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The retirement cliff: Power plant lives and their policy implications☆

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ABSTRACT

This paper examines more than a century of U.S. power plant additions and retirements in conjunction with several decades of utility capital investment data. While policy analyses often invoke assumptions of power plant *book* life, relatively little analysis has focused on the *physical* life of power-generating assets. The average age of the U.S. generator fleet has increased significantly over time despite continued investment, in part because more recent investment has tended to focus on shorter-lived assets. This may be due in part to risk-averse power sector investors and lenders responding rationally to regulatory uncertainty in a deregulated market environment. Power plant retirement trends suggest that the pace of retirements will increase significantly in the decade after 2030 for most reasonable estimates of physical life. These capital investment trends have important consequences for carbon policy and highlight the importance of including consideration of the longer term—particularly when evaluating more significant decarbonization policies.

1. Introduction

Since the birth of the U.S. power generator fleet in the late 19th century, its nature has evolved over time along dimensions of technological innovation, market and regulatory developments, environmental requirements, and varying operating costs. National and regional fleet-level studies have incorporated these dimensions into their analyses as a means of characterizing historical and future policy choices (e.g., Awerbuch (2000), Ladd (2000)). These dimensions have also been used as variables to influence certain outcomes (such as fuel diversity (Awerbuch, 2006), fuel procurement costs (Cicala, 2015), environmental compliance (Murray et al., 2015), or corporate investment portfolio optimization (Rode et al., 2002)). Rather less attention, however, has been devoted to the characterization of the fleet by age or by expected physical life.

"Life" has been an elusive concept in many analyses because its nature, even when defined, has been somewhat fluid, resulting in a proliferation of terms. To be sure, different applications may have differing objectives in the use of "life," but in many cases there is a problematic comingling of terms with differing underlying definitions in the same analysis.[1] More succinctly, many analyses make use of *judgment-based* estimates about age and life, rather than make use of historical data-based *statistical* estimates. The inherent uncertainties involved not just in estimating life, but also in defining it, will affect the appropriateness of any analysis. We identify three primary types of life definitions by application: (i) regulatory and taxation applications, (ii) policy analysis and engineering economics applications, and (iii) investment applications. Irrespective of the various objectives used to select a particular definition, we note that any means of assigning a particular life to a particular type of power plant in an analysis has the potential to either penalize or reward it relative to other power plant types. In addition, the specificity of any resulting analysis is only as good as that of its input assumptions and problem framing.

There is a considerable body of empirical evidence on actual physical life from which to draw inferences as to the estimated physical life of power-generating assets. In this paper, we review the historical evidence on physical life and present some of the stylized facts that emerge from the data. First, the U.S. power plant fleet has grown progressively older over time. Even as new investment has increased, the fleet's average age has steadily increased. Second, there appears to have been a distinct shift toward shorter-lived plants over time, and also to plants with lower operational utilization (as reflected by capacity factor). Third, due to a confluence of retirement trends, there appears to be a precipitous decline in installed capacity looming after 2030 (the

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[1] For example, an analysis of plant-level environmental compliance options may use book lives to evaluate costs (via a levelized cost of electricity), but employ market forecasts from the Energy Information Administration's NEMS model (which uses economic life and does not retire plants for physical reasons).

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compliance deadline in the U.S. Environmental Protection Agency's (EPA) proposed Clean Power Plan (CPP)). This decline presents significant challenges for long-term planning—in particular in regard to carbon reduction policy—and has been largely ignored in most policy analyses of carbon compliance strategies. Neither the EPA's own Regulatory Impact Analysis of the CPP (EPA, 2015) nor analysis of the impact of the U.S. Supreme Court's stay of the CPP (Linn et al., 2016) address the potential post-2030 retirements or even extend their analysis past 2030 (but see Shellenberger and Penafiel (2016) for an analysis of the environmental impact of potential nuclear retirements).

We address each of those issues in turn in this paper. Section 2 reviews the existing literature on the concepts of power plant age and life. Section 3 describes the data used in this analysis. Section 4 examines trends in how the U.S. power plant fleet is aging in the context of the evolution of its expected physical life and the role of age and life in capital investment productivity. Section 5 illustrates that one consequence of these trends is that likely retirement behavior may present a significant challenge to deep decarbonization efforts, as well as significant potential future costs. Section 6 reviews our conclusions and suggests policy implications of these findings.

2. Literature review

In Section 1 we identified three types of applications of life definitions. Understanding the differences between these applications and their relationships to actual, observed physical life and capital investment productivity serves to highlight the implications of this study's analysis for policy applications.

