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IS TECHNOLOGICAL CHANGE BIASED TOWARD ENERGY?

A MULTI-SECTORAL ANALYSIS FOR THE FRENCH ECONOMY

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Is technological change biased toward energy? A multi-sectoral analysis for the French economy

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Abstract

Since the adoption and implementation of new technologies has an important influence on the structure and performance of the economy in both developed and developing countries, many research papers are devoted to the technology-economy nexus. Motivated by the fact that the impact of technical progress on the demand for different production factors may vary depending on the bias of the technological change, in this paper, by estimating a translog cost-share system and using state space modeling technique, we investigate to what extent the direction of technical change is biased toward energy and away from other factors. By applying this methodology to the French economy for the period 1978-2006 the obtained results suggest that: first, technical change has a non-neutral impact on factor demands; second, capital saving technical progress is present in the majority of the sectors studied; third, energy demand has increased in all sectors but electricity and gas. These findings may have important policy implications for environmental and energy issues in France.

Keywords: Technical change; Energy use; France

JEL classification: C50; Q41; Q55

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1. Introduction and overview

Most energy related problems share the following two characteristics: they are associated with the resource scarcity, and they are connected with the trends in economic development. While the former comes from the fact that the production of the energy used in both developed and developing countries is still mainly based on extraction and utilization of nonrenewable natural resources (energy supply side), the later implies that, as far as energy is essential for production, the relationship between energy consumption and output or income may be different depending on the economic policies, technology choices, energy prices or degree of development of a country (energy demand side). Moreover, both of these characteristics are related with the environmental issues since resource using energy production and the externalities it creates constitute an important environmental concern (i.e. all kind of environmental deteriorations like air pollution, deforestation, etc.). Consequently, since economics is the science which focuses on the management of scarce resources, there has been a vast amount of research in the energy economics literature in the last three decades.

In the same research area, the impact of technical progress (or more specifically direction of technical change) on the overall economic activities has been the topic of considerable number of studies. Several researchers pointed out the evidence that technical change has a crucial role in several contexts such as resource scarcity, fuel switching, climate change, economic growth, etc. For instance, according to Carraro et al. (2003), "technological change constitutes an intrinsic and interwoven part of economic processes, and the understanding thereof is essential for apprehending the dynamics of economy-environment interactions. Moreover, since new technologies can fundamentally alter the extent and nature of the trade-offs that often need to be made between economic performance and environmental quality, the effect of public policies on the development and spread of new technologies is among one of the crucial determinants of the success or failure of environmental management" (Carraro et al., 2003, p. 2). However, understanding the dynamics of technical progress requires both theoretical and empirical research in this field.

Among others, Sato (1970) is one of the pioneering studies analyzing the mechanism of technical progress. He uses different forms of production function (Cobb-Douglas, constant elasticity of substitution (CES), constant elasticity of derived demand production (CEDD)) to construct a growth model where technical change is assumed to be exogenous. This model, while applied to the US economy data from 1909 to 1960, shows that the direction of technical change is not neutral and labor saving technical progress is present in the economy. Following the relevant literature, the same mechanism is also investigated in the energy and environmental economics literature. In the first papers on this subject, assuming still exogenous technology, theoretical frameworks have been built on the neoclassical resource-and-growth models following Dasgupta and Heal (1974), Stiglitz (1974) and Solow (1974). In these studies, technical progress is analyzed in an environmental context and the purpose is to determine the technological conditions under which economy could have a positive long-run growth in the presence of a non-renewable natural resource.

In the context of endogenous growth theory, an increasing number of recent papers push the analysis of technical progress further by analyzing directly how socio-economic conditions affect the direction of technical change which in turn has an effect on factor demands and productivities (for a major contribution for directed technical change, see Acemoglu, 2002). Again following these developments, technical change started to be viewed as an endogenous variable in the energy and environmental models, since many factors such as changes in relative energy prices or environmental policies may induce innovations (see Jaffe et al. (2000) and also Smulders and de Nooij (2003) for an analysis on the direction of technical change in this kind of models).

The empirical literature on the energy-technology-economy nexus seems to be less abundant than the theoretical one. This is simply because, as we will discuss later, it is difficult to measure correctly the rate and the direction of technical change, hence, more powerful tools are needed in empirical studies to provide robust results. Still in the relatively recent literature one may find some promising studies in this research area. For instance, in a very recent study, Okushima and Tamura (forthcoming) employ the multiple calibration decomposition analysis (MCDA) to estimate technological change that affects energy use and carbon dioxide (CO_2) emissions in the Japanese economy in the oil crises period from 1970 to 1985. They show the clear evidence of the importance of technological change in the context of the changes in both energy use and CO_2 emissions. Again on the basis of Acemoglu's (2002) theoretical modeling framework Otto et al. (2007) develop a computable general equilibrium (CGE) model to study energy bias in technical change. Their results are in line with Acemoglu's finding that if the final goods are gross substitutes, technical change is biased toward the non-energy intensive good. However, Sanstad et al. (2006) is perhaps the closest study to this paper. They investigate the relationship between technical change and the evolution of energy demand in several energy-intensive industries for three countries: India, South Korea and the USA. Using a Translog cost function (TRANScendental LOGarithmic) introduced by Christensen et al. (1973), and assuming that this relation remains constant, they argue that the technical change is biased towards installation of less energy-intensive technologies in two among four South Korean industries (energy saving industries are: fertilizer industry, and iron and steel industry; energy using industries are: cement industry, and pulp and paper industry). On the other hand, in the cases of India and the US, almost all sectors studied are found to have energy-using characteristic (such as chemical, paper, primary metals and cement industries). This result is not surprising in the case of the US since well before, Hogan and Jorgenson (1991) obtained the similar conclusions.

