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Abstract

Persistently rising energy prices have revived interest in the economic impact of changing energy costs. We explore the effects of these costs on sectoral change, particularly in relation to the rise and future prospects of the "service economy". Following Baumol's cost disease hypothesis, (unexplained) productivity differentials between the industrial and service sectors are often utilized to explain the recent dominance of the service sector. We hypothesize that the productivity differential results from the respective technological opportunities for substituting energy for labor in each of the sectors. To test our hypothesis, we analyze the U.S. economy for the period from 1970 to 2005. By means of the Autoregressive Distributed Lags (ARDL) bounds test, we examine whether a cointegrating relationship exists, in a given sector, between labor productivity and variables from our model representing the technological substitution conditions. Our findings support this hypothesis. Therefore, we can conclude that productivity differentials between the sectors may vanish if, as a result of rising energy costs, the substitution incentives are likely to fade out. Such a development might put the future of the service economy at risk.

Key words: Sectoral Change, Energy, Technical Change, Productivity Growth, Baumol's disease
JEL: D24, O41, O47, Q43, Q57

1. Introduction

The role of energy for the future of the economy is back on the agenda. After the oil price shock of the 1970s, the topic had already attracted much attention. Two new developments have revived the interest. First, since the turn of the millennium, energy prices have started a secular rise again. A growing energy demand of the now industrializing countries over-compensates the ongoing energy efficiency gains. At the same time it is assumed that oil extraction has reached its maximum – "peak oil" – nourishing concerns about the depletion of world oil resources (Hubbert, 1949; Campbell and Laherrère, 1998; Campbell and Heapes, 2008). Second, there is a growing awareness of the environmental threats implied by increasing fossil energy consumption and its effect on the CO2 concentration in the atmosphere (Stern, 2008). Regulatory interventions and rising taxes become likely and will drive up the cost of energy utilization even further. Now, the question arises: how will the economy adjust to less cheap energy?

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With respect to aggregate economic growth, the importance of energy use has extensively been discussed – with rather controversial results (Ozturk, 2010, see also Bruns et al., 2012 for a recent meta-analysis). In contrast, the problem of how a changing energy use has influenced the *structure* of the economy has attracted less attention. Yet, from an empirical point of view, the two problems are just two sides of the same coin (Gross, 2012) since structural change is simply a concomitant phenomenon of economic growth. This becomes apparent from the persistent shifts of value added and employment shares from the industrial sector to the service sector (Schettkat, 2007). In all OECD economies, the latter has now become the dominant sector – the rise of what is called the "service economy". In this process, the industrial sector with its high labor productivity growth rates has continuously laid off labor which was absorbed by the expansion of the service sector with much lower productivity gains. Policy makers and the public therefore often see the "service economy" as a way in which both economic growth and high employment rates will also be feasible in the future. However, if energy costs continue to strongly increase, it is not clear whether structural change will continue to follow the patterns of the past and what the future prospects of the service economy will be.

Since Baumol's (1967) seminal paper on a "cost disease" in the service sector, a huge literature has focused on productivity differentials between the sectors as an explanation for the observed sectoral change. However, in these contributions, a causal influence of energy use on sectoral change is not considered (in contrast to the reverse influence, see e.g. Schäfer, 2005; Huntington, 2010). In the present paper we will therefore explore the role that energy plays for the observed productivity differentials and the resulting shifts of the sectors' value added and employment shares. More specifically, we want to highlight the role of the technological conditions of energy use that differ between the sectors. As will be shown, these differences provide a key for understanding how a changing gross energy price (including tax) affects productivity growth differently and thus contributes to sectoral change.

In much of the second half of the 20th century, the price of energy stagnated or even fell relative to ever more expensive labor. The falling relative price of energy created incentives to substitute energy for labor in all sectors. Yet, for reasons of their technology, the sectors differ with respect to the substitution volumes and, hence, possible cost savings. In the industrial sector, the production technology allows for a large-scale substitution of both energy and capital for labor. This is not the case in the service sector – except in transport. (When the service sector is split up into "transport services" and what we will call "commercial services" as the remainder, the technology of the transport sector is characterized by an energy-labor ratio that is even higher than that of the industry sector.) For providing commercial services little energy is needed. Hence, the potential for substituting energy for labor is technologically narrowly constrained.

