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The causal relationship between energy use and economic growth in Switzerland ☆

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ABSTRACT

This paper investigates the relationships between energy consumption and economic growth in Switzerland over the period 1950–2010. We apply bounds testing techniques to different energy types separately. Robustness tests are performed by including additional variables and restricting the analysis to the period after 1970. The results show that there exist robust long-run relationships going from real GDP toward heating oil and electricity consumption. The relationship between heating oil and GDP is in fact bidirectional, although weaker from heating oil toward GDP than in the reverse direction. When investigating the period 1970–2010 only, the estimate of the long-run income elasticity of electricity consumption loses statistical significance and that for heating oil becomes negative. Those results imply a possible decoupling between GDP growth and energy consumption, so that energy conservation policies are not necessarily expected to have a negative impact on Swiss economic growth.

1. Introduction

Potential climate change threats, geopolitical tensions and recent nuclear accidents have triggered widespread concerns about energy supply security and environmental impacts associated with energy production and consumption. As a consequence, several countries are currently proposing strong energy substitution policies and radical energy conservation measures. In this context, it is of foremost importance to assess the costs of those policies, in particular in terms of GDP, because energy is thought to be intimately related with development (e.g. see Goldemberg and Lucon, 2010). At a theoretical level, energy can be considered as a production factor contributing to GDP or alternatively as a good or service consumed by economic agents, in which case income is a determinant of the amount of energy consumed. The literature distinguishes four potential causal relationships between energy consumption and GDP (see Payne and Taylor, 2010). First, the "growth hypothesis" considers a unidirectional causality running from energy consumption to GDP. In this situation, a decrease in energy consumption has a negative impact on growth. Second, the "conservation hypothesis" assumes a unidirectional causality running from GDP to energy consumption, in which case energy conservation policies have no impact on GDP growth. Third, the "feedback hypothesis" expects bidirectional causality between energy consumption and GDP, implying that they are jointly determined. Fourth, the "neutrality hypothesis" assumes no causal relationship, i.e. independence between energy consumption and GDP.

Chontanawat et al. (2006) and Ozturk (2010) summarize the results of about 100 empirical studies and show there is no consensus on the direction of the energy–GDP causality nexus, if any. Given the variety of countries and periods under analysis and the different empirical approaches used, it is difficult to provide general policy recommendations on the impact of energy and environmental policies. This is also confirmed by the latest meta-analysis on the subject (Chen et al., 2012).

Chontanawat et al. (2008) investigate causality between energy consumption and GDP for 30 OECD countries and 78 non-OECD countries. Causality from energy to GDP is found to be more prevalent in the OECD countries than in non-OECD countries. Other outstanding studies include Bowden and Payne (2009), who compute sector-specific causalities for the US, and Lee et al. (2008), who control for differences in capital stocks. Huang et al. (2008) introduce the possibility of nonlinear relationships and find that economic growth depends on several "threshold-variables" such as CO_2 emissions, energy efficiency,

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the ratio of industrial energy consumption to total energy consumption, and per-capita energy consumption. Focusing on nuclear energy consumption and using a panel cointegration test for 16 countries, Apergis and Payne (2010) find a bidirectional relationship with GDP in the short run, but a unidirectional causality running from nuclear energy consumption to economic growth in the long run. When countries are studied individually, it however becomes clear that no general conclusion can be drawn, even among high-income countries (see Wolde-Rufael and Menyah, 2010). According to Ozturk (2010), a general conclusion from the energy consumption–GDP literature is that there is no consensus, neither on the existence nor on the direction of causalities.

In this paper, we investigate the relationship between energy consumption and GDP in Switzerland. This country is an interesting case because of the peculiarities of its economy, its energy supply and its geographical characteristics. Switzerland is one of the richest countries in the world and two thirds of its workers are employed in the service sector. Since the energy intensity in the service sector is relatively low, one would expect Switzerland to be less energy dependant than other countries possessing larger manufacturing and agricultural sectors.[1] Recently, Filippini and Hunt (2011) identified Switzerland as one of the most energy-efficient (and less energy-intensive) countries in the OECD. Electricity supply comes from nuclear (about 40%) and hydropower (about 60%). Greenhouse gas emissions from electricity generation are thus remarkably small. Currently, about one third of greenhouse gas emissions come from the transport sector, 20% from each the households and the industry sector, 10% from each the agriculture and the service sector, and 5% from waste. Concerning transport activities, Switzerland is also a special case, with a well-developed public transport system offering a very high quality service. However, large parts of the country are mountainous regions, where there is no real alternative to private cars. Electricity generation is called to change radically in the near future: in May 2011 the Swiss Federal Council (the executive power) and the Parliament decided to phase out nuclear energy by closing the five power plants currently in operation between 2019 and 2034. Although serious efforts in renewable energy are planned, strong energy efficiency improvements and energy conservation measures are needed in any case. During the transition period, additional fossil fuel-based electricity production (cogeneration facilities, gas-fired combined-cycle power plants) might be needed. At the same time, CO_2 emissions reduction targets are maintained. In this context, it is of particular relevance to assess the relationship between energy consumption and GDP.