Empirical literature on the technical progress using energy data for the case of France seems to be very poor. There is no study devoted entirely to the determination of the direction of technical progress in relation to the energy factor demand for the French economy with the exception of the paper by Millok and Nauges (2006) who, after evaluating tax/subsidy systems introduced in order both to reduce air pollution and to promote abatement technologies, investigate the bias of technical progress using observations for 226 firms from three industrial sectors, namely coke, chemistry, iron and steel industries. They show that plants from the sectors of coke and chemistry have a higher probability to invest in an abatement technology than plants from the iron and steel industry.[1]

The main contribution of the present paper is that, to the best of our knowledge, this is the first attempt to examine the direction of technical change at the sectoral level focusing on energy as a production factor, thus, providing a comprehensive and integrated tool for extracting information about the evolution of factor demands in relation with the technical progress for the case of France.

The paper proceeds as follows. In Section 2, after we introduce the data definitions, we discuss the econometric methods and present the model employed in the empirical estimations. We provide the main results and their discussions in Section 3. In the final section, we review the conclusions we draw providing also some directions for future research.

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[1] We do not review in detail the vast literature on technical progress in energy-economy-environment models. See Loschel (2002) who provides an excellent survey on this issue.

2. Data and methodological issues

2.1. Data description

The models presented above are estimated on yearly French sectors data, coming from Input-Output tables published by French National Institute of Statistics and of Economic Studies (INSEE). Data for interest rate which is utilized to construct user cost of capital are obtained from Organisation for Economic Cooperation and Development (OECD). We decompose the French economy into 13 sectors according to two main criteria: (1) production technology employed in the sector; (2) degree of cleanness of the production process. Consequently, we have a group of 6 sectors characterized by high level of energy consumption and, in turn, high level of pollutant emissions. These sectors are (with their abbreviations used throughout in this paper): *che*-chemistry; *pap*-paper; *met*-metallurgy; *min*-mineral products; *con*-construction; *tra*-transport. On the other hand, we have 2 energy producer sectors: *ele*-electricity and gas; *pet*-petrol and coal, and 2 services sectors: *serm*-private services; *sernm*-public services. Finally, the last three sectors are *agr*-agriculture, *alim*-agro-alimentary sector and *man*-other manufacturing sectors which are *cleaner* than those regrouped in the first group of sectors.

We close this subsection by noting that the impact of technical progress on factor demands is estimated for each sector separately using time series data covering the period from 1978 to 2006.

2.2. The empirical model

We consider a representative producer for each of the sectors *j* making up the French economy. A sector produces one product with four factors: capital (K), labor (L), energy (E) and materials (M). According to duality theory, the optimization program of any sector consists of minimizing the cost function C^j (p^j_i, y^j, t) depending on input prices, production level and time variable that may be interpreted as technological change.

Using the Translog cost function, each sector is modeled by a log-linear equation that allows a large possibility of interaction among different inputs, level of production and technical progress:

$$\ln C_t^j = \beta_0^j + \sum_i \beta_i^j \ln p_i^j + \frac{1}{2}\sum_i \sum_{i'} \beta_{ii'}^j \ln p_i^j \ln p_{i'}^j + \sum_{i=1} \beta_{iy}^j \ln y^j \ln p_i^j +$$

$$\sum_i \beta_{it}^j t \ln p_i^j + \beta_y^j \ln y^j + \frac{1}{2}\beta_{yy}^j (\ln y^j)^2 + \beta_{yt}^j t \ln y^j + \beta_t^j t + \frac{1}{2}\beta_{tt}^j t^2 \qquad i, i' = K, L, E, M$$

(1)

At the optimum, applying a Shephard's lemma (Shephard, 1970), the differentiation of the cost production function given in Eq. (1) with respect to the log inputs prices is equal to input share equations. With four factors of production, the vector form of the system of input share equations can be thus represented as follows:

$$\frac{\partial \ln C_t^j}{\partial \ln p_i} = \frac{p_i}{C^j}\frac{\partial C^j}{\partial p_i} = \frac{p_i x^*_i}{C^j} = S_i^j = \beta_i^j + \sum_{i'} \beta_{ii'}^j \ln p_{i'}^j + \beta_{iy}^j \ln y^j + \beta_{it}^j t \qquad (2)$$

with

$$(S_i^j) = \begin{pmatrix} s_K^j \\ s_L^j \\ s_E^j \\ s_M^j \end{pmatrix}, \left(\beta_i^j\right) = \begin{pmatrix} \beta_K^j \\ \beta_L^j \\ \beta_E^j \\ \beta_M^j \end{pmatrix}, \left(\beta_{ii'}^j\right) = \begin{pmatrix} \beta_{KK}^j & \beta_{KL}^j & \beta_{KE}^j & \beta_{KM}^j \\ \beta_{LK}^j & \beta_{LL}^j & \beta_{LE}^j & \beta_{LM}^j \\ \beta_{EK}^j & \beta_{EL}^j & \beta_{EE}^j & \beta_{EM}^j \\ \beta_{MK}^j & \beta_{ML}^j & \beta_{ME}^j & \beta_{MM}^j \end{pmatrix}, \left(\beta_{iy}^j\right) = \begin{pmatrix} \beta_{Ky}^j \\ \beta_{Ly}^j \\ \beta_{Ey}^j \\ \beta_{My}^j \end{pmatrix}, \left(\beta_{it}^j\right) = \begin{pmatrix} \beta_{Kt}^j \\ \beta_{Lt}^j \\ \beta_{Et}^j \\ \beta_{Mt}^j \end{pmatrix}$$

where S_i^j is the share of factor *i* in the sector *j*. Furthermore, the parameters $\beta_i^j, \beta_{ii'}^j, \beta_{iy}^j$ and β_{it}^j measure respectively the Constance, the share effect of changing relative input prices, direction or bias of technical progress. Among these effects, in this paper employing two different methodologies, we focalized on the study of the last one: bias of technical progress.