Regulatory and taxation applications have tended to focus on the concepts of depreciable life (Phillips, 1993) and effective age (Appraisal Institute, 2013). Depreciable (or "book") life is defined as the time period over which fixed costs are assumed to be recovered for accounting purposes (Gitman et al., 2014). The effective age of a property measures age against a comparable new property and is used to capture the actual condition of the property rather than its chronological age or historical age (American Society of Appraisers, 2011). In many cases, these estimated lives are set either by rule or statute (such as those in the Internal Revenue Service's now-deprecated *Bulletin F* or *Publication 946*) or by administrative procedure or precedent and are not actually estimates in the statistical sense of the physical life (or "service life") of the property in question.[2] When these applications, such as integrated resource planning or tax assessment, make use of life, it is often for purposes of ranking or valuing alternatives, meaning that the assumptions made can have material consequences.

Policy analysis and engineering economics have tended to focus on the concepts of book life or economic life. Some forecasting analyses implicitly assume power-plant lives in projecting forward generator addition and retirement behavior.[3] These book-life figures, however, are estimates of cost amortization duration, and often not statistical estimates of how long a given power plant may last in operation. Indeed, some analyses often assume identical lives for all plant types (e.g., CEC (2014)). The U.S. Energy Information Administration (EIA), for example, uses the terms "financial life" and "economic life" (although they remain undefined), but allows plants to run with no predefined retirement age (NREL, 2010; EIA, 2014a). Other government sources use different estimates of book and economic life (e.g., NREL (2011a), NETL (2011)).

The investment world uses concepts such as "economic useful life" and "remaining useful life" that attempt to capture both the physical life of the plant and the economic value of its remaining in operation (Appraisal Institute, 2013). Traditional valuation methods such as discounted cash flows require projections of revenues and expenses across a plant's full economic useful life. The use of "survivor curves" in estimating lifespan and depreciation for power plants illustrates the importance the investment world attaches to empirically-based measures of life (Ellsworth, 2000). Implicit in these uses is the acknowledgement that certain plant components may be replaced or overhauled over the course of their lives, extending the physical life of the plant—but only if economic conditions justify the capital investment required.[4]

In spite of the pervasive use of differently-defined life concepts, few studies have attempted to address how long power plants actually remain in operation (the brief articles of EIA (2011) and Powell (2013) are exceptions). We shall refer to this as the "physical life" of a power plant. The physical life of a power plant would seem to be of considerable importance, notwithstanding its relative lack of use, because physical life reflects the actual period of time over which a plant's costs and benefits may be realized by consumers, the actual duration[5] of its emissions impact on the environment, the extent of actual economic productivity policymakers reasonably may expect from capital investment in it, and its value as an investment. In addition, at a fleet level, the average age of the fleet tells us something about future capital investment activity and the productivity of such investment capital.

Utility productivity has typically been measured in economics by estimating output (Q, as electricity production) as a function of labor (L), fuel (F), and capital (K) inputs: $Q = f(L, F, K)$. On this basis, Rhine (2001), among others, noted that utilities had excess capital and that deregulation of the industry would reduce overcapitalization and thereby increase (capital) productivity. In empirical work looking back at the transition to deregulation, Goto and Makhija (2009) find that deregulation did not increase productivity as expected. However, their study measured output as utility revenue. As Granderson (2006) noted, however, firms that seek to pursue (voluntarily or compulsorily) "corporate socially responsible behavior" may face an accounting problem in measuring productivity because Q must measure both production of good outputs *and* the reduction in "bad" outputs (e.g., emission of pollutants). That is, productivity may increase even if "good" Q (megawatt-hours) stays flat and K increases if production of "bad" Q also decreases (as a result of technological improvements that increase the efficiency of fossil plants, for example). While Goto and Makhija (2009) did not find general evidence of productivity increases, they did find positive productivity effects for high levels of spending on "environmental production facilities," which is consistent with Granderson's (2006) work showing that productivity may increase with a reduction in "bad" outputs, not only an increase in "good" outputs. We note in this paper that the same results appear to be present: increasing capital investment over the past 20 years appears to coincide not with increasing electricity production, but more with reduction of emissions. We leave to future work whether this shift has translated into gains in capital productivity.

3. The data

In this paper, we use simple definitions of age and life. The age of a power plant is the difference between the date of the analysis and the

[2] For example, many states have implemented administrative procedures to standardize property taxation practice. Nevada, for example, specifies a uniform 30-year life for all "electric power generation, transmission, and distribution" property (Nevada Department of Taxation, 2013: p. 20).

[3] We say "implicitly" here because the U.S. Energy Information Administration, for example, uses 30-year lives for generator entry and exit decisions, but otherwise imposes no physical life constraints on generators. Generators modeled in its NEMS framework are assumed to exist until no longer economically viable (NREL, 2010: p. 15). While increasing maintenance capital expenditures with plant age is assumed as part of the assessment of plant economic viability, no consideration is given to physical age itself.

[4] Or, to use the appraisal terminology, reducing its effective age.

[5] We refer here specifically to emissions while operating, and not to any potential environmental impact that may occur during construction or continue after a plant ceases operation, such as waste disposal.