Although we are not aware of specific studies on the relationship between real GDP and energy consumption in Switzerland, Swiss data are used in some international databases and several multi-country papers report separate results for Switzerland. An overview of these results is provided in Table 1.

The five papers in the top panel of Table 1 find that in Switzerland total energy consumption has a statistically significant impact on GDP. The first and the last studies of the top panel find bidirectional causality between energy and GDP, while the other studies show causality from energy to GDP only. The bottom panel of Table 1 lists papers investigating specific energy types. Focusing on electricity consumption, Narayan and Prasad (2008) find a cointegrating vector and hence a long-run relationship between electricity consumption and GDP. They could however not identify any causal relationship. Focusing on nuclear energy consumption, Yoo and Ku (2009) find bidirectional causality, while with a very similar dataset but using a modified version of Granger causality tests and introducing physical capital and labour as additional variables, Wolde-Rufael and Menyah (2010) unexpectedly find a negative unidirectional causality from nuclear energy consumption to real GDP. They argue that this negative impact might be due to production shifting toward less energy intensive sectors or to excessive nuclear energy consumption in unproductive sectors.

Table 1
Results for the energy-GDP nexus in Switzerland, from multi-country studies.

Studies	Data	Results
Total energy consumption (EC)–real GDP		
Chontanawat et al. (2006)	1960–2000 (per capita)	Cointegrating equation, bidirectional causality
Lee (2006)	1960–2001	Unidirectional causality from EC to GDP
Huang et al. (2008)	1960–2002	Positive significant relationship from EC to GDP
Acaravci and Ozturk (2010)	1960–2005 (per capita)	Unidirectional causality from EC to GDP (and bidirectional short-run causality)
Narayan et al. (2010)	1980–2006	Positive bidirectional causal relationship
Electricity (ELC) or nuclear energy consumption (NEC)–real GDP		
Narayan and Prasad (2008)	1960–2002, ELC	Cointegrating equation, but no causality
Yoo and Ku (2009)	1969–2005, NEC	Not cointegrated but bidirectional causality
Wolde-Rufael and Menyah (2010)	1971–2005, NEC	Negative unidirectional causality from NEC to GDP

Notes: EC: energy consumption, ELC: electricity consumption, NEC: nuclear energy consumption, GDP: real GDP.

It is somehow surprising to observe such different results for the same country, but since all these papers are multi-country studies, they do not focus on Switzerland and differences in results are not discussed. Extending previous studies and taking the suggestions by Zachariadis (2007) into account, the present paper investigates the energy–GDP relationship for Switzerland thoroughly. With respect to the existing literature, the novel features introduced in this paper are i) the very long observation period including most recent data (1950–2010); ii) the fractional integration methodology using bounds testing, as suggested by Ozturk (2010); iii) the analyses conducted for each energy type separately and iv) robustness checks using price data for each energy type.

The remainder of the paper is structured as follows. Section 2 presents the empirical approach and the data. Section 3 discusses the main results. Section 4 proposes robustness checks by introducing additional control variables in the regressions and restricting the analysis to the period 1970–2010. Section 5 concludes and suggests further research directions.

2. Data and empirical approach

We use annual data from 1950 to 2010.[2] Fig. 1 displays the evolution of total energy consumption per capita and Swiss real GDP per capita in Swiss Francs (CHF).[3] We use per-capita values to abstract from changes in population size and therefore follow the suggestion by Zachariadis (2007), i.e. per-capita variables should be matched with per-capita variables. Total energy use per capita grew relatively fast from 1950 until the first oil shock, then less rapidly until 1990, and it eventually stabilised in the last couple of decades. In Fig. 2, total energy consumption per capita is decomposed into different energy types. It shows in particular that since 1970 the evolution of total energy consumption is mostly driven by the regular decrease in heating oil consumption, in combination with the increase in fuel, electricity, and gas.

