An Efficient Energy Portfolio for Switzerland

Boris Krey and Peter Zweifel*
Socioeconomic Institute, University of Zurich

March, 2005

ABSTRACT: Using financial portfolio theory, this paper investigates energy mixes of Switzerland that efficiently satisfy two constitutional objectives, viz. secure provision and low cost to the economy. The efficient frontier in terms of final consumption is constructed estimating time-varying variances and covariances in energy prices using GARCH (Generalized Autoregressive Conditional Heteroscedastic) models. Additionally, the TGARCH variant serves to control for excess kurtosis. The results suggest that at observed market prices, a shift towards nuclear power and away from natural gas and gasoline would reduce both expected increase in the Swiss energy bill and its price volatility.

Keywords: energy portfolio theory, efficiency frontier, GARCH, TGARCH.

JEL: C22, C32, C53, G11, Q49.

This research was supported by the Federal Energy Research Commission and Swiss Federal Office of Energy. The authors thank Matthias Gysler, Lukas Gutzwiller, Tony Kaiser, Michel Piot, and Pascal Previdoli for many helpful comments.

*Socioeconomic Institute, University of Zurich, Hottingerstr. 10, 8032 Zurich, Switzerland. Tel. (B. Krey): +41-1-634 06 08; Fax: +41-1-634 49 87. E-mail addresses: boris.krey@soi.unizh.ch (B. Krey), pzweifel@soi.unizh.ch (P. Zweifel)
1 Introduction

The objectives of Swiss energy policy are laid down in art. 24 octies of the Constitution. The desired provision of energy is described by the attributes "sufficient", "diversified", "secure", "economical" and "environmentally compatible". Apart from the last attribute, this description reminds the reader very much of the decision problem of an individual who holds a portfolio of assets or liabilities. Liabilities such as bank credit, bonds floated, and shares floated all have their (negative) rates of return (i.e. interest and dividends payable) which however cannot be predicted with precision. Since Switzerland is a permanent net importer of energy (Swiss Federal Energy Agency, Schweizerische Gesamtenergiestatistik, several issues), the different types of energy constitute liabilities that must be accepted and paid for now and in the future. Their uncertain rate of return is their future increase in price; the lower the future price, the more the Swiss economy will benefit from "economical" supplies.

The holder of a portfolio of liabilities is also concerned with risk in that payables may exceed their expected value. Indeed art. 24 octies ostensibly addresses risk, the constitution speaking of "sufficient" and "secure" supplies. While this relates to quantities of energy, this risk translates into a financial risk once it is realized that (given low short-run price elasticities of demand (for the case of electricity, see e.g. Zweifel et al., 1997), a sudden reduction of supply would boost Switzerland’s energy bill.

One important way to reduce the risk of a portfolio of liabilities is diversification. In terms of energy policy, security of supply is enhanced if one relies on several sources whose prices are uncorrelated or negatively correlated. The attribute "diversified" in the constitutional article demonstrates once more that a portfolio interpretation of Swiss energy policy is admissible and fruitful.

Adoption of the portfolio approach has the important benefit that an efficient frontier for energy sources can be established. The efficient frontier indicates the minimum amount of risk (measured by variance) that can be attained for a given rate of return through appropriate diversification of the portfolio (Markowitz, 1952). In terms of energy policy, it indicates the set of efficient future mixes of energy sources (depending on the development of future energy prices). The key question to be answered by this paper is whether a gap between the present actual energy allocation and the efficient energy frontier exists and to what extent a change of the weights in the energy mix contributes to closing this gap.

The plan of this contribution is as follows. After a literature review in section 2, portfolio theory is adapted to the case of a portfolio of energy liabilities in sec-
In section 4, there follows a description of the econometric methodology applied to the time series of energy prices in order to filter out the systematic components of variances and covariances (GARCH, TGARCH). Section 5 contains the results of portfolio optimization. Conclusions are offered in the last section.

2 Literature Review

Portfolio theory and diversification have proved useful in areas other than corporate and personal investment.

Bar-Lev and Katz (1976) examine fossil fuel procurement to determine to what extent the U.S. utility industry has been an efficient utilizer of scarce resources. They create a Markowitz efficient frontier of fuel mixes which minimize the expected increase of fuel cost at a given risk. Their results show that while generally utilities are efficiently diversified, their portfolios are characterized by both high (negative) rates of return and risk. Furthermore, the authors suggest that regulation causes utilities to opt for high-risk alternatives. Utilities could move towards the efficient frontier by purchasing more higher-priced fuels that however exhibit little price fluctuation. A major problem with the approach of Bar-Lev and Katz is that it does not account for varying covariances in energy prices over time.