Based on these observations we argue that there are technological differences between the sectors in how, and to what extent, energy (plus capital) can be substituted for labor. These differences are a major reason for why, in the sectors with a high energy intensity of production, productivity increases are in real terms significantly higher than in the sector with low energy intensity. To evaluate this hypothesis empirically, we use data for the U.S. for the period from 1970 to 2005. By means of the Autoregressive Distributed Lags (ARDL) bounds test developed by Pesaran and Shin (1999) and Pesaran et al. (2001) we test the relationship for the three sectors industry, transport, and commerce, as well as for the macro level. The evidence we find suggests that the soaring use of cheap energy in the "progressive" industry sector has indirectly fueled much of the inflationary development of the "stagnant" commercial service sector in which energy is of only minor quantitative importance. We dub this phenomenon the "energy paradox of sectoral change". By reverse inference the energy paradox seems to suggest that, as an ideal for an employment preserving economic growth strategy, the "service economy" may run into troubles if gross energy prices continue to grow substantially in the future.

We will develop our argument in more detail as follows. Section 2 discusses how the sectors' production technologies differ in their utilization of energy and what role labor and capital goods play in the sectors' production technologies. Furthermore, we explain why we see a need to distinguish transport from other services. In Section 3 we introduce a simple sectoral production model based on a modified Cobb-Douglas function. We understand the model as locally approximating the relationships between energy, labor, and capital at different points in time. Following the discussion in the preceding section, we use the model framework to derive the hypothesis mentioned before. Section 4 explains both the data we use for the empirical tests of the working hypothesis and our methodology. In Section 5 we present the empirical results and discuss the energy paradox together with its implications for the future of the service economy. Section 6 presents some tentative conclusions.

2. Sectoral Change in the U.S. – Background and Technological Contingencies

The systematic shift of value added and employment shares between the sectors of the economy has been recognized since long (see Schettkat and Yocarini, 2006 for a recent survey). It is likely to have several causes, whose significance is varying historically. At present, for example, changes in international specialization patterns seem important. Among them are outsourcing and/or off-shoring particularly of manufacturing activities from high to low wage countries. The result is that the service intensive parts of the value chains are concentrated in the most developed economies. In addition, enabled by a highly educated work force and mature institutions, these economies specialize strongly in advanced services such as research, education, health, and finance. However, energy-related factors – on which the present paper focuses – do not seem to play a role for these topical changes. We will therefore leave them out of consideration here.

Instead, we concentrate in our analysis on the well known more persistent phenomenon accompanying sectoral change: the differential growth of the sectors' labor productivity. This phenomenon has been put center stage by Baumol's diagnosis of a "cost disease" in the service sector. Baumol (1967; see also Baumol, Blackman and Wolff, 1985) observed that, over time, comparatively less labor is needed in the producing industries. In real terms, labor productivity therefore rises faster in these industries than in the service sector. With by and large the same wage rate being paid in all sectors, the productivity differential results in average unit costs of services rising relative to average unit costs in the industrial sector. If the prices of services can be raised sufficiently relative to those of industrial goods, the unit cost differentials can be compensated. But this will induce consumers to substitute away from some of the ever more expensive services (Baumol and Bowen, 1966). Indeed, it is not the entire sector that suffers from substitution. To the contrary, the sector has been able to increase not only its employment share but also its value added share (see Nordhaus, 2008 for a recent empirical evaluation).

In this explanation, differential productivity growth appears as the ultimate reason for the changing sector shares. It can be argued, however, that differential sectoral productivity growth is in itself a result of more basic causal mechanisms. Indeed, we claim that the deeper causes can in good part be attributed to the technological conditions of energy use and a changing energy price. To motivate this interpretation it is helpful to highlight a few technological characteristics of how and for what purpose energy (in terms of physics: free energy) is used in the different sectors.

