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Mean-variance portfolio methods for energy policy risk management☆

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ABSTRACT

The risks associated with current and prospective costs of different energy technologies are crucial in assessing the efficiency of the *energy mix*. However, energy policy typically relies on the evolution of average costs, neglecting the covariances in the costs of the different energy technologies in the mix. The Mean-Variance Portfolio Theory is implemented to evaluate jointly the average costs and the associated volatility of alternative energy combinations. In addition systematic and non-systematic risks associated to the energy technologies are computed based on a Capital Asset Pricing Model and considering time varying betas. It is shown that both electricity generation and fuel use imply risks that are idiosyncratic and with relevant implications for energy and environmental policy.

1. Introduction

Sustainability, competitiveness and security of supply are central objectives for energy policy in developed countries. The achievement of those goals requires in the near future a transition towards an energy mix more balanced among the different energy sources (IEA, 2010). The process is not at all free of uncertainties, from demand and supply challenges in the oil market to regulatory risks and factors related to energy security (EC, 2006). Further, climate change concerns cannot be disregarded in relation to sustainable alternatives while taking into account the uncertainty of CO_2 emission costs. Whereas the electricity sector seems in a stage of somewhat an efficient managing of aggregate risks [cf. Moselle, 2010], this does not appear to be the case at all for the road transport sector. In this context, identifying the optimal degree of fuel mix diversity for a country or a particular company requires valuation approaches of energy investments which trade off the risk and returns of diversification.

To analyze these issues, we build upon tools that have been widely used in the financial literature. First, we implement the *Mean-Variance Portfolio Theory* [MVPT; Markowitz (1952); Luenberger (1998)] to assess the trade-offs in risk management from the point of view of energy policy. In so doing, both the average cost and the associated risk of the different energy technologies are simultaneously taken into account for energy planning. This enables to compute minimum variance energy portfolios for any given level of expected generation cost. Such efficient portfolio therefore minimizes risk, as measured by the standard

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deviation of return, and shows directions for improvement in both average cost and risk while starting from a reference energy mix.[1]

Second, beyond the MVPT approach to the risk of an energy portfolio, a contribution in this paper is to consider the Capital Asset Pricing Model (CAPM) framework to compute systematic and non-systematic risks. Since the seminal papers by Sharpe (1964) and Lintner (1965), such a distinction has been commonly implemented in the financial literature [Boyle (1994); Jagannathan and McGrattan (1995); Fama and French (2004)] and recently considered in risk management analysis of commodity prices (Chen, 2010), but it has not been implemented to evaluate energy portfolios to the best of our knowledge. Clearly, though, if the main concern for energy policy risk management is hedging against oil price shocks then, systematic, that is, undiversifiable aggregate risk, rather total risk, has to be the instrument to characterize the efficient energy mix. In this framework, we check the time-varying properties of CAPM beta parameters.[2] We show that, from an energy policy perspective, it is important to consider the stability of parameters against time-varying risks rather than to capture the dynamics of these parameters.

Indeed, one key feature in the application of MVPT to energy portfolios is the complementarity among the various technologies in the mix. In that respect, Awerbuch (2000) analyzes US gas-coal generation mix, and shows that adding Wind, Photovoltaics and other fixed-cost renewables to a portfolio of conventional generation technologies serves to reduce overall portfolio cost and risk, even though their stand-alone generating cost may be higher. Several authors have elaborated on better characterizing that kind of complementarity. Krey and Zweifel (2006) refine the econometric evidence for Swiss and US power generation efficient frontiers, by implementing SURE to obtain reasonably time-invariant covariance matrices as an input to the determination of efficient electricity-generating portfolios. Roques, Newbery, and Nuttall (2008) introduce simulation techniques and portfolio optimization to illustrate the dominance of coal technologies in optimal portfolios due to the high degree of correlation between electricity and gas price in liberalized markets.

Another key feature of the approach is the potential for consideration of external costs. Marrero, Puch, and Ramos-Real (2011) considers CO_2 externalities to analyze the projected generating mix for Europe in 2020 (EU-BAU) highlighting the importance of complementarity between traditional and renewable energies to reduce not only portfolio risk and average cost but also total CO_2 emissions. Roques, Hiroux, and Saguan (2010) apply the MVPT to identify cross-country portfolios that minimize the total variance of wind production for a given level of production across Austria, Denmark, France, Germany and Spain. They find that projected portfolios for 2020 are far from the efficient frontier, suggesting that there could be large benefits in a more coordinated European renewable deployment policy.