Humphreys and McClain (1998) construct an efficient portfolio frontier of U.S. energy consumption using time-varying variances and covariances estimated with generalized autoregressive conditional heteroscedastic (henceforth: GARCH) models. GARCH modeling allows to filter out changes in volatility in response to price shocks that could result in unstable estimates of the covariance matrix. The results indicate that while the electric utility industry is operating close to the minimum variance portfolio (see section 3), a shift towards coal would still reduce overall price volatility at a given expected increase in cost. With the inclusion of expected externality costs, the shift away from oil remains but favours natural gas instead of coal.

The study by Humphreys and McClain provides evidence that the price change series are characterized by skewness and excess kurtosis, suggesting that conditional densities are not normal. Under these conditions GARCH does not provide useful inferences and should be replaced by an alternative approach.

Yu (2003) presents a short-term market risk model again based on the Markowitz mean-variance approach for spatial electricity markets. Yu includes transaction costs and other constraints such as minimum contracting quantities
in wheeling into the model, resulting in a mixed integer programming problem. An interesting observation is that the Markowitz mean-variance efficient frontier is neither smooth nor concave anymore. The model is extended by specifying a GARCH process for the error term. However, the case of non-normal conditional densities is not considered.

3 Portfolio Theory

Rational holders of liabilities seek to minimize the expected increase of the liability portfolio (a negative rate of return) at a given risk. The expected (negative) return of such a portfolio depends on the expected returns of the individual liabilities and the percentage of funds invested in each. The risk of the portfolio depends on the covariance or correlation matrix of the individual returns.

The expected return on a portfolio $p$ consisting of $m$ risky liabilities is given by

$$E(R_p) = \sum_{i=1}^{m} w_i E(R_i)$$

where $E(R_i)$ is the expected percentage increase of liability $i$ and $w_i$ is the weight of liability $i$. The corresponding risk of such a portfolio, as measured by its variance, is

$$\sigma_p^2 = \sum_{i=1}^{m} \sum_{j=1}^{m} w_i w_j \text{cov}(R_i, R_j),$$

with $\rho(R_i, R_j) = \text{cov}(R_i, R_j) \cdot \sigma_i \sigma_j$,

where $\text{cov}(R_i, R_j)$ is the covariance between two risky returns on liabilities $i$ and $j$, $\rho$ is the correlation coefficient between $R_i$ and $R_j$, and $\sigma_i$ is the standard error of $R_i$. The efficient frontier is then given by the $w_i^*$ that solve either

$$\min_{w_i} E(R_p) = \max_{w_i} E(R_p) \quad \text{S.T. } \sigma_p^2 = \text{const.}$$

or

$$\min \sigma_p^2 \quad \text{S.T. } E(R_p) = \text{const.}$$
In an efficient portfolio, expected negative return cannot be decreased while holding variance constant and variance cannot be decreased while holding expected return constant.

Figure 1: Efficient portfolio of energy sources

Figure 1 displays the adjustment of the basic theory to the case of energy sources as liabilities. The objective now becomes to minimize the expected rate of increase of expenditure on energy subject to a given amount of volatility in this increase. In eqs. (3) and (4) $R_p$ is defined as the rate of increase per unit energy expenditure, i.e. of the price per MJ (megajoule). For example, let a country only hold Energy Source 1 at point A as a liability, which has low volatility but a high expected increase in price. By adding Energy Source 2 with its high volatility but low expected price increase to the portfolio (point B), the country may profit from a diversification effect. Thus, if correlation between the two prices is less than perfect ($\rho_{12} < 1$), the efficient frontier between points A and B runs concave. For determining the optimal mix between the two energy sources (symbolized by point $C^*$), the slope of the indifference curves $EU$ (reflecting risk aversion) would have to be known. Of course, the portfolio in figure 1 can be extended by including more energy sources, which may result in an upward shift of the efficient frontier (to $A'B$) if a source such as $A'$ exists.
4 Econometric analysis of energy prices

For the construction of the efficient frontier in terms of energy sources, estimation of the covariance matrix of energy price changes is crucial. In the financial literature, it is a common finding that the covariance matrix of returns e.g. on shares is not stable over time (Bollerslev, et al., 1992). A lack of stability also characterizes energy prices (Kroner and Claessens, 1991). This section is devoted to a discussion of two variants of econometric modeling that have been developed to reflect the fact that after a shock, variances and covariances may be modified for a number of periods before returning to their initial values. The objective is to filter out the stable systematic component of the covariance matrix (GARCH).