Stern (2000) points out that substitution from lower (e.g. coal) to higher-quality energy types (e.g. electricity) may take place during the growth process. However, although such substitution is important for countries like Korea (see Oh and Lee, 2004), it is not very relevant for Switzerland given the limited substitution possibilities. Indeed, heating oil is used for heating, fuel is used for transport, while electricity is mostly used for the remaining activities. The only

[1] For this reason, we conduct a causality analysis including the share of workforce employed in the service sector as an additional variable (Section 4).

[2] Descriptive statistics are provided in Appendix Table A1.

[3] As of April 23rd, 2012, CHF 1 = EUR 0.832 = USD 1.094.

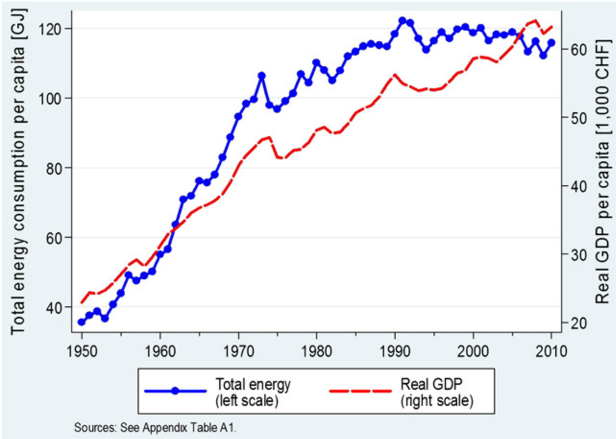

Fig. 1. Evolution of total energy consumption per capita and GDP per capita, 1950–2010.

significant substitution takes place in house heating from heating oil toward natural gas, waste incineration, heat pumps (i.e. electricity) and solar energy. Since our analysis is not only performed on aggregate measures of energy use but also distinguishes the largest energy types, substitution phenomena toward electricity should show up in the separate analyses.

The above-mentioned papers using Swiss data apply error correction models as proposed by Engle and Granger (1987). To apply these estimation techniques, all series should be integrated of order I (1) (with the exception of the approach used by Wolde-Rufael and Menyah (2010), where the series can be of any integration order or even not integrated). Hence, most existing studies fail to consider explicitly that energy consumption might be a fractionally integrated process, in the sense that it might have long memory. Lean and Smith (2009), Akinboade et al. (2008), Amusa et al. (2009), Elder and Serletis (2008) and Wolde-Rufael (2010) apply a more general setting in the energy context and prove its relevance. Using an unrestricted error correction model (UECM) to test cointegration between two series has the following advantages. First, the bounds test procedure proposed by Pesaran et al. (2001) and Narayan (2005) is applicable whether the variables are integrated of order I(0) or I(1). Second, the approach is not sensitive to sample size and can therefore be applied to datasets having a small number of observations (Zachariadis, 2007). Third, it can be used even if some regressors are endogenous. The proposed approach provides unbiased long-run estimates and valid *t*-statistics. It does however not allow for I(2) variables, and series must therefore be tested for unit roots.

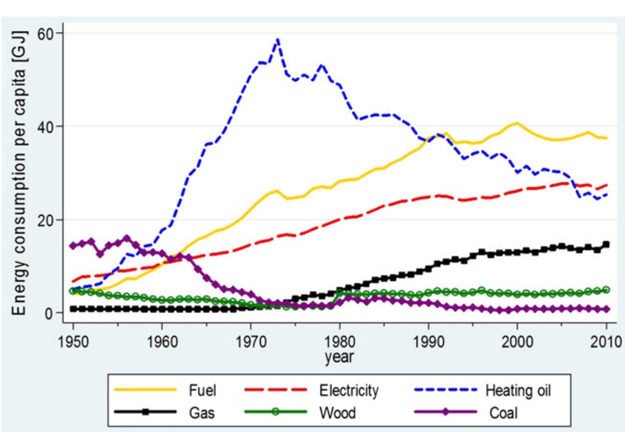

Fig. 2. Evolution of energy consumption per capita by energy type, 1950–2010.