In the industrial sector, "production" can generically be characterized as the transformation and shaping of materials which requires energy in various forms (see Buenstorf, 2004). The application of energy (apart from human physical work) is mediated by specific facilities and equipments, i.e. capital goods. Real capital is "productive" – and can replace human labor[1] – in industrial production processes

[1] Another reason is, of course, that, in sufficiently standardized production, know-how and skills of labor built into

Table 1 — Sector Statistics 1970-2005

Sector	Industry	Commercial	Transport
Value added share (macro deflator)	21 (33)	76 (63)	3 (4)
Value added share (sector deflator)	30 (33)	66 (63)	4 (4)
Employment share	21 (35)	76 (61)	3 (4)
Δ Labor productivity (macro deflator)	1.9	1.7	1.7
Δ Labor productivity (sector deflator)	3.1	1.7	2.5
Δ Relative wage level[1]	1.0	1.0	0.8
Energy/Labor ratio	0.56	0.01	1.15
Δ Energy/Labor ratio	1.1	1.0	1.7
Capital/Energy ratio	0.05	0.19	0.08
Δ Capital/Energy ratio	1.9	2.2	1.3
Energy/Output ratio	12.9 (22.0)	1.9 (3.2)	44.1 (43.5)

Note: Values for 2005 (1970); Δ denotes the growth factor (1970=1);
[1]development relative to commercial sector.

precisely because it is the medium through which non-anthropogenic energy is transmitted and put to work in a controlled form at the point of use. By its technical design, the capital stock existing in the industrial sector has a certain energy mediation capacity per period of time. Compared to other sectors, in the industrial sector the energy-output ratio is, by the nature of its physical transformation and shaping processes, comparatively high.

If the energy actually processed falls short of the designed capacity of the capital stock, some of the facilities and equipments are left idle or run at less than their productive capacity. Thus, unlike in much of the literature using energy-dependent Cobb-Douglas production functions for the macro level (see e.g. Berndt and Wood, 1975; Kümmel et al., 1985; Ayres and Warr, 2005), we submit that, in the short run, energy and capital are limitational inputs. The energy-capital ratio and, hence, energy intensity of the capital stock can, however, be changed in the longer run by replacing the existing facilities and equipments, i.e. by investment.

In the service sector – except in transport – this is quite different. As mentioned in the introduction, we therefore separate "transport services" from the rest of the service sector to which we attach the label "commercial services". In transport, passengers or freight are moved from one location to another. By definition this amounts to carrying out physical work. Capital in the form of transport vehicles and energy that fuels their moving again are limitational inputs in the short run. (Vehicles can, of course, be "parked" and their energy consumption thus be saved proportionately.) Unlike in industrial production, a transport service requires hardly any other material input. Not surprisingly, both the energy-capital ratio and the energy-output ratio are therefore even higher in the transport sector than in the industrial sector. (For the empirical facts see the sector statistics for the U.S. for the years 1970 and 2005 in Table 1.)

For the commercial services the opposite holds. Facilities and equipments do not typically serve energy applications for moving or transforming things. To a large extent they rather serve automated and computerized information processing and application. To accomplish this task, little energy is needed. Therefore, the energy-output ratio in this sector is the lowest of all sectors, and so is the energy-capital ratio where, in the short run, the two factors are limitational inputs here too. (The

machinery allow to re-use human knowledge over and again at a marginal cost close to zero, see Langlois (1999).

difference in the energy intensity is intuitively evident if one considers the role that energy plays, say, in producing an insurance service vs. producing a car or a chemical like chlorine.)

Once these differences are acknowledged, it is quite easy to understand the role energy has played for sectoral change in the past and, thus, for the rise of the "service economy". During much of the 20th century, the prices of the energy inputs were very low or even declining (Ayres and Warr, 2005). In contrast, the wage level in the three sectors increased significantly and, as Baumol assumed, without much difference between the sectors (see line 6 in Table 1). The decreasing relative price of energy meant a strong incentive to substitute energy (jointly with capital) for labor. However, given the strongly differing significance of energy in the sectors' production technology, both the incentives and the average volume of substitution differed substantially between the sectors. Industry and transport were able to replace relatively more labor by energy (and capital) than the commercial service sector. This resulted in pushing up labor productivity in real terms in the former ("progressive") sectors more so than in the latter ("stagnant") sector (see the first two lines in Table 1). Hence, in our explanation of sectoral change, industry and transport appear as progressive sectors because they can take advantage of their higher average energy requirements while the commercial service sector, which requires significantly less energy, cannot.