4.1 GARCH

The generalized autoregressive conditional heteroscedastic (GARCH) process introduced by Engle (1982) and Bollerslev (1986) allows the error variance to respond to shocks. The GARCH(p,q) process is defined in term of the properties of the error terms as follows,

\[ y_t = x_t^\delta + \varepsilon_t, \quad t = 1, ..., T. \]  
(5)

Here \( y_t \), is the percentage change in price, \( x_t \) is a \( k \times 1 \) vector of exogenous variables which can contain lagged dependent variables, \( \delta \) is a \( k \times 1 \) vector of regression coefficients, and \( \varepsilon_t \) is the error term, which is modelled as

\[ \varepsilon_t = \sqrt{h_t} \cdot v_t. \]  
(6)

The "classical" component of the error term is \( v_t \), which is i.i.d. with zero mean and unit variance:

\[ E(v_t) = 0, \quad E(v_t^2) = 1. \]

The instability in the covariance matrix of the errors is reflected by \( h_t \), which evolves according to

\[ h_t = c_0 + \sum_{j=1}^{p} \beta_j h_{t-j} + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 \]  
(7)

The GARCH(p,q) model allows the current conditional variance to depend on past conditional variance in addition to past squared innovations. For its "classical" error component, a unit normal density is assumed (Hamilton, 1994, ch. 21):
\[ f(v_t) = \frac{1}{\sqrt{2\pi}} e^{-\frac{v_t^2}{2}} \]

In addition, the following constraints are placed on the coefficients in eq. (7), where the last constraint is necessary for stationarity (Hamilton, 1994, ch. 21):

\[
\begin{align*}
    c_0 &> 0 \\
    a_i &\geq 0 \\
    \beta_j &\geq 0 \\
    \sum_{j=1}^{p} \beta_j + \sum_{i=1}^{q} \alpha_i &< 1.
\end{align*}
\]

(8)

4.2 TGARCH

It is widely recognized that the unconditional distributions of energy prices and their changes tend to have fatter tails than the normal distribution (excess kurtosis). Although the unconditional distribution for \( \varepsilon_t \) in the GARCH(p,q) model with conditional normal errors as given by (7) has fatter tails than the normal distribution (see Bollerslev (1986)), for many financial time series, it still does not adequately account for excess kurtosis. This implies that standard errors obtained on the assumption of conditional normality tend to understate the true standard errors of the parameters contained in equation (7), resulting in underestimates of predicted variances and covariances (Bollerslev et al, 1992).

As a remedy, Baillie and DeGennaro (1990) adopt the assumption of conditionally \( t \)-distributed errors in combination with a GARCH(1,1) model [called TGARCH(1,1)] because the \( t \) distribution has higher kurtosis than the normal. When comparing TGARCH(1,1) with GARCH(1,1), they find that failure to model the fat-tailed property can indeed lead to spurious results in terms of the estimated risk-return tradeoff. Thus to overcome the problem of excess kurtosis, the TGARCH(p,q) alternative will be examined below, following Bollerslev (1987) and Baillie and Bollerslev (1989). In analogy to GARCH(p,q), the TGARCH(p,q) process models the residuals as

\[ \varepsilon_t = \sqrt{h_t} \cdot v_t. \]

(9)

However, rather than using a unit normal distribution for \( v_t \), TGARCH instead applies the \( t \) distribution:
\[ t(u_t) = \frac{n^{-\frac{1}{4}}}{B\left(\frac{1}{2}, \frac{n}{2}\right)} \left(1 + \frac{v_t^2}{n}\right)^{-\frac{n+1}{2}}, \]

where \( B(\cdot) \) is the beta distribution and \( n \) a measure of kurtosis, i.e. the "fatness" of the tails of the distribution. The restrictions of eq. (8) apply as well. Kurtosis is measured as:

\[ Kurtosis = \frac{\mathbb{E}(v_t)^4}{(\mathbb{E}(v_t^2))^2}. \]  (11)

5 An efficient energy frontier for Switzerland

5.1 Time series analysis

Our data set consists of monthly real price data \(^1\) of total final consumption of energy in Switzerland measured at the busbar before distribution. We use four different producer price variables, production costs of nuclear power [\textit{Nuclear}] \(^2\), producer price of imported gas [\textit{Nat.Gas}] \(^3\), producer price of imported gasoline [\textit{Gasoline}] \(^4\) and production costs of hydro power [\textit{Hydro}] \(^5\).