We estimate the following UECM:

$$\Delta y_t = \alpha + \sum_{i=1}^{m} \beta_i \Delta y_{t-i} + \sum_{i=0}^{n} \lambda_i \Delta x_{t-i} + \varphi y_{t-1} + \delta x_{t-1} + \eta_t \tag{1}$$

where Δ is the first-difference operator; t is the time index; m and n indicate numbers of lags; y stands for the dependent variable of the model, i.e. ln(GDP per capita) or ln(energy consumption per capita), x is a vector of independent variables; α, β, λ, φ and δ are parameters to be estimated; and η is an error term. To test for the existence of a cointegration relationship, the *F*-statistic from the test of H_0: $\varphi = \delta = 0$ (against H_1: $\varphi \neq 0$ or $\delta \neq 0$) is compared with the bottom and top critical values computed by Pesaran et al. (2001) and Narayan (2005). If the *F*-statistic is lower than the bottom critical value, then there is no cointegrating relationship between the series. If the *F*-statistic is within the bounds defined by the bottom and top critical values, no conclusion can be drawn. If the *F*-statistic is larger than the top critical value, there is a cointegrating relationship between the series.

If a cointegrating relationship is identified with the UECM, an autoregressive distributed lag model (ARDL) can be used to establish short and long-run elasticities (see for example Fuinhas and Marques, 2012, and Gross, 2012). The long-run model is given by the following equation in levels:

$$y_t = \theta + \sum_{i=1}^{p} \sigma_i y_{t-i} + \sum_{i=0}^{q} \kappa_i x_{t-i} + \varepsilon_t \tag{2}$$

where p and q are numbers of lags, θ, σ and κ are parameters to be estimated, and ε is an error term. To obtain the long-run elasticity, we use the delta method (see Greene, 2012), i.e. let $y = y_t = y_{t-i}$ and $x = x_t = x_{t-i}$, and compute the long-run elasticity using the transformed equation.[4]

Using the lagged residuals $\hat{\varepsilon}_{t-1}$ from the long-run relationship, the short-run relationship is given by:

$$\Delta y_t = \mu + \sum_{i=1}^{r} \pi_i \Delta y_{t-i} + \sum_{i=0}^{s} \omega_i \Delta x_{t-i} + \tau \hat{\varepsilon}_{t-1} + \upsilon_t \tag{3}$$

where τ measures the speed of adjustment. When the long-run equilibrium is modified, convergence takes place at a rate of τ percent per year.

Following the literature, we use the tests proposed by Dickey and Fuller (1979) and Phillips and Perron (1988) to identify the order of integration of the time series. The number of lags included is determined using the usual information criteria: Akaike (AIC), Schwarz Bayesian (SBIC) and Hannan Quinn (HQIC), which all indicate the same number of lags to be included for the integration test of each series. In Table 2, we report this set of results. It can be observed that the ADF and the Phillips–Perron tests do not reject the null hypothesis of a unit root for the series in levels, but reject it for the series in first differences. The only exception is heating oil, where the ADF test rejects the H_0 of a unit root also for the variable in levels, while the other tests do not reject it. KPSS tests (Kwiatkowski et al., 1992) are used to check the null hypothesis of stationarity. Results show that stationarity is rejected for all variables in levels. In first differences, stationarity is not rejected except for heating oil and very weakly for fuel. Hence, the series seem to be generally stationary in first differences, with some doubts for heating fuel. Appendix Table A2 reports tests for long memory and fractional integration. The H_0 of no long range dependence (i.e. series have no long memory) is rejected for all variables in levels and some in first differences. This is a strong argument to proceed with the bounds test proposed by Pesaran et al. (2001) and Narayan (2005).

[4] If (2) is given by: $y_t = \theta + \sigma_1 y_{t-1} + \sigma_2 y_{t-2} + \kappa_0 x_t + \kappa_1 x_{t-1}$, in the long run equilibrium we get: $y = \theta + (\kappa_0 + \kappa_1)/(1 - \sigma_1 - \sigma_2)x$. The long run elasticity is then given by (with x and y in logarithms): $(\kappa_0 + \kappa_1)/(1 - \sigma_1 - \sigma_2)$.

Table 2
Stationarity tests (all variables in logs and per capita).

	Lags[a]	ADF		Phillips–Perron		KPSS	
		Levels	Diff	Levels	Diff	Levels	Diff
Real GDP	AIC: 3 SBIC: 3 HQIC: 3	−2.27	−3.26***	−1.86	−5.53***	B: 0.26*** Q: 0.52***	B: 0.07 Q: 0.06
Total energy	AIC: 1 SBIC: 1 HQIC: 1	−1.14	−4.02***	−1.17	−6.64***	B: 0.28*** Q: 0.56***	B: 0.08 Q: 0.07
Heating oil	AIC: 3 SBIC: 3 HQIC: 3	−4.46***	−2.45***	−2.74	−5.51***	B: 0.26*** Q: 0.53***	B: 0.17** Q: 0.22***
Fuel	AIC: 1 SBIC: 1 HQIC: 1	−2.53	−2.53***	−1.79	−3.93***	B: 0.27*** Q: 0.54***	B: 0.11 Q: 0.12*
Electricity	AIC: 1 SBIC: 1 HQIC: 1	0.43	−3.89***	−0.92	−7.54***	B: 0.29*** Q: 0.58***	B: 0.06 Q: 0.05