The bias of technical change can be defined as the time variation of the demand for a factor $i, (x_i^*)$, holding both the input prices and production level constant. A negative sign of (β_{it}^j) signifies that the technical progress is biased in favor of input i or is an "input-saving" technical progress. Alternatively, a positive sign reflects the fact that the technical progress is 'input-consuming" (or "input augmenting"). In addition, the technical progress is described as neutral in Hicks sense in case we have the same reaction of factor's demand over time for all inputs. That is, we have $\beta_{it}^j = \beta_{i't}^j \, \forall i \neq i'$.

In order to have a well behaved cost production function, some restrictions called "regularity conditions" are imposed to the coefficients of the system given in Eq. (2):

- Homogeneity: $\sum_i \beta_i^j = 1; \sum_{i'} \beta_{ii'}^j = \sum_i \beta_{iy}^j = \sum_i \beta_{it}^j = 0$
- Symmetry: $\beta_{ii'}^j = \beta_{i'i}^j, \beta_{iy}^j = \beta_{yi}^j$
- Monotony: $\dfrac{\partial \ln C_t^j}{\partial \ln p_i^j} = S_i^j \geq 0$
- Concavity: We adopt here the notion of local concavity according to Ryan and Wales's (2000) approach.

In the next step, while applying these conditions in the econometric estimation procedure, to avoid the singularity of covariance matrix, we reduce the number of equations in the system represented in Eq. (2) to tree equations. Consequently, each equation depends on relative prices and the equation dropped has no impact on estimation results (Christensen and Greene, 1976).

The estimation of the relevant system subject to the regularity conditions given above is realized in two steps which are complementary to each other. First, we use an iterative Zellner's method (Zellner, 1962), which models the technical progress for each factor as a linear trend. This approach is introduced for the first time by Binswanger (1974), and employed later in many studies, for example, by Jorgenson et al. (1987), Betts (1996) and Eruygur (2009). Although this econometric methodology presents a major advantage by taking in consideration, during the estimation procedure, the correlation between the share equations, it is very restrictive since the coefficients estimated are all supposed constant over time. This weakness is particularly undesirable in the case of this study, because there is no doubt that the bias of technical progress changes over time depending at the same time on economic, social and environmental policies and external shocks such as the oil choc or economic crisis, which by affecting the cost of production may have an influence on the direction of technical change.

Therefore, in the second time, a more flexible method, which considers the bias of technical progress as a dynamic process, is also used. In fact, it consists in replacing the constant time trends in the system (Eq. (2)) by unobservable (or latent) variables in the state-space model. We believe that the bias of technical progress is very adequate to be interpreted as an unobserved variable for at least two reasons: (1) the data for both the nature of production technology in micro-economic level and explanatory variables which may induce in the future some technological transformations are not easily accessible; (2) technological change is a long term process in which there may be a quiet large time span between the period of making a decision for investing in new technologies and the period of reaping the fruits of such an investment. Hence, the bias of technical progress may not be resulting just from a simple investment decision but also from a mix of other factors, such as energy prices or environmental policies in our case, which makes it difficult to understand its nature and to measure it.

We now represent the standard vector structure of a multivariate state-space model composed of two types of equations: measurement (signal or observation) equation and state equation (see Eq. (3)). This model is presented in the majority of relevant books[2] as follows:

$$\begin{cases} Y_t^j = Z_t^j + A^j . X_t^j + \varepsilon_t^j \\ Z_t^j = C^j . Z_{t-1}^j + \theta_t^j \end{cases} \tag{3}$$

$$\text{with: } \begin{pmatrix} \varepsilon_t^j \\ \theta_t^j \end{pmatrix} \sim NID \begin{pmatrix} 0; Q^j \\ 0; \lambda^j * Q^j \end{pmatrix};\ \lambda^j = R^j / Q^j$$

where Y_t, X_t and Z_t[3] are respectively the vector forms of observed, explanatory and unobserved latent variables at date t for any sector. Both A and C represent constant matrices. ε_t and θ_t are the Gaussian independent disturbance with R and Q as covariance matrices. λ is a diagonal matrix with the coefficients named signal/noise ratio. The matrices A, C, Q and R include unknown parameters, which are estimated using the Maximum Likelihood estimator based on a normal distribution.

A high signal/noise ratio means that the unobserved variable explain a large part of variation of endogenous variable, and consequently the quality of the estimation of measurement equation is improved. On the contrary, when the value of this ratio is close to zero, the smoothed estimation of the state-space model yields the similar results to those obtained by the ordinary least squares (OLS) method. In most of the empirical studies, this ratio is usually

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[2] One of the simple and very pedagogic introductions for the state-space modeling technique is given in Commandeur and Koopman (2007). One can find an exhaustive description of this method in Hamilton (1994) or in Harvey (1990).

[3] For simplicity, the index "*j*" is drooped in the rest of the text.

imposed to be small enough in order to reproduce smoothed time-varying parameters. Nevertheless, in our study, the signal/noise ratio is estimated for each factor shares equations in each sector.

As we have already mentioned, the bias of technical progress is considered as an unobserved variable. It is measured by state variable (Z_t) in the state-space model case, applying the Kalman filter technique (Kalman; 1960). Hence, the econometric model presented in the system given by Eq. (3) can be expressed in the form required by the Kalman filter with the following definitions:

$$Y_t = \begin{pmatrix} S_{Kt} \\ S_{Lt} \\ S_{Et} \end{pmatrix}; \quad X_t = \begin{pmatrix} 1 \\ (\ln p_{Kt} - \ln p_{Mt}) \\ (\ln p_{Lt} - \ln p_{Mt}) \\ (\ln p_{Et} - \ln p_{Mt}) \\ \ln y_t \end{pmatrix}; \quad Z_t = \begin{pmatrix} B_{Kt} \\ B_{Lt} \\ B_{Et} \end{pmatrix}$$