![Relative energy price changes (CHF/MJ), from June 1993 to April 2004 (months 2 = June 1993, 132 = April 2004)](image)

Figure 2: Relative energy price changes (CHF/MJ), from June 1993 to April 2004 (months 2 = June 1993, 132 = April 2004)

\(^1\) Real price is based on May 2000 = 100

\(^2\) Data sources: Prognos AG, Cameco and UX.

\(^3\) Data source: Bundesamt für Statistik (BFS).

\(^4\) Data source: Bundesamt für Statistik (BFS).

\(^5\) Data source: Centre for Energy Policy and Economics, ETH.
All prices are in Swiss Francs (CHF) per mega joule (MJ) energy. In keeping with the definition of returns ($R_t$ in section 3), first differences of logarithmic prices are shown in Figure 2. The data extend from May 1993 to April 2004 (132 observations).

As can be seen from Figure 2, gasoline exhibits the strongest price fluctuations of the energy sources considered. These fluctuations are not expected to decrease over time, particularly not in the short to medium run, given gasoline supply uncertainties due to international conflicts and suddenly increasing demand by China. In contrast, nuclear energy prices tend to be very stable over time. According to forecasts of nuclear production costs in Switzerland by 2030, uranium prices are expected to remain very stable in the future as well (Prognos, 1996).

A necessary condition for estimating the systematic component of the covariance matrix of price changes is that estimates be based on stationary time series.

\[
\begin{align*}
\hat{p}_t &= m_0 + m_1 \hat{p}_{t-1} + \epsilon_t, \text{ (no trend)} \\
\hat{p}_t &= m_0 + m_1 \hat{p}_{t-1} + m_2 \delta_t + \epsilon_t, \text{ (with trend)}
\end{align*}
\]

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|}
\hline
& \text{Log & Diff} & \text{m}_1 & \text{ADF Statistic} & \text{m}_1 & \text{ADF Statistic} \\
\hline
\text{Nuclear} & -0.122 & -12.81*** & -0.12 & 0.0000007 & -12.76*** \\
\text{Nat.Gas} & -0.232 & -8.93*** & 0.224 & 0.000046 & -8.97*** \\
\text{Gasoline} & -0.007 & -11.403*** & -0.009 & 0.00002 & -11.373*** \\
\text{Hydro} & -0.03 & -11.65*** & -0.032 & 0.0000061 & -11.608*** \\
\hline
\end{tabular}
\caption{Unit Root tests of relative price changes}
\end{table}

Note: The 5%** and 10%* critical values are -3.446 and -3.146.

The results of stationarity tests based on the augmented Dickey-Fuller (ADF) test are reprinted in Table 1. Regardless of the specification (with or without trend variable), the ADF test indicates that the hypothesis $m_1=1$ (unit root) can be rejected.

Given stationarity of the time series, their moments need to be checked for skewness and excess kurtosis. Starting with the means, Table 2 indicates that Gasoline has the lowest value with -0.00044 (i.e. a decrease of its real price by 0.04 percent per month) and Nat.Gas the largest with 0.00115 (0.115 percent per month). The variance takes on the largest value in the case of Gasoline and the smallest with Nuclear. The Jarque-Bera test indicates that all variables are non-normally distributed; in particularly Nat.Gas and Hydro have excess kurtosis.
Table 2: Moments of distribution of price changes

According to the evidence presented in Table 1, relative price changes are stationary when modeled as a first-order autoregressive process, i.e. they are I(1). However, the correct lag order still needs to be determined. Two frequently used lag-order selection statistics can be applied in the presence of I(1) variables, viz. Akaike’s information criterion (AIC) and Schwartz’s Bayesian information criterion (SBIC). The result of this selection is shown in Table 3. In three out of four cases, the optimal lag is 3 months, while for Nuclear, it amounts to 4 months. However, calculation of the covariance matrix of price changes is still problematic as long as the predicted price changes are skewed and excessively kurtotic. Rather than examining predicted values \( \hat{p}_t \), one can focus on residuals \( \hat{\varepsilon}_t = p_t - \hat{p}_t \) which inherit the properties of \( \hat{p}_t \). Indeed, analysis of the residuals pertaining to eq. (A) in Table 3 indicates skewness for Nuclear and excess kurtosis for Nat.Gas and Hydro; only Gasoline can be said to yield predictions that are neither skewed nor excessively kurtotic.

