. This is especially true if regulators in these countries adopt automatic tariff adjustment mechanism and power generation cost reflectivity for operators. For countries with a regulatory agency in place, the cumulative loss over five years due to a currency crisis, in terms of installed capacity, is 3.36% compared to 7.58% for countries without a regulatory agency in place. The loss is twice as great for the latter. When analysing the impact of an inflation crisis, the five-year loss in installed capacity is only 1.67% for countries with a regulatory agency in place, compared to 5.66% for countries without an independent regulatory agency.

For regulators who have put in place an automatic tariff adjustment mechanism, the cumulative loss over five years due to a currency crisis, in terms of installed capacity, is 2.31% compared to 5.47% for agencies that have not adopted this measure. The loss is twice as great for the latter because it is not only a question of setting up a regulator, but above all that this regulator, once established, should put in place incentives for private actors. When we analyse the impact of an inflation crisis, we have no loss over five years in installed capacity for agencies that have opted for an automatic tariff adjustment mechanism, compared to 3.23% for agencies without this measure.

When analysing the impact of a currency crisis, the five-year loss in installed capacity is only 1.52% for regulators that have adopted cost reflectivity, compared to 6.19% for regulators that have not. Also, when analysing the impact of an inflation crisis, the five-year loss in installed capacity is only 2.36% for regulators that have adopted cost reflectivity, compared to 4.18% for regulators that have not.

Figure 2 displays the coefficients shown in the Table 3. Broadly, our results underline that inflation or currency crises have negative effects on the evolution of installed capacity, both in terms of year-by-year impact and in terms of the cumulative five-year period. However, the establishment of an independent regulator, which in addition develops measures such as automatic tariff adjustment mechanism and power generation cost reflectivity, significantly mitigates these negative effects.

It should also be noted that the establishment of an independent regulator is certainly necessary, but this is not sufficient to correct all the currency (-3.36% of cumulative loss over five years) and inflation (-1.67%) shocks. The implementation of an automatic tariff adjustment mechanism, for example, would reduce the impact of a currency shock to -2.31% and of inflation to +0.07%. Better still, the implementation of the cost reflectivity reduces the impact of currency shocks to only -1.52% and that of inflation to +2.36%. It should also be noted that the impact of a currency shock is on average more severe than that of an inflation shock. This could reflect the fact that domestic wages would not be a priori indexed to inflation in most countries in Africa, so domestic inflation which does not lead to a depreciation of the exchange rate will not have necessary a considerable effect on the cost of power generation. It could also reflect the fact that the inflation-depreciation vicious cycle does not always have to be verified.

VIII. Concluding remarks

To follow up on this literature on the relationship between regulation and investment in a global way, we focused on the African power sector and clarified what type of regulation (tariff regulation) and what type of shock it corrects (currency shock and inflation shock). First, our theoretical framework set out the ideas on how an inflation shock could give rise to a currency shock (vicious circle of inflation and depreciation), and then how these currency fluctuations impact the investment decision, particularly of private actors in power generation in Africa. Second, we have developed a methodology that combines impact assessment and local projections (LP) à la Jordà (2005) to capture the effect of inflation and currency crises on the evolution of installed capacity according to the characteristics of the electricity sectors on the African continent (existence of an independent regulatory agency, application of standard norms in terms of tariffs).