$$A = \begin{pmatrix} \beta_K & \beta_{KK} & \beta_{LK} & \beta_{EK} & \beta_{KY} \\ \beta_L & \beta_{KL} & \beta_{LL} & \beta_{EL} & \beta_{LY} \\ \beta_E & \beta_{KE} & \beta_{LE} & \beta_{EE} & \beta_{EY} \end{pmatrix}; \quad C = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$Q = \begin{pmatrix} \mathrm{var}(\varepsilon_t^K) & 0 & 0 \\ 0 & \mathrm{var}(\varepsilon_t^L) & 0 \\ 0 & 0 & \mathrm{var}(\varepsilon_t^E) \end{pmatrix}; R = \begin{pmatrix} \mathrm{var}(\theta_t^K) & 0 & 0 \\ 0 & \mathrm{var}(\theta_t^L) & 0 \\ 0 & 0 & \mathrm{var}(\theta_t^E) \end{pmatrix}$$

where B_{it} reflects the bias of technical progress for factor i at time t. We suppose that state variable follows a random walk process, that is, we have an identity matrix for C. In fact one should make such an assumption since there is not any prior knowledge about the appropriate form of the evolution of the technological change. Besides, the initial value of each variable is deducted from the iterative Zellner estimation of the system given in Eq. (2) (first step of the empirical study)[4], except parameters λ_t which are chosen arbitrary. The sensibility tests show that the estimation results are not sensitive to the starting values of these parameters.

3. Main results and discussion

As a preliminary analysis, we report the results for three production factors, namely capital, labor and energy. The estimation results for our state-space model are plotted in Fig. 1.[5]

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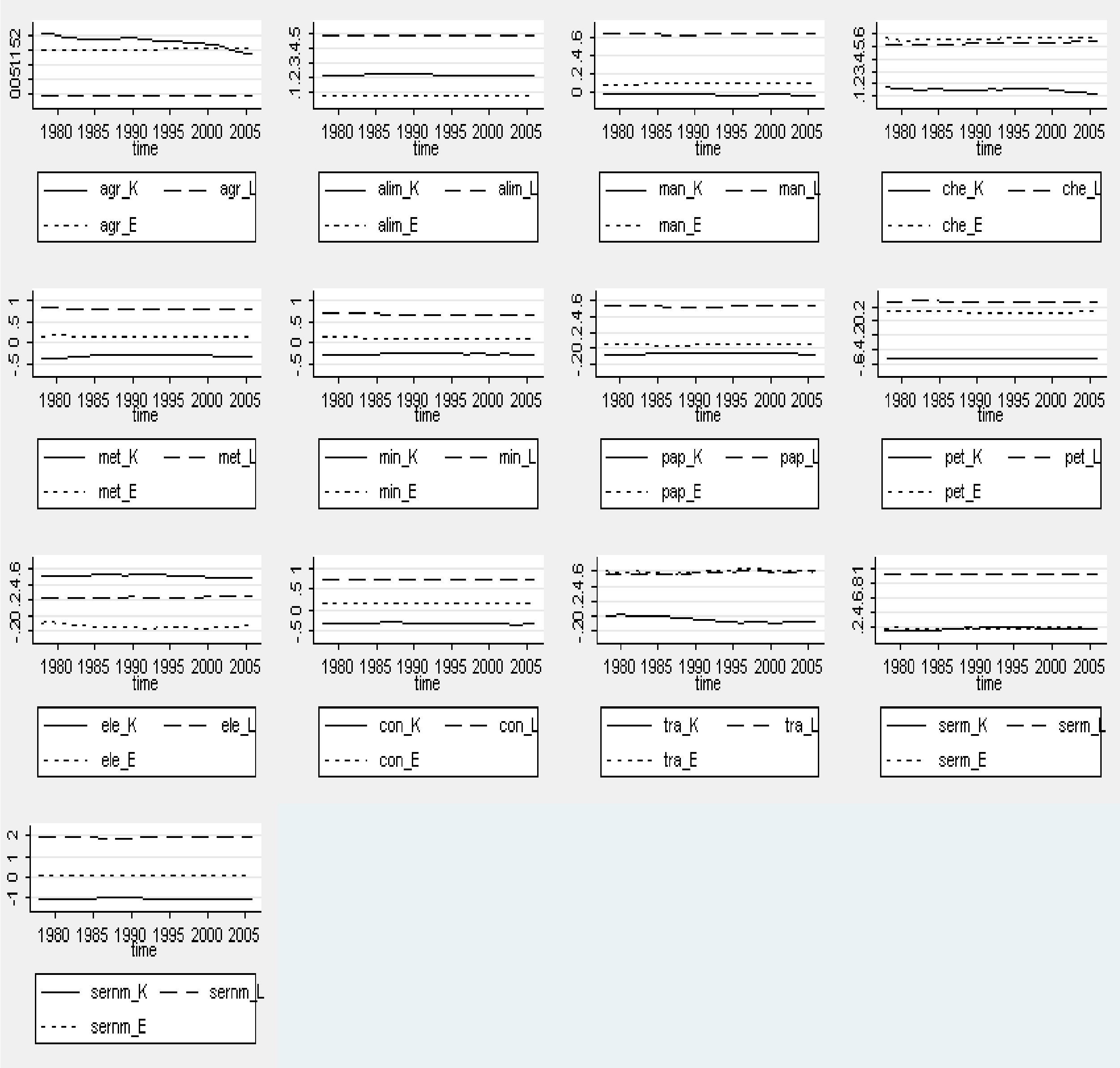
[4] Since the variables involved are all non stationary, the iterative Zellner estimation is conducted with the first differenced variables. The unit root test results are given by augmented Dickey Fuller (ADF; Dickey and Fuller, 1981) test (see Table A1 in Appendix A). However, with the Kalman filter tool, we do not have such a problem since the non-stationarity of a variable does not have any effect on the output estimation processes.

[5] The estimations of signal/noise ratio yield a relatively high value, which prove that the explanatory variables in the measurement equations explain the large part of variations of the endogenous variables. As a result, the estimation quality is improved. Other indicators proving the good performance of the estimations are given by the likelihood values and different information criterions in Table A2 in Appendix A.