This evidence suggests time series characterized by shocks that result in one-sided outliers (skewness) and "higher-than-normal" variances (excess kurtosis) during parts of the observation period. Since both problems may be present in all of the four price series, GARCH and TGARCH methods are used to estimate the parameter governing the development of the error process as specified in eqs. (6) and (7).
5.2 Estimation of the systematic variance components

In section 3, the GARCH and TGARCH specifications were described as a way to split up the variance of the error term into a systematic, autoregressive component and a stochastic autocorrelated component [see eqs. (6) and (7), respectively]. The parameter estimates pertaining to these equations appear in Tables 4 to 6. In table 4, the data encompass the entire observation period, while in Table 5 and 6, the period ends in December 2002, the most recent year for which the actual Swiss energy portfolio is known. The comparison between the two observation periods provides preliminary evidence regarding the stability of the estimated processes determining variance. We adopted GARCH(2,1) and TGARCH(2,1) approaches, the notation indicating that only $\beta_1$ of the autoregressive component is retained because $\beta_1$ proved insignificant throughout.

In Table 4, GARCH(2,1) is pitted against TGARCH(2,1). In the case of Nuclear; the sign of TGARCH-estimated $\beta_2$ fails to satisfy the restriction stated in (8), making GARCH the preferred specification, in spite of the significant Jarque-Berra test statistic shown in Table 2. As to Nat:Gas, the evidence is inconclusive; however, the Jarque-Berra suggests non-normality due to marked excess kurtosis and hence adoption of the TGARCH alternative. GARCH again the preferred alternative for Gasoline because the autocorrelation parameter $\alpha_1$ of the TGARCH estimate lacks significance. Finally, for Hydro both the GARCH and TGARCH estimates of $\alpha_1$ violate eq. (8); since the Jarque-Berra test strongly points to non-normality due to excess kurtosis, the TGARCH alternative seems appropriate.

Since these choices cannot be claimed to be entirely convincing in all cases, they are subjected to a test in Tables 5 and 6. In Table 5, GARCH is imposed on all of the four shorter time series. In the cases Nat:Gas ($c_0 < 0; \beta_2 > 1$)

\[
\dot{p}_t = \dot{d}_t + \sum_{i=1}^{\infty} \dot{d}_i \dot{p}_{t-i} + \varepsilon_t \quad \text{Eq. (A)}
\]

<table>
<thead>
<tr>
<th>Residuals of</th>
<th>Lags used</th>
<th>Std. Dev.</th>
<th>*Skewness</th>
<th>*Kurtosis</th>
<th>**Jarque-Berra</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>4</td>
<td>0.003</td>
<td>-0.14</td>
<td>4.7</td>
<td>0.0006*</td>
</tr>
<tr>
<td>Nat:Gas</td>
<td>3</td>
<td>0.020</td>
<td>4.68</td>
<td>45.2</td>
<td>0.0000*</td>
</tr>
<tr>
<td>Gasoline</td>
<td>3</td>
<td>0.025</td>
<td>0.01</td>
<td>3.6</td>
<td>0.4175</td>
</tr>
<tr>
<td>Hydro</td>
<td>3</td>
<td>0.012</td>
<td>0.99</td>
<td>34.5</td>
<td>0.0000*</td>
</tr>
</tbody>
</table>

*Under normal distribution the value of skewness is zero and the value of kurtosis is 3
**H0: normal distribution, *indicates violation of normality

Table 3: Moments of residuals derived from eq. (A)
and Hydro ($\beta_2 < 0$) the GARCH alternative appears to be wrongly used on a time series that has TGARCH properties, according to Table 4. For Nuclear and Gasoline, the GARCH categorization of Table 4 is confirmed by Table 5.

An important issue is the stability of estimates. The focus is on Nuclear and Gasoline for which the GARCH specification appears to be justified. The shortening of the observation period by 16 months does not affect the estimates for Nuclear and only slightly increases the autocorrelation parameter $\alpha_1$ of Gasoline. For these two energy sources, the GARCH variant thus results in stable estimates.