TABLE 3—AIPW ESTIMATES

Average Treatment Effect of Currency Crisis on Installed Capacity						
	Year 1	Year 2	Year 3	Year 4	Year 5	Sum
Independent Regulatory Agency = 1	-0.43	0.34	-0.26	-1.22	-2.62**	-3.36**
	(0.78)	(0.75)	(0.90)	(0.93)	(1.07)	(1.28)
Independent Regulatory Agency = 0	0.19	-0.49	-2.66***	-4.54***	-7.75***	-7.58***
	(0.30)	(0.44)	(0.73)	(1.26)	(1.82)	(2.17)
Auto. Tariff Adjust. Mechanism = 1	-3.15	0.26	-0.54	-1.78	-2.17	-2.31
	(3.45)	(3.68)	(3.21)	(3.39)	(3.47)	(3.13)
Auto. Tariff Adjust. Mechanism = 0	0.18	-0.67	-2.42***	-3.38***	-5.41***	-5.47***
	(0.42)	(0.53)	(0.84)	(1.01)	(1.26)	(1.44)
Tariff Cost-Reflectivity = 1	-4.77	-1.62	0.28	-1.30	-2.20	-1.52
	(3.71)	(3.59)	(2.75)	(2.20)	(2.26)	(2.12)
Tariff Cost-Reflectivity = 0	0.11	0.38	-0.50	-2.21***	-4.89***	-6.19***
	(0.45)	(0.59)	(0.70)	(0.68)	(1.05)	(1.39)
Observations	1105	1064	1023	981	939	897
Average Treatment Effect of Inflation Crisis on Installed Capacity						
	Year 1	Year 2	Year 3	Year 4	Year 5	Sum
Independent Regulatory Agency = 1	-0.60	0.11	-0.18	-1.14	-0.74	-1.67
	(0.74)	(0.82)	(0.78)	(0.80)	(0.83)	(1.08)
Independent Regulatory Agency = 0	-0.29	-2.04**	-1.76***	-2.71***	-3.58***	-5.66***
	(0.68)	(0.79)	(0.62)	(0.72)	(0.92)	(1.35)
Auto. Tariff Adjust. Mechanism = 1	-3.44	-0.46	1.22	0.60	0.52	0.07
	(3.69)	(4.16)	(3.97)	(3.81)	(3.71)	(3.15)
Auto. Tariff Adjust. Mechanism = 0	-0.03	-0.29	-0.79	-1.32	-2.19**	-3.23***
	(0.41)	(0.38)	(0.51)	(0.80)	(0.85)	(0.98)
Tariff Cost-Reflectivity = 1	-2.34	-0.92	-0.31	-0.62	-0.39	2.36
	(2.25)	(2.00)	(1.79)	(1.63)	(2.28)	(2.89)
Tariff Cost-Reflectivity = 0	-0.06	-0.38	-0.93*	-1.51*	-2.57***	-4.18***
	(0.43)	(0.41)	(0.50)	(0.80)	(0.84)	(0.83)
Observations	1100	1057	1014	970	926	882

Note: Empirical sandwich standard errors (clustered by country) in parentheses. ***/**/* Indicates p $<$ 0.01/0.05/0.10. Controls: cyclical component y^C of y, two lags of change in y, country fixed effects. y^C is the cyclical component of log y, from the HP filter with k=100. The propensity score is based on the probit model and includes treatment($t-1$), current and lagged values, cyclical component, and growth rate of inflation or exchange rate depending on the model. It includes also two lags of change in inflation/exchange rate. The specification includes country fixed effects in the propensity score model and in the AIPW model.