Fig. 1. Bias of technical progress between the production factors; capital, labor and energy



The results reveal that in all of 13 sectors technical progress does not have a neutral characteristic. Furthermore, direction of technical change is found to be different with respect to each sector. In the majority of the sectors (namely, *man*, *che*, *met*, *min*, *pap*, *pet*, *con*, *tra*, *serm* and *sernm*), technical change may be qualified *relatively* capital saving[6] since in these

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[6] To avoid any ambiguity, we would like to precise that we use the term "factor saving" if technical progress decreases the demand for a specific factor (by increasing its efficiency) and "factor augmenting" if it increases

sectors estimated B_{Kt} is found to be inferior to both B_{Lt} and B_{Et}. We have *absolute* capital saving technical progress in the sectors *man*, *met*, *min*, *pap*, *pet*, *con*, *tra* and *sernm* where $B_{Kt} < 0$. This result may be found reasonable upon examining in depth the variation of capital demand in time since, although we can not detect it from Fig. 1, beginning from 1986, raise in interest rates increased the cost of capital, and hence more effort has been devoted to the invention and implementation of capital saving technologies.[7] On the other hand, labor is found to be the factor which's demand is the less diminished by technical change. This result is not surprising since, as in other developed countries, skill complementary technologies have been introduced in a wide range of domains, thus, demand for skilled labor increased.[8] This affirmation seems to hold in all sectors but one: agriculture. Following technical progress, while the demand for both capital and energy has been increasing, labor demand has slightly decreased in the French agriculture where the ratio of skilled to unskilled workers is very low with respect to other sectors. In addition we should mention that overall results indicate that the impact of technical progress is less time varying for labor force which makes relatively stable its demand. In fact, if one monitors thoroughly the variation of B_{Lt}, one can see that when the French government decreased employer payroll taxes in 1994, relative price of labor (i.e. wage) has declined in the following years, thus labor augmenting technical progress gained momentum in the economy.

We now move to investigate the impact of technical progress on energy use on which we focus in the present study. From Fig. 1, it follows that energy saving technical progress is

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its demand. In the literature one may find different appellations. For instance, one may use the term "energy augmenting technical progress" to say that new technologies increase the efficiency of use of energy.

[7] The impact of technical progress is displayed in detail only for energy, and other factors are not included in order to conserve space. All detailed results for other production factors are available from the authors upon request.

[8] Similar reasoning can be found in Acemoglu (1998) who in a well constructed theoretical framework discusses the interactions between skilled labor supply and direction of technical change.

present in only electricity and gas sector. However, as we have already mentioned, this figure does not give us the opportunity to provide a detailed factor specific analysis. That is why, more focus is needed here and in what follows, we conduct our analysis only on the energy use.