Our contribution here is in the application of the MVPT and the CAPM tools to characterize both an electric generation and a transport fuel frontier. The scope of use of these tools is well established in finance, but it is not sufficiently developed for the very relevant question of energy portfolio management, despite its strong potential as we show. In addition, while most energy applications in existing literature focus on the generation of electricity, here we show that it turns out overly useful to simultaneously analyze the electricity and fuel mixes while addressing the tension between total and systematic risks in energy portfolios.[3] Finally, the approach we take in this paper is that of a quasi-social planner maximizing social welfare, which is the standard approach for energy policy purposes, as emphasized by Awerbuch and Berger (2003).[4] Thus, in the two applications (electricity and road transport fuels), we analyze the consequences of the complementarities between the different energy technologies (Thermal Classic and Renewables), and for the case of electricity we apply sensitivity analyses to test the effects of including CO_2 external costs or to discuss various counterfactuals that are key for energy planning. An integrated specification of the risks in a joint primary energy mix for an energy system has major difficulties and goes beyond the scope of this paper.

In all of the cases we report the corresponding findings, but we focus on the methodological contribution rather than in the seldom energy results. We do so even though we use for the quantitative experiments precise input data that are also relevant for related applications. The reason is not that those findings are field oriented. Rather, we consider that the contribution of the methods in this paper, namely to offer a measure of how diversifiable an energy portfolio is, as well as of the stringency of systematic energy risks, is key for energy policy and does not belong to common wisdom in the field. We find that the complementarities of the technologies in electricity and fuel portfolios have to be effectively balanced with the target of total and systematic risks.

The paper is organized as follows. Section 2 describes the theoretical framework. Section 3 organizes the evidence on the various production costs and energy prices. In Section 4, the estimation of the energy efficiency frontiers for both total risk and systematic risk is discussed. Section 5 examines the main results of the paper for electricity and fuel frontiers, and the last section concludes.

2. Methodology: the mean-variance energy portfolio approach

By maximizing a social welfare function, the energy portfolio is characterized by a set of weightings, each between zero and one, of all feasible energy alternatives. Those weightings, say $X_1, \ldots, X_n$, must add up to unity, and are subject to certain technological

[1] MVPT theory has been often used in the financial sector to identify portfolios of bonds or stocks [see, among many others, Merton (1973); Shefrin and Statman (2000); Levy and Levy (2004) and, more recently, Hsu and Szu-Lang (2012)]. Bar-Lev and Katz (1976) is the first application of MVPT to the U.S. electricity industry [see also Humphreys and McClain (1998)]. Galvani and Plourde (2009) apply MVPT within energy asset and commodity markets. Bazilian and Roques (2008) provide a complete survey of the research applying MVPT to energy planning.

[2] For an alternative analysis on risk management, see Hammoudeh, Araújo-Santos, and Al-Hassan (2013), which uses Value-at-Risk based optimal portfolios for precious metals, oil and stocks. See also Chang, McAleer, and Tansuchat (2013) on crude oil.

[3] Guerrero-Lemus et al. (2012) is an exception to the traditional focus of existing literature in the electricity sector. These authors analyze in detail the average costs and cost volatility of conventional and renewable fuels, and of electricity of either non-renewable or renewable nature for vehicles, and discuss the findings obtained from the MVPT when implemented to worldwide road transport sector.

[4] It is also possible to apply MVPT from a private investor perspective to identify optimal portfolios for energy suppliers. Roques et al. (2008) analyze optimal portfolios for electricity generators in the UK electricity markets with this approach, concentrating on profit risk rather than production cost risk. Muñoz, Sánchez- Nieta, Contreras, and Bernal-Agustín (2009) present a model for investing in renewable energies in the framework of the Spanish electricity market. These authors show that technologies that have the lowest risk and the lowest return (PV and Thermo electrical) increase their market quota in more conservative scenarios.