In Table 6, TGARCH estimates are displayed, again also for time series that do not fit this description according to Table 4 (Nuclear, Gasoline). As to the Nuclear time series, the summation restriction of (8) is possibly violated ($0.743+0.418=1.171$ with s.e. $= (0.099^2 + 0.18^2)^{1/2} = 0.205$ if the covariance between estimated parameters is neglected). In the case of Gasoline, the lack of significance of all estimates suggests that the GARCH specification indeed performs relatively well.

Turning to Nat:Gas and Hydro, where TGARCH appears to be appropriate judging by Table 4, the evidence contained in Table 6 points to problems. The TGARCH estimates for Nat:Gas, besides $c_0 < 0$, are not in accordance with the summation restriction of (8) [$1.12+0.018 = 1.138$, s.e. $= (0.0067^2 + 0.004^2)^{1/2} = 0.008$, again neglecting covariance]. Moreover, the autocorrelation parameter $\alpha_1$ is negative for Hydro, contrary to the requirement of eq. (8).

With regard to stability, the TGARCH results for Nat:Gas and Hydro (with some reservations for the case of Hydro as argued above) shown in Tables 4 and 6 need to be compared. The coefficients for Nat:Gas differ strongly, with $\hat{\beta}_2$ jumping from 0.59 to 1.12 in the shorter data set, and $\hat{\alpha}_1$ dropping from 1.86 to 0.02. Thus, the transition to the shorter observation period entails a marked shift in favor of the systematic autoregressive component and away from the autocorrelation component in the determination of the error variance. Finally, the Hydro estimates display a very high degree of stability.

In conclusion of this section, the GARCH estimates of the Nuclear and Gasoline time series are acceptable, as is the TGARCH estimate of Hydro. However, neither alternative seems to be entirely successful in determining the systematic component of the process governing the evolution of the variance that characterizes the price changes of Nat:Gas.
Table 4: GARCH and TGARCH estimation (observation Period 1993/5 to 2004/4)

<table>
<thead>
<tr>
<th>Data</th>
<th>GARCH</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>TGARCH</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$c_0$</td>
<td>$\beta_2$</td>
<td>$\alpha_1$</td>
<td>$c_0$</td>
<td>$\beta_2$</td>
<td>$\alpha_1$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuclear</td>
<td>0.0000017</td>
<td>0.694***</td>
<td>0.14648**</td>
<td>0.00002***</td>
<td>-0.9808***</td>
<td>-0.01069</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[GARCH]</td>
<td>(1.36e-06)</td>
<td>(0.14922)</td>
<td>(0.07132)</td>
<td>(1.80e-06)</td>
<td>(0.04652)</td>
<td>(0.01864)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nat. Gas</td>
<td>-0.0000056</td>
<td>0.53650***</td>
<td>1.215***</td>
<td>0.00001*</td>
<td>0.5864***</td>
<td>1.8566***</td>
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<td></td>
</tr>
<tr>
<td>[TGARCH]</td>
<td>(0.00002)</td>
<td>(0.06315)</td>
<td>(0.34677)</td>
<td>(7.58e-06)</td>
<td>(0.03678)</td>
<td>(0.39035)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline</td>
<td>0.0000736</td>
<td>0.59946***</td>
<td>0.2824141*</td>
<td>0.00018</td>
<td>0.62544*</td>
<td>0.1756651</td>
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</tr>
<tr>
<td>[GARCH]</td>
<td>(0.000046)</td>
<td>(0.1921411)</td>
<td>(0.1636233)</td>
<td>(0.0001836)</td>
<td>(0.37813)</td>
<td>(0.2221526)</td>
<td></td>
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</tr>
<tr>
<td>Hydro</td>
<td>0.00000015</td>
<td>1.0041***</td>
<td>-0.0125***</td>
<td>0.00000125</td>
<td>1.006***</td>
<td>-0.0259***</td>
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<tr>
<td>[TGARCH]</td>
<td>(2.50e-06)</td>
<td>(0.0135241)</td>
<td>(0.002567)</td>
<td>(1.37e-06)</td>
<td>(0.0077)</td>
<td>(0.002435)</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Table 5: GARCH estimation (observation period 1993/5 to 2002/12)