Fig. 2. Impact of technical change on energy demand

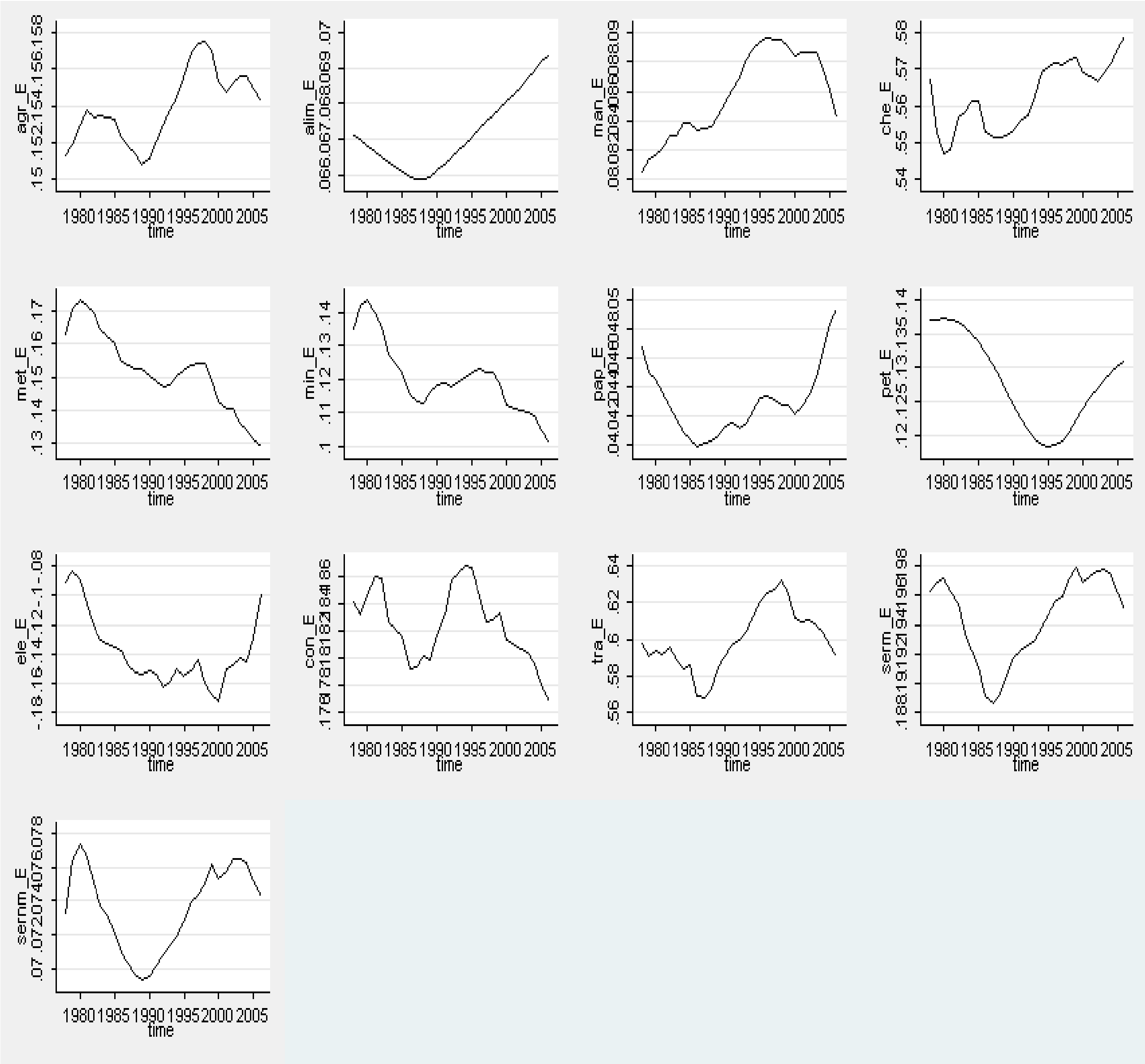
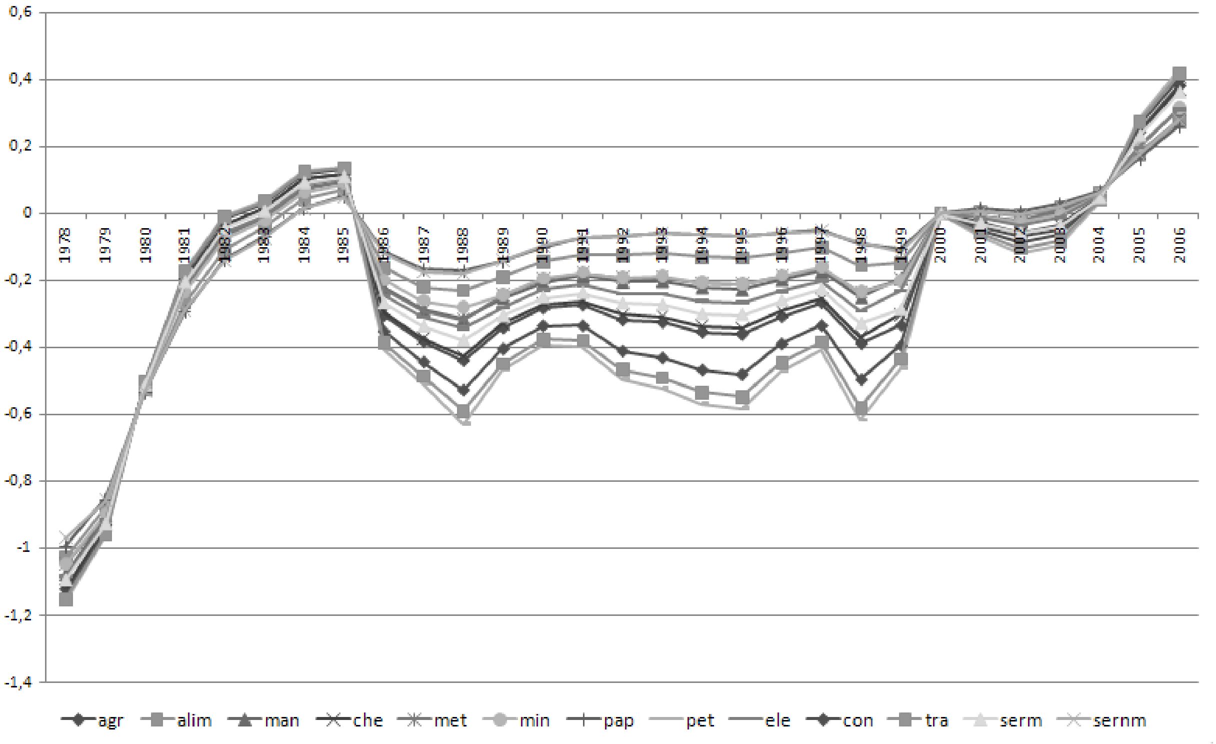


Fig. 2 presents how energy demand is affected by technical change in 13 sectors of the French economy, thus provides much more detailed representation of the impact of technical progress on the energy demand than that of Fig. 1. In our case energy-technology-economy relationship can be discussed under three periods with respect to developments at both international and national levels: (1) post-energy crises (1978-1985), (2) economic growth and decline in energy prices (1986-1990 and 1994-2000), (3) economic stagnation, pre-Kyoto protocol and increase in energy prices (2001-2006).

In the first period, since energy crises increased sharply world energy prices, almost in all sectors of the French economy, energy requirements have decreased by the implementation of new energy saving technologies (see Fig. 3 for the time path of energy prices). However, in the *clear* manufacturing industry, *man*, which seems to be also less energy dependent, we do not observe significant reduction, but a slight increase in the energy demand.

Fig. 3. Time path of energy prices in the 13 sectors of the French economy (2000=0)



In the second period which is dominated by two sub periods of economic growth, the impact of technical progress on energy use has been reversed and in the majority of the sectors studied, we have energy augmenting technical progress. This substantial change in energy demand trend can be seen especially in the sectors like services, agriculture, transport, food agro industry where energy consumption keeps on growing as long as the economy grows. Furthermore we see that our first statement related to the relationship between direction of technical change and energy prices is confirmed by the results obtained in this second period which suggest implementation of energy-complementary technologies after a fall in energy prices.

Increase in energy demand induced by technical change seems to slow down in the third period where on the one hand the French economy falls into stagnation and on the other hand following the Kyoto Protocol, negotiated in December 1997, where countries committed to reduce their emissions of greenhouse gases, environmental consequences of energy consumption are accounted for more seriously in energy and environmental policies. A third factor which can also be explanatory in the reestablishment of energy saving technical progress is, once again, energy prices which have increased in this period. In consequence, in recent years new technologies decreased energy demand in all sectors except *alim*, *che*, *pap*, *pet* and *ele*.