With similar wage increases across sectors and a strongly differing growth of labor productivity in real terms, a soaring wage-productivity gap between the sectors seems inevitable. Not so, however, if the price level in the low-productivity sectors rises sufficiently beyond that of the high-productivity sectors. Indeed, this is what happened. The relative price of commercial services increased to such an extent that, in nominal terms, labor productivity was almost equalized across sectors[2]. Rising real income apparently enabled consumers to pay the increasing prices of the commercial services, allowing the entire sector even to expand. Thus, a paradoxical effect emerged. The energy-intensive sectors made use of their technical opportunity to extensively substitute cheap energy for expensive labor. Via several intermediaries this drove up both the relative costs and employment where only comparatively little energy is used: in the commercial service sector. Similarly, this sector profited least from the technical progress in energy efficiency, i.e. the falling energy-capital and energy-output ratios in the economy. Both effects establish together what we call the energy paradox of sectoral change, meaning that, in monetary terms, energy had the greatest effect in a sector, the commercial sector, where the use of energy is muss less significant.

3. A Sectoral Production Model with Energy-Labor Substitution

In the previous section we argued that the key for understanding the persistent drivers behind the rise of the service economy lies in the sectors' different energy technology. In accounting for these differences in a suitable sectoral production model it has to be recognized, we argued further, that, at any given point in time, energy and capital are limitational factors. Let the sectors of the economy be denoted by the suffix i and time by the suffix t. Let E_{it} give the size of the energy input and $K^*_{it} = u_{it}K_{it}$ that part of the capital stock K_{it} that is active at time t. u_{it} is a utilization rate, $0 \leq u_{it} \leq 1$. Complementarity between these factors can then be expressed by

$$E_{it} = \varepsilon_{it}K^*_{it}. \tag{1}$$

[2] See the comparison of labor productivity in line 4 and 5 of Table 1 calculated on the basis of a GDP price index and a sector-specific price index respectively; see also the discussion in Henriques and Kander (2010).

The parameter $\varepsilon_{it} > 0$ reflects the energy dependence of a sector's capital stock. The inverse, the energy efficiency $1/\varepsilon_{it}$ of capital at the prevailing technological efficiency boundary, increases over time through technical progress[3].

While we submit that the sectors' production technology is in the short run limitational in energy and capital, this is different for labor. Energy-capital packages of the given technological vintage on the one hand and labor on the other can be assumed to be substitutes. To keep things simple we capture this feature by choosing a Cobb-Douglas production function for each sector with the arguments

$$Y_{it} = A_{it} \left(K_{it}^{*}\right)^{\alpha_i} \left(L_{it}\right)^{1-\alpha_i} . \tag{2}$$

Here Y_{it} and A_{it} denote value added[4] and total factor productivity respectively. Labor as the factor input L_{it} warrants some further reflections. Every production technology requires a certain quality of labor services as input. To the extent to which training does not take place on the job, knowledge and skills need to be acquired with a time input L_{it}^{s}. This input is necessary for making qualified labor available in the labor market, but it is only indirectly compensated for by income earned with the paid labor time L_{it}^{p} (measured in hours of contracted work time). If the skilling time ratio is denoted by $L_{it}^{s}/L_{it}^{p} = \sigma_{it} > 0$, we can write for the factor input

$$L_{it} = \left(1 + \sigma_{it}\right) L_{it}^{p} \tag{3}$$

Inserting Eqs. (1) and (3) into (2) we get

$$Y_{it} = \tilde{A}_{it} \left(E_{it}\right)^{\alpha_i} \left(L_{it}^{p}\right)^{1-\alpha_i} \tag{4}$$

with

$$\tilde{A}_{it} = A_{it} \left(\frac{1}{\varepsilon_{it}}\right)^{\alpha_i} \left(1 - \sigma_{it}\right)^{1-\alpha_i} . \tag{5}$$