<table>
<thead>
<tr>
<th>Data</th>
<th>GARCH(2,1)</th>
<th></th>
<th>Mean $\hat{p}_t$</th>
<th>St. D.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$c_0$</td>
<td>$\beta_2$</td>
<td>$\alpha_1$</td>
<td></td>
</tr>
<tr>
<td>Nuclear</td>
<td>0.0000018</td>
<td>0.61374***</td>
<td>0.23**</td>
<td>0.0005*</td>
</tr>
<tr>
<td>[GARCH]</td>
<td>(0.06)</td>
<td>(0.19359)</td>
<td>(0.117)</td>
<td>(0.00025)</td>
</tr>
<tr>
<td>Nat. Gas</td>
<td>-0.000079*</td>
<td>1.1451***</td>
<td>-0.0029</td>
<td>0.0008</td>
</tr>
<tr>
<td>[TGARCH]</td>
<td>(0.000044)</td>
<td>(0.07686)</td>
<td>(0.0067)</td>
<td>(0.0037)</td>
</tr>
<tr>
<td>Gasoline</td>
<td>0.0000783*</td>
<td>0.54443***</td>
<td>0.339*</td>
<td>0.00125</td>
</tr>
<tr>
<td>[GARCH]</td>
<td>(0.000045)</td>
<td>(0.2035)</td>
<td>(0.203)</td>
<td>(0.0021)</td>
</tr>
<tr>
<td>Hydro</td>
<td>0.00018***</td>
<td>-1.0003***</td>
<td>0.000022</td>
<td>0.001</td>
</tr>
<tr>
<td>[TGARCH]</td>
<td>(3.83e-06)</td>
<td>(0.00178)</td>
<td>(0.00049)</td>
<td>(0.0006)</td>
</tr>
</tbody>
</table>

*significant at 10%, **significant at 5%, ***significant at 1%,
-Standard errors in parenthesis
5.3 Construction of Efficient Energy Portfolios

The GARCH and TGARCH procedures yield estimates of systematic standard deviations (see last column of Tables 5 and 6). For example, retaining the GARCH estimate for Nuclear in Table 5, the systematic component of the standard deviation in price changes amounts to 0.00334, which makes up for just about the observed standard deviation (which is given as 0.003 in Table 3 for the entire observation period, 1993/5 to 2004/4). Had one retained the GARCH estimate of 0.00721 in Table 6, the estimated systematic component of variance would even have exceeded the observed total, which is additional evidence in favor of GARCH. With regard to Nat.Gas, whose parameter estimates were judged problematic in the preceding section, it is reassuring to see that at least the choice between GARCH and TGARCH does not matter, the estimated systematic standard deviation being 0.027 and 0.022, respectively.

The estimations derived from eqs. (6) and (9) not only permit the calculation of systematic error variances but covariances between the price changes of the four energy sources as well. Using this information, the optimization program defined by eqs. (3) or (4) can be implemented.

Figure 3 displays a first snapshot of the efficiency frontier based on the data set 93/3 to 02/12. If the sole interest were to minimize the expected price increase in energy sources, one would end up with a portfolio that contains only Nuclear energy. In contrast, Hydro would be the only energy choice in a portfolio minimum variance portfolio. The current energy mix as of 2002 is

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>TGARCH(2,1)</th>
<th>(93/3 to 02/12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear [GARCH]</td>
<td>0.000008</td>
<td>0.743***</td>
</tr>
<tr>
<td>Nat.Gas [TGARCH]</td>
<td>-0.00007***</td>
<td>1.12***</td>
</tr>
<tr>
<td>Gasoline [GARCH]</td>
<td>0.00019</td>
<td>0.614</td>
</tr>
<tr>
<td>Hydro [TGARCH]</td>
<td>2.26e-06</td>
<td>1.004***</td>
</tr>
</tbody>
</table>

*significant at 10%, **significant at 5%, ***significant at 1%
-Standard errors in parenthesis
also entered in Figure 3. Clearly Switzerland's current energy mix is far off the efficient frontier. A shift towards nuclear power and away from natural gas and gasoline would reduce price volatility for overall Swiss energy consumption while minimizing the expected increase in the energy price bill.