Taking together all above provided results on the direction of technological change – energy price nexus we may open a brief discussion related to the impact of energy and environmental policies on the direction of technical progress. We see that energy prices may have a direct effect on the energy bias of technical progress. Among others, Popp (2002) confirms the role played by variation in energy prices in inducing technological change. He shows more specifically that increase in fossil energy prices leads to adoption of new less energy intensive technologies in the US firms. We may reasonably expect that all increase in energy taxes which are reflected on energy prices will rise relative price of energy and consequently induce new technologies to be more energy saving. Nevertheless, this inference should be viewed with caution since an increase in energy prices resulting from a pass through mechanism (which suggests that an increase in international energy prices would raise national prices) has not the same characteristic as an increase following a rise in energy taxes. Because while the former is exogenous (oil chocks, for instance) the latter may be anticipated. Hence, economic agents may have different behaviors in these two cases. We should, in consequence, acknowledge that such a discussion needs more empirical evidence to be more effective.

Another important finding is that, as mentioned above, only in electricity generation sector we have energy saving technical progress since during the whole period considered, B_{Et} is found to negative sign. At this point, the following remarks are not useless. Nuclear power is the main source of electricity in France. In fact, the national nuclear program has been launched after the first oil crisis in 1973 and gained impetus after the second one in 1978. In 2006, with its 58 nuclear power reactors in 19 nuclear plants, France is the one of the most developed country in nuclear energy and nuclear power covers about 40% of the country's energy needs.[9] Therefore, it is logical to find out that energy demand in the electricity generation has been decreased following the implementation of new technologies in this sector.

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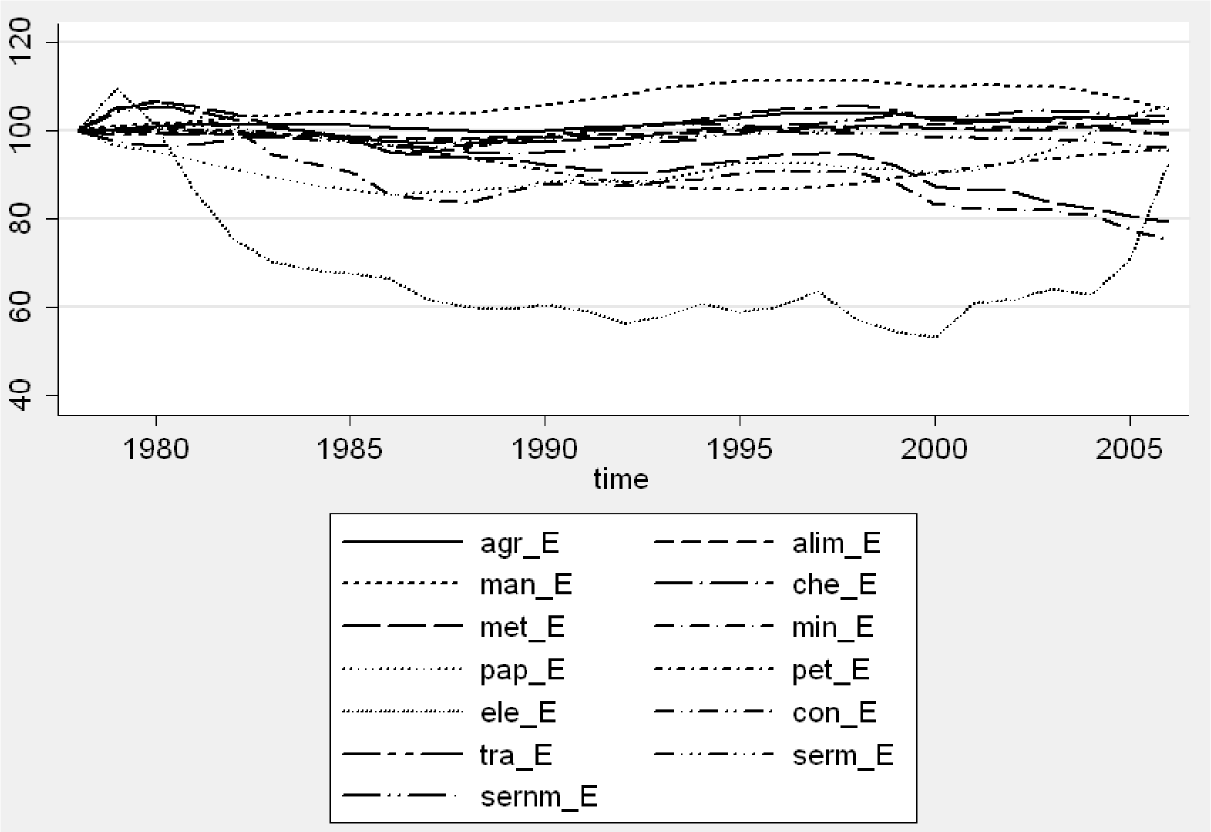
[9] For a brief overview of the French energy situation compared to other European Union countries and the energy policies applied in the country see Meritet (2007).

Fig. 4. Sectoral comparison of the impact of technical change on energy demand (1978=100)



To conclude this analysis, we plot on the same graph the series given in Fig. 2 which makes it easier to make a sectoral comparison of the variation in time of the impact of technical change on energy demand (Fig. 4). We see clearly that sectors can be divided into two separate groups and an outlier: the first group is composed of sectors in which technical progress reduced energy demand during the sample period. These sectors are *min*, *met*, *pap* and *pet*. The first two sectors seem to move together (about 20 percent of increase in the energy-biased technical progress with regard to 1978) and while the others converge to the second group of sectors, in which technical change have induced increases in energy demand, they diverge from the average. Finally, the outlier of our sample is *ele*. Recall that *ele* is the sole sector for which we have *absolute* energy saving technical progress. In this sector, while in 2000 the impact of energy saving technical progress on the energy demand was nearly 47 percent higher than that of 1978, it is about to reach its initial level in 2006. In fact, this finding suggests that in the electricity and gas sector the rate of energy saving technical progress reached saturation point and it becomes harder to reduce further the energy demand in this sector.