In the explanatory sketch of the rise of the service economy in the previous section we have emphasized the sector-specific differences in technological opportunities for substituting energy for labor with their impact on labor productivity. Dividing Eq. (4) by L_{it}^{p} and inserting Eq. (5) we get the labor quality and energy efficiency augmented labor productivity which, after taking logs, can be written as

$$y_{it} = \underbrace{a_{it}}_{\substack{\text{Unexplained}\\ \text{TFP}}} + \underbrace{\alpha_i b_{it}}_{\substack{\text{Energy}\\ \text{efficiency}}} + \underbrace{\left(1 - \alpha_i\right) c_{it}}_{\substack{\text{Up-}\\ \text{skilling}}} + \underbrace{\alpha_i d_{it}}_{\substack{\text{Energy-labor}\\ \text{substitution}}} \tag{6}$$

where $y_{it} = \ln\left(\frac{Y_{it}}{L_{it}^{p}}\right)$, $a_{it} = \ln A_{it}$, $b_{it} = \ln\left(\frac{1}{\varepsilon_{it}}\right)$, $c_{it} = \ln\left(1 - \sigma_{it}\right)$, $d_{it} = \ln\left(\frac{E_{it}}{L_{it}^{p}}\right)$.

On the basis of Eq. (5) we can now empirically assess the influence which the different variables have on the labor productivity development in the three sectors. Following the working hypothesis that has been outlined, we expect that sectoral differences in the energy-labor substitution and increases in

[3] We assume that the energy throughput by the actually used part of the capital stock is always at the energy efficiency boundary. u_{it} fluctuates in historical time without any clear trend. In contrast, ε_{it} decreased in all three sectors in the U.S. over the period 1970 - 2005, most significantly, however, in manufacturing (see Table 1).

[4] More specifically, deflated value added, as $Y_{it} = Y_{it}^{n}/p_{it}$ with p_{it} as the sector-specific output price index and Y_{it}^{n} as nominal value added measured in current USD.

energy efficiency are significant for the sectors' labor productivity growth differentials.

4. Data and Methodology

Data on GDP as well as sectoral value added are provided by the Bureau of Economic Analysis (2010) for the U.S. and cover the period from 1970 to 2005. In order to transform the output measures into constant U.S. Dollars, we used sector specific deflators for sectoral value added as well as a GDP deflator for total GDP. The deflators are provided by the same source. The NAICS-based data on value added are available for three sectors: industry (including agriculture, mining, manufacturing and construction), commerce (wholesale trade, retail trade, information, finance, insurance, real estate, rental and leasing, professional and business services, educational services, health care and social assistance, arts, entertainment, recreation, accommodation and food services, and government), and transport (transportation and warehousing; we excluded the residential sector from the analysis because the focus of this paper is on the production side of the economy).

Energy data are provided by the Energy Information Administration (2011). They cover the same sectors as the output data. The energy input is measured as final energy consumption in Billion Btu. Capital data used for the calculation of the capital to energy ratio are taken from the EU-KLEMS Growth and Productivity Accounts (2009). The real fixed capital stock is calculated in constant U.S. Dollars. For the calculation of the capital-energy ratio in the commercial sector we excluded real estate.

Data on capacity utilization in the industry sector are provided by the Federal Reserve Board (2011). For the other sectors we proxy the utilization of capital by one minus the unemployment rate. These data are taken from the Bureau of Labor Statistics (2011). We approximate the up-skilling of the labor force by years of schooling. The data are derived from the UNESCO Institute for Statistics database (2011). All variables have been transformed to logs.