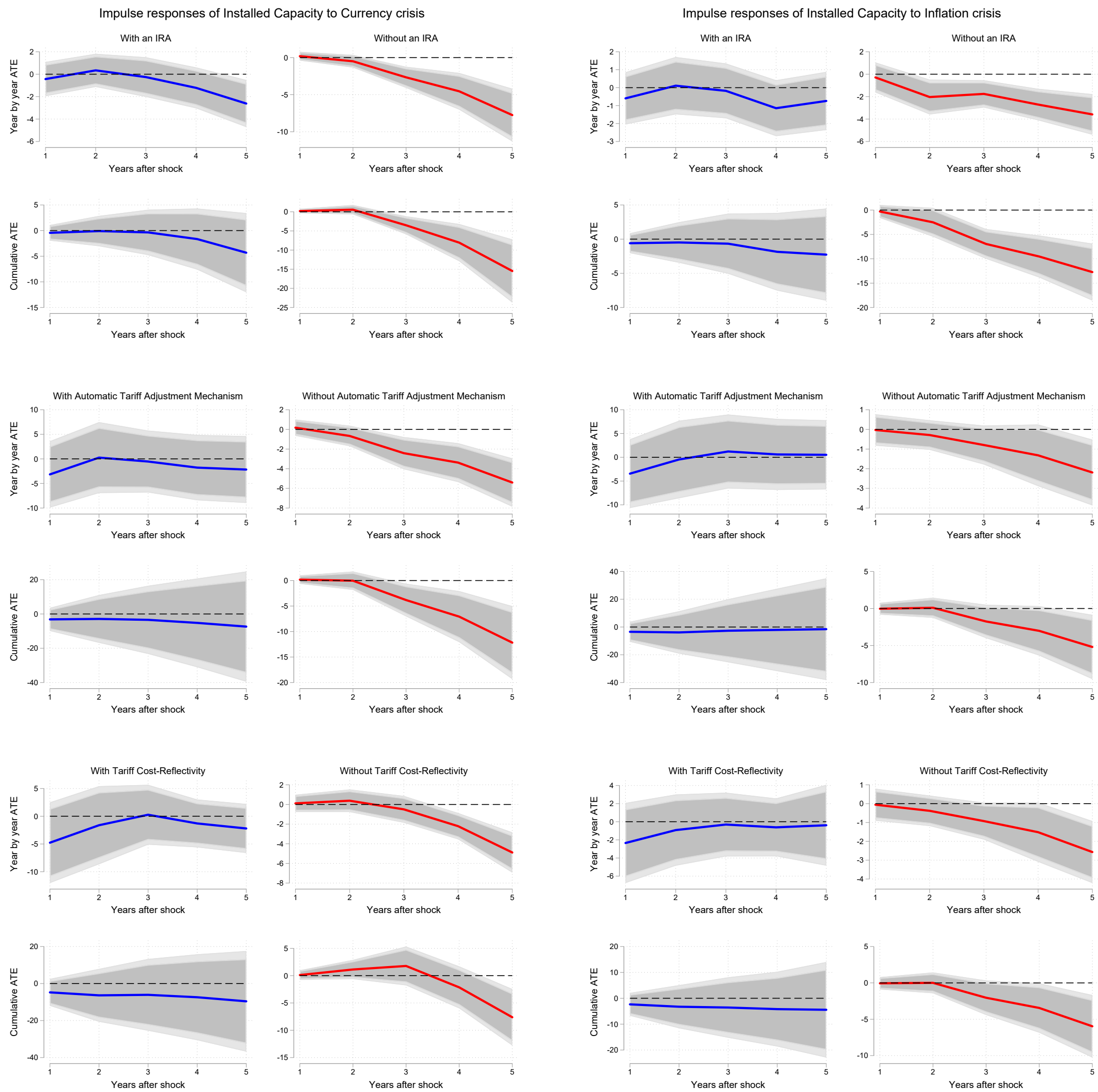

FIGURE 2. AIPW ESTIMATES OF THE RESPONSE OF THE OUTPUT (CAPACITY), DEVIATIONS OF LOG OUTPUT (RELATIVE TO YEAR 0, × 100). NOTES. THE ACCUMULATIVE ATE RESPONSES ARE BASED ON $y_{t+h} - y_t$, WHILE THE ACCUMULATED ATE OUTPUT LOSS IS THE RUNNING SUM OF THE COEFFICIENTS DISPLAYED IN THE TABLE 3. 95% AND 90% CONFIDENCE BANDS DISPLAYED.

To correct for potential endogeneity problems, we estimate the ATE of inflation and currency crises by the AIPW Estimator. Broadly, our main results show that the effects of inflation and currency crises on private participation (installed capacity) are mitigated for the group of countries that have established an independent electricity regulator compared to the countries that have not yet done so. This mitigation effect is reinforced for countries whose regulator adopts an automatic tariff adjustment mechanism and the cost reflectivity for private operators in particular. Also, the establishment of a regulatory agency without some relevant measures cannot correct all the effects of currency and inflation shocks. Indeed, the empirical results show that cost reflectivity measures would be much more effective, followed by the automatic tariff adjustment mechanism, compared to a simple implementation of an independent regulatory agency. Finally, currency crises appear to be much more severe than inflation crises over the period of our analysis.

For the countries of the region, the authorities must imperatively ensure that domestic prices are controlled. As we have recalled in the vicious circle of inflation and depreciation, a rise in domestic prices could lead to a depreciation of the national currency against the currencies of trading partners. This, as we have shown through our theoretical framework, could penalise private actors who import fixed capital (turbines, generators, etc.) and variable inputs such as fuel in their power generation process. If domestic prices cannot be controlled for structural reasons, the implementation of a fixed change regime could limit the link between domestic price increases and local currency depreciation. In the extreme case where the country is facing important exogenous shocks, which makes the fixed change regime inappropriate, then for the proper continuation of the electrification programs, as suggested by Jamasb et al. (2021), the authorities must imperatively put in place independent regulatory agencies which will in turn ensure that a proper tariff methodology is put in place in order to further incite the private sector to invest massively in the sector.