Notes: AIC: Akaike's Information Criterion. SBIC: Schwarz's Bayesian Information Criterion. HQIC: Hannan Quinn Information Criterion. ADF: Augmented Dickey–Fuller test with trend on levels, and with drift and constant in first differences.Phillips–Perron test with trend in levels, H_0: unit root. KPSS-test: H_0: stationarity, autocovariances weighted by Bartlett kernel (B) or quadratic spectral kernel (Q). All variables available over 1950–2010.
[a] Results with Lütkepohl statistics (excluding the constant term from the likelihood) give the same results.
* significant at 10%.
** significant at 5%.
*** significant at 1%.

3. Results and discussion

Table 3 reports the results for the UECM estimations and the corresponding bounds tests. Results show that the H_0 of no long-run relationship is strongly rejected for fuel, heating oil, electricity and for aggregate energy, as functions of real GDP. GDP is thus a statistically significant driver for each of the three main energy types in the long run. In addition, heating oil seems to be a driver of GDP, but the statistical significance of the relationship in this direction is weaker. All other models with GDP as a function of energy consumption do not show a statistically significant relationship. Causality is therefore running mainly from GDP to the consumption of energy. In other words, economic growth induces more demand for energy, but the consumption of energy (except heating oil) does not stimulate economic growth.[5]

These results have important implications, since they suggest that policies aimed at cutting energy consumption in Switzerland would have little adverse effect on long-run economic growth. In the current context, where climate policies aim at strongly reducing greenhouse gas emissions and nuclear energy is planned to be phased out, our findings are of utmost importance.

For the equations where a long-run relationship is established, we investigate the long- and short-run effects more thoroughly using the ARDL framework described in Section 2. Table 4 reports the results for long-run relationships.

ARDL estimations partially confirm the results obtained with the UECM. For total energy, we find a statistically significant income elasticity of 1.3, implying that an increase in GDP induces a more than proportional increase in total energy consumption. In the long-run relationship for electricity consumption, the income elasticity is 0.9.

Results in Table 4 are however not all easily interpretable. Indeed, while current real GDP is a statistically significant determinant of fuel and heating oil consumption, long-run elasticities are statistically insignificant. Long-run elasticities thus seem to imply that economic growth is not significantly influencing consumption of fuel and heating oil. The non-significant effects and the degenerate estimation for GDP as a function of heating oil (the lag selection process leads to keep GDP as the only explanatory variable, completely discarding heating oil lags) could also result from a structural break in the series (this is further explored in Section 4).

[5] Murray (1994) provides a humorous illustration of cointegration, which might help understand our results.

Table 5 reports the estimations for the short-run relationships. Real GDP is found to have a positive and significant impact on fuel and total energy consumption, while its impact is also positive but not statistically significant on heating oil consumption. For electricity, GDP is not retained in the short-run specification. For all three energy consumption types, the coefficients of the error correction terms have the expected negative sign and are highly significant. If there is a shock in the long-run relationship, 35% (fuel), 74% (electricity) and 84% (heating oil) of the disequilibria will be filled within 1 year (for heating oil, note that the heteroskedasticity test is not passed). For total energy as a function of GDP and for GDP as a function of heating oil, the error correction terms are not significant. Those relationships should thus be interpreted with care.

To summarize, we identify significant positive long-run elasticities from real GDP toward energy consumption, but we do not find clear evidence for a causal relationship going in the opposite direction. For the Swiss economy, the "conservation hypothesis" thus seems to hold over the last decades, and energy conservation policies are not expected to impact real GDP.

Table 3
UECM estimations.