This surprising result must be qualified in at least three ways. First, prices for \textit{Nuclear} are in effect approximated by the unit cost of imported uranium, which is a primary rather than a final energy source. As shown in the first column of Table 2, its unit cost is much lower than the price of \textit{Gasoline}, a final energy source. Second, observed prices do not take into account external costs that may have evolved differently between energy sources. Third, detailed analysis shows that the efficient mix changes substantially when there is a departure from one of these two extreme positions.

In view of these qualifications, and the fact that major changes in the energy portfolio would entail considerable adjustment costs, two constraints are imposed. The first limits the share of \textit{Nuclear} to 30 percent (31 percent observed in 2002, see Figure 3). Second, the share of non-renewables must not exceed 50 percent (39+12+31=82 percent in 2002).

These constraints have a profound effect on the efficient frontier of energy sources. Not surprisingly, it now runs much closer to the observed mix of 2002. As before, however, the minimum variance portfolio entirely consists of \textit{Hydro}. At the other extreme, the "minimum-increase-in-the-energy-bill" portfolio now contains 50 percent \textit{Hydro}, 20 percent \textit{Gasoline}, and less than 1 percent \textit{Nat.Gas}. The low share of natural gas may well be the consequence of the fact that neither the GARCH nor TGARCH specification succeeded in filtering out the systematic component of its variance characterizing the price changes over time.
Expected Return (X10^2)

Risk (Standard Deviation X10^2)

Nuclear
ER: -0.05
SD: 0.33

Gasoline
ER: -0.125
SD: 2.588

Hydro
ER: -0.21
SD: 0.9

Nuclear
ER: -0.05
SD: 0.33

0 20 40 60 80 100 120
Current (2002)

Hydro
Gasoline
Nat. Gas
Nuclear

Figure 3: Efficient Frontier (predicted for 2002)

Expected Return (X10^2)

Risk (Standard Deviation X10^2)

Nuclear
ER: -0.05
SD: 0.33

Current Mix

Nuclear
ER: -0.05
SD: 0.33

Gasoline
ER: -0.125
SD: 2.588

Hydro
ER: -0.21
SD: 0.9

Renewables

CONSTRANTS
Nuclear ≤ 30%
Non renewables ≤ 50%
Renewables remainder

Figure 4: Constrained Efficient Frontier (predicted for 2002)
6 Conclusions

The objective of this paper was to determine the efficient frontier of Swiss energy sources using portfolio optimization methods. Relative changes in real price were calculated for Nuclear, Nat.Gas, Gasoline, and Hydro for 132 months, from 1993 to 2004. These changes proved to be stationary, permitting the application of generalized autoregressive conditional heteroscedastic (GARCH) modeling of the development of error variance over time. GARCH turned out to be appropriate for determining the systematic variance component of Nuclear and Gasoline. A generalization using the more disperse t distribution rather than the normal (TGARCH) fitted the Hydro time series reasonable well, whereas neither GARCH nor TGARCH were entirely satisfactory for Nat.Gas.

Nevertheless, GARCH and TGARCH residuals were used to construct a systematic covariance matrix (whose values should not reflect fully transitory shocks) for the year 2002, when the effective energy mix of Switzerland is still known. The surprising result is that the minimum variance portfolio entirely consists of Hydro, while the "maximum expected return" portfolio (i.e. the one minimizing the expected increase of Switzerland’s energy bill) is entirely Nuclear. However, the other two energy sources would enter the efficient frontier as well as soon as an intermediate point on the frontier was considered optimal. In view of these qualifications additional constraints were imposed, viz. maximum shares of 30 percent for Nuclear (compared to 31 percent in
2002) and of 50 percent for non-renewables (82 percent in 2002). Interestingly, \textit{Nat.Gas} retains a very small share in a "maximum expected return" portfolio.

These findings need to be checked and corroborated in several ways. First, completion of the database for \textit{Hydro} (which had to be interpolated from a few annual observations) has high priority. Second, a better specification of the error variance process characterizing \textit{Nat.Gas} must be found. Third, for the construction of a truly efficient energy frontier, observed prices should be corrected for external costs and their development over time. This would pave the way for consideration of alternative sources such as wind, solar, biomass, and geothermal energy. Finally, the determination of the optimal energy allocation among the efficient ones will require information about the amount of risk aversion prevalent in the Swiss population.

However, the analysis performed in this paper does constitute a promising approach to instructing Swiss energy policy. Indeed, constructing an efficient frontier of energy portfolios can be seen as an important step towards a policy that is in accordance with the very objectives laid down in the constitution.
References