For the analysis of our hypothesis we test whether the time series of each sector enter a cointegration relationship. For this purpose we use the ARDL bounds testing procedure recently developed by Pesaran and Shin (1999) and Pesaran et al. (2001). There are several advantages of the ARDL approach over alternatives such as those suggested by Engle and Granger (1987) and Johansen and Juselius (1990). (1) Here, it is not a prerequisite to examine the non-stationarity property and order of integration of the variables; (2) bounds tests produce robust results also for small sample sizes like the present one (Pesaran and Shin, 1999) and (3) empirical studies have established that energy market-related variables are either integrated of order 1 [I(1)] or I(0) in nature and one can rarely be confronted with I(2) series (Narayan and Smyth, 2007, 2008), justifying the application of ARDL for our analysis. Narayan (2005) provided tables with critical F values for sample sizes ranging from 30 to 80. As our sample size is within this range, we will use the critical values provided by Narayan. The ARDL bounds testing procedure involves two steps: (1) we conduct a Phillips-Perron test to ensure that the variables are not I(2). (2) we apply an unrestricted error correction model (ECM) to test for cointegration among the variables and display also the short-run dynamics.

The ARDL modeling approach does not require unit root tests to check whether all variables are I(0) or I(1). We conduct the unit root test, nonetheless, in order to ensure that no variable is I(2) or higher. If a variable is found to be I(2), then the critical F-statistics computed by Pesaran et al. (2001) and Narayan (2005) are no longer valid. For stationarity tests we use the semi-parametric Philips-Perron test, as proposed by Phillips and Perron (1988).

We derive the regression equation from Eq. (6). Accordingly, the notation of an unrestricted ECM in first log-differences for the ARDL $(p, q_1, ..., q_3)$ bounds test is:

Table 2 — Results of the Phillips-Perron Test

Sector	Variable	Level	First difference
Macro	y	-0.275	-4.560***
	b	0.080	-4.219***
	c	-1.770	-8.175***
	d	-1.270	-4.073***
Industry	y	1.831	-5.469***
	b	-1.388	-3.289**
	d	-1.245	-3.601***
Commercial	y	-0.544	-5.308***
	b	1.223	-5.442***
	d	-1.624	-5.439***
Transport	y	-0.040	-5.882***
	b	0.221	-3.325**
	d	-2.546	-4.994***

Note: ***, **, * denotes 1%, 5%, 10% level of significance.

$$\begin{aligned}\Delta y_{it} = a_i &+ \beta_{i1} y_{it-1} + \beta_{i2} b_{it-1} + \beta_{i3} c_{it-1} + \beta_{i4} d_{it-1} \\ &+ \sum_{j=1}^{p-1} \theta_{ij1} \Delta y_{it-j} + \sum_{j=0}^{q_1-1} \theta_{ij2} \Delta b_{it-j} + \sum_{j=0}^{q_2-1} \theta_{ij3} \Delta c_{it-j} + \sum_{j=0}^{q_3-1} \theta_{ij4} \Delta d_{it-j} + \eta_{it}.\end{aligned} \tag{7}$$

The residual term η_{it} is assumed to be a white noise error process. The model is tested for $i =$ Macro, Industry, Commercial, and Transport. The lag length of the explanatory variables is denoted by q. The optimal lag order is selected following the minimum values of the Bayesian information criterion (BIC). According to Pesaran et al. (2001), the BIC is generally a preferred choice, sinc it tends to define more parsimonious specifications. The null hypothesis of 'no cointegration relationship' is tested by means of an F-test of the joint significance of the lagged level coefficients: $H_0 : \beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$. The null hypothesis of no cointegration will be rejected provided the upper critical bound is less than the computed F-statistic.

5. Empirical results

The results of the stationarity tests (see Table 2) show that all of the variables are non-stationary at level. After differencing the variables once, all variables are confirmed to be stationary. As none of the variables is integrated of order two, the ARDL bounds procedure can be used to examine the existence of a cointegration relationship among the variables.

The results of the ARDL bounds test (see Table 3) show that a long-run relationship between labor productivity and the explanatory variables exists only in the industrial sector and the transport sector, i.e. the F-statistics exceed the critical F-values provided by Narayan (2005)[5]. The fit of the

[5] The critical values for the investigation of the long-run relationship are 6.988, 5.090, 4.274 at the 1%, 5%, 10% level of significance (case IV, p. 1989 in Narayan, 2005).