	F-stat on long-run relationship	Adjusted *R*-squared	Ramsey-Reset test: *F*-stat (*p*-value)
Total energy = *f*(GDP)	9.94***	0.42	0.14 (0.94)
Fuel = *f*(GDP)	22.35***	0.61	0.18 (0.91)
Heating oil = *f*(GDP)	15.57***	0.57	0.63 (0.60)
Electricity = *f*(GDP)	8.76***	0.47	1.40 (0.25)
GDP = *f*(Total energy)	2.68	0.23	0.98 (0.41)
GDP = *f*(Fuel, heating oil, electricity)	2.71	0.50	2.13 (0.11)
GDP = *f*(Fuel)	1.25	0.24	0.13 (0.94)
GDP = *f*(Heating oil)	6.25**	0.15	1.63 (0.19)
GDP = *f*(Electricity)	1.36	0.36	0.81 (0.49)

Notes: Critical values of the *F*-statistics for the bounds test with intercept and no trend taken from Narayan (2005) for 60 observations.
Selection of the number of lags based on the SBIC (Schwarz's Bayesian Information Criterion) and specification tests.
* significant at 10%.
** significant at 5%.
*** significant at 1%.

Table 4
ARDL long-run estimations.

	Energy(−1)	Energy(−2)	GDP	GDP(−1)	GDP(−2)	Constant	Long-run elasticity
Total energy = f(GDP)			1.268***			−2.174***	1.268***
			(0.042)			(0.446)	(0.042)
Fuel = f(GDP)	0.977***		0.556**	−0.352	−0.260	0.853	−2.374
	(0.034)		(0.203)	(0.304)	(0.192)	(0.523)	(6.7692)
Heating oil = f(GDP)	0.979***		−0.180***			2.171***	−8.752
	(0.022)		(0.048)			(0.382)	(10.852)
Electricity = f(GDP)	0.875***	0.073	0.453***	−0.405***		0.010	0.924**
	(0.104)	(0.099)	(0.102)	(0.106)		(0.219)	(0.384)
GDP = f(Heating oil)				0.966***		0.382	
				(0.010)		(0.104)	

Notes: Standard errors in parentheses. Standard errors for long-run elasticity estimated with delta method. Selection of the number of lags based on the SBIC and specification tests.
* significant at 10%.
** significant at 5%.
*** significant at 1%.

Table 5
ARDL short-run estimations.

	Δenergy(−1)	Δenergy(−2)	ΔGDP	ΔGDP(−1)	EC(−1)	Constant	Tests	Adj. R^2
ΔTotal Energy = f(ΔGDP)	−0.189		0.813***	0.465*	−0.028	0.002	BP: 0.23 (0.63)	0.21
	(0.148)		(0.247)	(0.238)	(0.057)	(0.006)	Reset: 1.71 (0.18)	
							ARCH: 1.03 (0.31)	
ΔFuel = f(ΔGDP)	–	–	1.142***		−0.352**	0.033***	BP: 2.54 (0.11)	0.48
			(0.226)		(0.165)	(0.008)	Reset: 1.37 (0.26)	
							ARCH: 0.08 (0.78)	
ΔHeating oil = f(ΔGDP)	0.529*	0.125	0.304		−0.837***	0.045	BP: 4.91 (0.03)	0.53
	(0.288)	(0.130)	(0.440)		(0.287)	(0.036)	Reset: 1.36 (0.27)	
							ARCH: 1.49 (0.22)	
ΔElectricity = f(ΔGDP)	0.708***				−0.738***	0.006	BP: 0.04 (0.85)	0.20
	(0.175)				(0.238)	(0.005)	Reset: 1.78 (0.16)	
							ARCH: 0.91 (0.34)	
ΔGDP = f(ΔHeating oil)				0.165	−0.004	0.025	BP: 0.34 (0.56)	0.18
				(0.577)	(0.569)	(0.017)	Reset: 0.28 (0.84)	
							ARCH: 0.21 (0.65)	

Notes: Standard errors in parentheses. EC: error correction term. BP: Breusch–Pagan/Cook–Weisberg test for heteroskedasticity, H_0: constant variance, reported values: chi-square (p-value). Reset: Ramsey-Reset test, H_0: no omitted variables, reported values: F-statistic (p-value). ARCH: LM test for ARCH, H_0: no ARCH effects, reported values: chi-square (p-value). To test for parameter stability, the cumulative sum of recursive residuals (cusum) and the cusum of squares (cusumsq) tests based on Brown et al. (1975) were applied (see Appendix Fig. A1).The statistics remain within the 95% confidence bandwidth.
* significant at 10%.
** significant at 5%.
*** significant at 1%.

However, many determinants of GDP and energy consumption have been ignored. In the next section, we investigate whether the previous results hold if we account for energy prices, for the economic structure of the Swiss economy, and climatic conditions (measured by heating degree days). Because data on energy prices are available since 1970 only, we proceed in two steps. First, we restrict the period to 1970–2010 and repeat the same analysis as before. Second, we add the new control variables to the restricted observation period 1970–2010. This methodology allows a clear separation of the effects of the two changes introduced in the analysis.