The authorities also should promote local production of equipment used in power generation in order to reduce foreign dependence in terms of fixed inputs. For net fossil fuel importing countries, it would be ideal to invest more in renewable energy sources in order to reduce energy bills, especially in times of currency depreciation. Finally, interconnection projects between the various power networks in the continent, for example through initiatives such as the West African Power Pool (WAPP), should be more frequent and supported by regional development institutions such as the African Development Bank (AfDB) or the West African Development Bank (BOAD).

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APPENDIX A: PRIVATE PARTICIPATION

TABLE A1—PRIVATE SECTOR SHARE OF INSTALLED CAPACITY AVAILABLE IN 2016 IN 20 AFRICAN COUNTRIES

Country	*Capacity (MW)*	*IPP's share (%)*
Cabo verde	100	20
Cameroon	1,300	24
Côte d'Ivoire	1,900	52
Gambia	100	43
Ghana	3,800	18
Kenya	2,200	25
Madagascar	500	10
Mauritius	800	39
Mozambique	2,700	10
Namibia	600	2
Nigeria	4,900	31
Rwanda	200	34
Senegal	900	32
South Africa	50,200	11
Swanziland	200	23
Tanzania	1,600	19
Togo	200	49
Uganda	900	49
Zambia	2,600	15
Zimbabwe	2,100	6
Total	**77,800**	**25.6**

Proparco, IEA, WEO 2016

APPENDIX B: THE AUGMENTED INVERSE PROPENSITY WEIGHTED (AIPW) ESTIMATOR

In this analysis, we consider that crises (inflation crisis or currency crisis) represent the treatment variables, and changes in installed capacity at each h horizon represent the outcome variable. The average treatment effect (ATE) is defined as follows:

$$ATE = \Lambda^h = E\left[y_{i,t+h} - y_{i,t} \mid D_{i,t} = 1\right] - E\left[y_{i,t+h} - y_{i,t} \mid D_{i,t} = 0\right];\ \forall h \tag{B1}$$

But $E\left[y_{i,t+h} - y_{i,t} \mid D_{i,t} = 0\right]$ is not observable. We must therefore use a counterfactual to approximate it. Under the assumption of independence $\left[y_{i,t+h} - y_{i,t}\right] \perp D_{i,t} \mid Z_{i,t}$; $\forall h$, i.e. for a crisis occurrence independent of potential outcomes conditional on a set of covariates $Z_{i,t}$, we estimate the ATE by comparing the outcome in countries with and without crisis conditional on the set of variables $Z_{i,t}$. The ATE becomes:

$$ATE = \Lambda^h = E\left[y_{i,t+h} - y_{i,t} \mid D_{i,t} = 1;\ Z_{i,t}\right] - E\left[y_{i,t+h} - y_{i,t} \mid D_{i,t} = 0;\ Z_{i,t}\right];\ \forall h \tag{B2}$$

To estimate the ATE in this paper, we use the AIPW estimator which requires the estimation of two models, the treatment model and the outcome model. For the treatment model, we estimate a probit for each crisis on the determinants, and obtain the propensity scores $\hat{p}_{i,t}$ and $1 - \hat{p}_{i,t}$ for country i in year t to be in the treatment and control group respectively. Introduced by Rosenbaum and Rubin (1983), the propensity score is of particular interest for our analysis in order to eliminate biases between the treatment and control groups, and we use the weighting by propensity scores to mimic a situation where crises occur at random. The outcome model (LP Equation, see Equation 17) is estimated separately on the treatment and control groups, and we predict the potential outcome $\widehat{E}\left[y_{i,t+h} - y_{i,t} \mid D_{i,t} = d;\, Z_{i,t}\right];\ \forall d \in \{0,1\}$ for the whole sample, based on the characteristics of each group. This provides the potential outcome for countries in the treatment (control) group if they did (did not) experience crises, conditional on all control variables. Following the general expression for the AIPW provided by Lunceford and Davidian (2004), we calculate the estimated ATE of crises on our outcome variables for h years or horizons as:

$$\text{(B3)}\quad \widehat{\Lambda}^{h}_{AIPW} = \frac{1}{n}\sum_{i}\sum_{t}\left(\left[\frac{D_{i,t}\left(y_{i,t+h} - y_{i,t}\right)}{\hat{p}_{i,t}} - \frac{\left(1 - D_{i,t}\right)\left(y_{i,t+h} - y_{i,t}\right)}{1 - \hat{p}_{i,t}}\right] - \frac{D_{i,t} - \hat{p}_{i,t}}{\hat{p}_{i,t}\left(1 - \hat{p}_{i,t}\right)} \times \left[\left(1 - \hat{p}_{i,t}\right)\widehat{E}\left[y_{i,t+h} - y_{i,t} \mid D_{i,t} = 1;\, Z_{i,t}\right] + \hat{p}_{i,t}\widehat{E}\left[y_{i,t+h} - y_{i,t} \mid D_{i,t} = 0;\, Z_{i,t}\right]\right]\right)$$

This semi-parametric estimator has the particularity of being the most efficient of the doubly robust estimators, i.e. it is unbiased when at least the outcome or treatment model is correctly specified (Lunceford and Davidian, 2004; Imbens, 2004). Moreover, compared to the inverse propensity weighted (IPW) estimator, it includes an additional adjustment term consisting of the weighted average of the two predicted potential outcomes, which stabilises the estimator when the propensity scores are close to zero or one, and whose expectation is zero when the treatment or outcome model is correctly specified (Glynn and Quinn, 2010). Finally, they conclude that the AIPW estimator has a mean square error comparable to or lower than competing estimators when both the treatment and outcome models are correctly specified, and outperforms them when one of these models is misspecified.

Appendix C: Kernel density

C1. Inflation Crisis

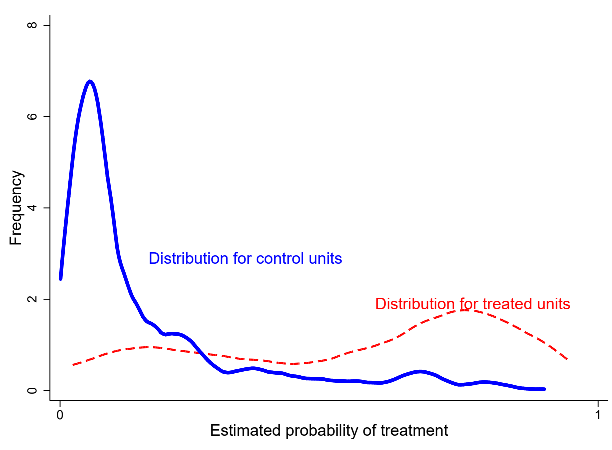

FIGURE C1. *Kernel density of the distribution of the propensity scores for the treated and control groups*

NOTES. THE PROPENSITY SCORE IS ESTIMATED USING THE PROBIT SPECIFICATION, WHICH INCLUDES COUNTRY FIXED EFFECTS. THE FIGURE SHOWS THE PREDICTED TREATMENT PROBABILITIES WITH A DASHED LINE FOR THE TREATMENT OBSERVATIONS AND A SOLID LINE FOR THE CONTROL OBSERVATIONS.

C2. *Currency Crisis*

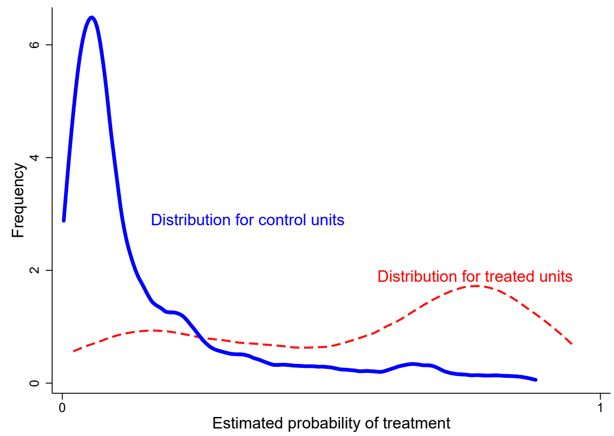

FIGURE C2. *Kernel density of the distribution of the propensity scores for the treated and control groups*

NOTES. THE PROPENSITY SCORE IS ESTIMATED USING THE PROBIT SPECIFICATION, WHICH INCLUDES COUNTRY FIXED EFFECTS. THE FIGURE SHOWS THE PREDICTED TREATMENT PROBABILITIES WITH A DASHED LINE FOR THE TREATMENT OBSERVATIONS AND A SOLID LINE FOR THE CONTROL OBSERVATIONS.