4. Conclusions and future work

The main contribution of the present work to the question of direction of technical change might be the identification of the effect of technical progress in relation with different regulatory variables and exogenous structural variables on the demand for three main production factors, capital, labor and energy. First of all, the methodological framework presented in the present paper indicates that non neutral technical change is present in the French economy. Taken as a whole, from the estimation results provided by our state-space model, various trends have been detected for all of three production factors. In general, policy choices seem to determine, at least in some extent, the direction of technical change in the economy. In most of the sectors, technical progress is directed to decrease capital demand. High level of interest rates may be one of the explanatory factors for this. Again the presence of labor augmenting technical progress in labor intensive sectors may be explained by the decline in employer payroll taxes since 1994.

Turning to the question of whether technical progress is biased toward energy in France, our verdict is rather mixed. Although our model gives us the opportunity to study also other factors, factor specific analysis shifted the focus to investigate differences in the impacts of technical change on the energy demand for 13 sectors in France. We find out that the energy bias of technical change is very sensitive to the changes in energy prices. To be more specific, the rate of energy saving technical progress is found to be higher during the periods of high energy prices, and *vice versa* for the periods of low energy prices. The sensitivity of the rate of energy saving technical progress to the variations of energy prices seems to be less important in relatively more energy dependent and more pollutant sectors. Interestingly, during the whole sample period studied, only electricity and gas sector experienced *absolute* energy saving technical change. This is because the share of nuclear power in this sector is one of the highest shares in Europe.

To end up this last section we would like to suggest some future research directions. The main objective of this study was limited to detect the direction of technological progress, without providing detailed information on how it was affected and in what proportion. Thus, a possible complementary research around the environment-technical progress nexus within the French multi-sectoral framework would be conducted in three directions: the first major extension may be to try to measure the effects induced by a restrictive environmental policy (such as pollution tax) in terms of directing technical progress to decrease fossil energy demand; the second one consists of endogenizing the technical progress in the firms optimization programs in order to explain the development of clean technologies in an empirical fashion; finally, if one wishes to make a more complete analysis of the relationship between technological change and environment including also social and economic consequences of this relationship, building a specific applied general equilibrium model may be a good tool for this purpose.

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Appendix A.

Table A1 : Augmented Dickey-Fuller unit root test results[1]

Variables	S_K	S_L	S_E	S_M	lny	Lnp_K	lnp_L	lnp_E	lnp_M
agr	-2.937244	-0.254024	-1.797155	-1.281506	-2.368832	-3.553627	-2.337186	-2.518927	-5.758150
alim	-1.900640	-0.288225	-0.403909	-2.987842	-4.629491	-3.416813	-1.969705	-4.040617	-6.312936
man	-2.139545	0.101633	-1.128366	-2.024863	-0.297989	-3.931324	-2.075737	-3.346107	-4.242157
che	-2.116215	-1.459336	-1.311517	-7.301157	-1.654489	-3.287539	-3.056945	-2.647702	-0.227886
met	-2.336246	-1.916063	-0.748578	-2.552401	-0.237097	-1.141372	-8.030386	-3.351231	-4.353535
min	-1.847357	-1.069754	-1.192107	-3.156541	-0.332893	-3.364296	-6.083972	-3.300310	-12.08780
pap	-1.923067	-1.976303	-1.084660	-1.446582	-0.800588	-2.815552	-5.006944	-4.676672	-5.488854
pet	-1.406503	-1.633550	-1.204173	-4.037076	-3.517444	-3.541820	-2.793075	-1.886656	0.251821
ele	-0.310154	-1.552765	-0.845199	-1.161268	-0.822292	-4.369169	-5.603091	-3.108268	-3.103786
con	-1.827768	-2.113948	-1.130444	-0.852824	-0.736536	-3.931224	-6.665976	-2.164625	-2.168538
tra	-1.454314	-0.734781	-1.269622	-0.750008	-0.426327	-3.249153	-5.550570	-1.973005	-1.471535
serm	-1.296324	-0.350358	-1.042881	-2.725711	0.445842	-2.794489	-3.399409	-2.730895	-9.865629
sernm	-3.041410	-2.262938	-0.926923	-1.677604	-4.071552	-3.298922	-6.981434	-4.181471	-5.615360

[1] Null hypothesis: the variable has a unit root
(with intercept, no trend)

Test critical values:	1% level	-3.699871
	5% level	-2.976263
	10% level	-2.627420

Table A2: Estimation of the bias of technological change by Kalman Filter (for the year 2006)

Final State	B_K	B_L	B_E	Log likelihood	Akaike criterion	Schwarz criterion	Hannan-Quinn criterion
agr	0.247066	0.003226	0.136613	296.2364	-19.60251	-19.03673	-19.42532
alim	0.320049	0.483615	0.061701	364.0790	-24.28131	-23.71553	-24.10412
man	-0.056879	0.646896	0.083802	351.4217	-23.40839	-22.84262	-23.23120
che	0.107303	0.552686	0.588006	281.5981	-18.59298	-18.02720	-18.41578
met	-0.388496	0.808517	0.125500	301.3029	-19.95192	-19.38615	-19.77473
min	-0.283748	0.688662	0.097971	287.9256	-19.02935	-18.46357	-18.85215
pap	-0.133628	0.536011	0.051497	322.4454	-21.41003	-20.84425	-21.23283
pet	-0.529589	0.297397	0.151153	183.1341	-11.80235	-11.23657	-11.62515
ele	0.467722	0.250801	-0.101987	237.4601	-15.54897	-14.98320	-15.37178
con	-0.314108	0.742932	0.180192	314.6478	-20.87226	-20.30649	-20.69507
tra	-0.082826	0.609531	0.592405	264.4559	-17.41075	-16.84497	-17.23356
serm	0.187662	0.933111	0.195273	345.6969	-23.01358	-22.44780	-22.83638
sernm	-1.051725	1.916619	0.086998	326.7810	-21.70904	-21.14326	-21.53184

All estimations are significants at 1%