Table 6A
UECM estimations, restricted period 1970–2010.

	F-stat on long-run relationship	Adj. R^2	Ramsey-Reset test: F-stat (p-value)
Total energy = f(GDP)	3.70	0.17	0.96 (0.42)
Fuel = f(GDP)	3.47	0.28	1.05 (0.38)
Heating oil = f(GDP)	7.55**	0.32	0.75 (0.53)
Electricity = f(GDP)	14.30***	0.57	1.38 (0.27)
GDP = f(Total energy)	1.30	0.06	0.51 (0.68)
GDP = f(Fuel)	0.62	0.17	1.22 (0.32)
GDP = f(Heating oil)	0.36	0.08	0.90 (0.45)
GDP = f(Electricity)	4.82	0.44	1.62 (0.21)

Notes: Critical values of the F-statistics for the bounds test with intercept and no trend taken from Narayan (2005) for 40 observations.
* significant at 10%.
** significant at 5%.
*** significant at 1%.

Table 6B
UECM estimations with additional variables, 1970–2010.

	F-stat on long-run relationship	Adj. R^2	Ramsey-Reset test: F-stat (p-value)
Fuel = f(GDP, Pricefuel, Servshare)	2.26	0.54	2.29 (0.10)
Heating oil = f(GDP, Priceheat, Servshare)	7.04***	0.38	0.78 (0.51)
Electricity = f(GDP, Priceelec, Servshare)	7.09***	0.56	1.28 (0.30)
GDP = f(Fuel, Pricefuel, Servshare)	2.05	0.74	2.08 (0.13)
GDP = f(Heating oil, Priceheat, Servshare)	1.20	0.59	1.25 (0.31)
GDP = f(Electricity, Priceelec, Servshare)	1.05	0.67	0.06 (0.98)
Heating oil = f(GDP, Priceheat, Servshare, HDD)	5.54**	0.78	1.64 (0.21)
GDP = f(Heating oil, Priceheat, Servshare, HDD)	2.40	0.65	1.45 (0.25)

Notes: Critical values of the F-statistics for the bounds test with intercept and no trend taken from Narayan (2005) for 40 observations.
* significant at 10%.
** significant at 5%.
*** significant at 1%.

Table 7
Long-run elasticities, for the period 1970–2010 and with additional variables.

	ARDL	GDP	Energy price	Share of services	HDD
Heating oil = f(GDP)	(1,1)	−2.132***	–	–	–
		(0.182)			
Electricity = f(GDP)	(1,2)	−3.526	–	–	–
		(8.403)			
Heating oil = f(GDP, Priceheat, Servshare)	(1,1,1,1)	−1.056***	−0.077***	−0.014***	–
		(0.363)	(0.039)	(0.005)	–
Electricity = f(GDP, Priceelec, Servshare)	(1,2,0,0)	−3.526	–	–	–
		(8.403)			
Heating oil = f(GDP, Priceheat, Servshare, HDD)	(3,3,1,3,3)	−0.860**	−0.116***	−0.016***	0.045
		(0.317)	(0.038)	(0.004)	(0.069)

* significant at 10%.
** significant at 5%.
*** significant at 1%.

4. Robustness checks: restricted sample period and additional explanatory variables

This section investigates whether the results based on the traditional bivariate analysis are confirmed when additional determinants of energy consumption are included. Zachariadis (2007) and Gross (2012) show that the causality between energy consumption and economic growth might in fact be influenced by other variables suggesting the use of multivariate models. The additional variables included are real energy prices and the share of workforce employed in the service sector. By including these additional variables as determinants of energy consumption, we in fact investigate the link between energy and GDP from the demand side (as opposed to the production function approach used by Shahiduzzaman and Alam, 2012). This is the prevalent direction of causality indicated by the bivariate bounds tests. Filippini and Hunt (2011) use a similar demand framework for a panel of OECD countries, including Switzerland. Since energy prices are available from 1970 only, our analysis in this section covers a reduced time period. Stationarity tests for the new variables are reported in Appendix Table A3.

Results of the bounds tests on the long-run relationships are displayed in two tables. Table 6A presents the results of the bivariate models when the period is reduced from the initial 1950–2010 to 1970–2010. Table 6B shows the results obtained for the multivariate model, where the different energy types and GDP are functions of each other, and the energy prices and the share of workforce employed in the service sector are additional explanatory variables.[6] Heating oil consumption depends probably also on climate, since cold winters trigger higher demand. Hence, in the case of heating oil, we additionally consider heating degree days (HDD) as a potential determinant (Christenson et al., 2006; Silk and Joutz, 1997). Both tables confirm the long-run relationships for heating oil and electricity as functions of GDP, which were already identified in Section 3 over the longer time period. For fuel consumption as a function of GDP, however, the long-run relationship is no more significant.

For models where a significant relationship is established, long-run elasticities are obtained through ARDL estimations and reported in Table 7. The top panel of the table displays estimations with the same variables as in Section 3 on the reduced period 1970–2010, so that they constitute stability tests. The coefficients are substantially different from those obtained over 1950–2010, indicating structural breaks. While heating oil had no statistically significant long-run income elasticity over 1950–2010, it is estimated at −2.1 over 1970–2010. For the multivariate model, we find an income elasticity of −1.1, indicating an almost proportionally negative relationship. Heating oil prices and the share of services display a significant and negative long-run elasticity with respect to heating oil consumption, as economic intuition would suggest. When heating degree days are included, the preferred specification changes, but results are not significantly altered. Elasticities with respect to GDP, heating oil prices, and the service sector share are quantitatively similar, while the elasticity with respect to heating degree days turns out to be non-significant.[7]

For electricity, both specifications with and without additional variables lead to the same results: the selected specifications include GDP and energy consumption only, rejecting the prices and the share of workforce in tertiary sector. While electricity consumption was found to be closely linked to GDP over the whole observation period 1950–2010, this is no longer true over 1970–2010, where the long-run elasticity is not significant.[8]

It may seem contradictory that no significant long-run income elasticity can be estimated despite the fact that the GDP and electricity consumption are cointegrated. However, the question answered in Tables 6A and 6B (is there cointegration?) is more general than the one in Table 7 (is there a tight quantitative relationship between series?). Here, our results indicate that economic growth and electricity consumption do move together (they are cointegrated), but it is not possible to precisely assess the long-run change in electricity consumption induced by a GDP increase (long-run income elasticity is not significant over the last 40 years).

This new set of results seems to indicate a gradual de-linking between economic growth and energy consumption in Switzerland. First, over the period 1970–2010, heating oil consumption decreased while GDP increased, perhaps indicating that policies promoting better housing insulation and installation of heat pumps had significant success.[9] Second, while electricity consumption increased almost proportionally with GDP over the period 1950–2010, the long-run elasticity is no longer significant after 1970. This is probably due to a significant decrease in the electricity intensity in the industry sector, which makes up roughly one third of total electricity consumption and GDP. In addition, with a non-significant long-run relationship between GDP and fuel consumption since 1970, the Swiss economy should not be negatively impacted by energy policies decreasing energy consumption.

5. Conclusions

This paper investigates the relationships between energy consumption and real GDP per capita in Switzerland over the period 1950–2010. We find that there exist separate long-run relationships

[6] Results remain qualitatively similar when including prices of substitutable energies, i.e. heating fuel prices in the equation of electricity consumption and electricity prices in the equation of heating fuel consumption (results are available upon request).

[7] The non-significant long-run elasticity of heating degree days in the heating oil regression might be due to measurement problems. Each statistical year is in fact based on information coming from two different winters (end of year and beginning of next one). Moreover, heating oil reserves are considerable. Hence, climate effects are probably smoothed out.

[8] Short-run elasticities are of limited interest and not reported here. They are available upon request.

[9] Note that electricity consumed for running heat pumps makes up only a very small part of electricity consumption (around 1% in 2000, less than 2% today).

from GDP toward transport fuel, heating oil and electricity consumption. In the other direction, a relationship running from heating oil toward GDP is also established, but it is less robust. Hence, the empirical evidence points to a unidirectional causality from GDP toward the consumption of different energy types, mainly heating oil and electricity.

Over the whole observation period 1950–2010, real GDP is found to boost electricity consumption. If analysis is limited to the period 1970–2010, this long-run elasticity is no longer statistically significant, while heating oil consumption is even decreasing as real GDP increases. This gives hope that energy consumption can be decoupled from economic growth. From our analysis, we therefore deduce that energy conservation policies would not necessarily impede economic growth. In the current context, where CO_2 regulation is being largely discussed and nuclear power is going to be phased out, these findings appear encouraging.

Further research should try to model specific energy demands (see for example Baranzini and Weber, 2012, for transport fuel demand). This should be done both for households and for industries by introducing additional determinants and specifically addressing energy substitution possibilities, energy efficiency measures and possible structural breaks.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.eneco.2012.09.015.

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