Table 3 — Results of the Cointegration Test

F-test	Macro	Industry	Commmerce	Transport
$\forall\beta = 0$	4.25	5.65**	4.19	5.95**
Const.	-0.3535	-0.3776	5.1328***	-3.1920**
Adj. R^2	0.63	0.37	0.41	0.72
Obs	34	32	34	32

Note: ***, **, * denotes 1%, 5%, 10% level of significance.

models and the low or insignificant values of the unexplained technological progress indicate that the development of labor productivity is well described by the selected explanatory variables in these two sectors.

In the commercial sector, in contrast, labor productivity neither gains from the substitution of energy for labor nor from the increasing energy productivity of production in the long run. In addition, this finding also explains the low increase in labor productivity in the commercial sector. Factors which are found to be significant for the other two sectors do not affect the development of labor productivity in this sector. As total GDP is dominated by commercial value added, an analysis at the macro level hides the strong relationship we find for the industrial and transport sector.

The comparison of the findings for the macro level with those for the sectoral level suggests that the impact of energy-related changes on the economy falls victim to an aggregation effect once one moves to the macro level. The growth of labor productivity at the aggregate level hides the significant differences at the sectoral level to which Baumol's cost disease hypothesis refers. Although labor productivity in the commercial sector changed little over the last decades, the average wages increased there at the same rate as in the industry sector. The unfolding gap between labor productivity and the wages rate inflated labor costs. Since the prices of commercial services could be raised sufficiently to compensate the soaring labor costs, value added in the commercial sector grew more so (nominally) than in the other sectors, making commercial services today's dominant sector.

As conjectured, the reason for this development seems to be an extensive substitution of cheap energy for labor in the "progressive" industry sector (and in transport) where this is technologically feasible. In the "stagnant" commercial service sector, in contrast, energy is of only minor quantitative importance, leaving little room for an energy-for-labor substitution. As a consequence, cheap energy costs have caused a rise of value added and employment shares where energy is technologically least significant – the energy paradox of sectoral change. Given that the development of labor productivity both in the industrial sector and the transport sector strongly depends on the substitution of energy for labor and the attempts to increase the energy efficiency of production, what conclusion can be drawn for the future sectoral development?

It has been the cheap energy and, hence, historically low energy costs, that made the extensive substitution of energy for labor possible in the past. If energy prices like these will not return and, in addition, energy costs will further be increased by future climate change policies, it is unlikely that the rising trend of the energy-labor ratio can be prolonged; it may even be reversed. Attempts to reduce the energy demands by increasing energy efficiency of production will go on, but there are thermodynamic limitations to reducing the energy-capital ratio. It is possible then that the growth of labor productivity which industry and transport have seen in the past will sooner or later slow down. If so, it is likely that real wage increases slow down as well in all sectors. In the long run this tendency may narrow down or even close the gap between labor productivity and wages in the service sector where the development of labor productivity was found to be independent of energy-related parameters. Under competitive conditions, the development of the sectoral price levels may then also converge and tend to cure Baumol's cost disease. By the same token, this would of course end the heydays of the service economy. Its value added share would no longer be inflated by productivity increases due to cheap energy in the other sectors. Should labor continue to be laid off, be it for a stagnating or even contracting demand or for productivity increases mainly in the commercial service sector, it is not clear whether there will be any sector left to absorb it in the future.

6. Conclusions

In this paper we have highlighted the role that energy plays for sectoral change more generally and for the rise of the "service economy" in particular. We have distinguished three sectors in our analysis: industry, transport, and commercial services. The "service economy" is characterized by a dominant role of the commercial service sector in terms of value added and employment. In order to understand the importance of energy, the focus on the sectoral level is essential. Empirical tests which investigate the causality from energy consumption to economic growth at an aggregate level often reject the hypothesis that there exists a causal link. Our empirical analysis shows, however, that the significant, systematic effects which energy-related factors have had on the U.S. economy over the period 1970-2005 at the sectoral level disappear once we move to the macro level.

Regarding the observed sectoral changes, our hypothesis was that technological differences in the substitutability of energy (plus capital) for labor together with the cheap energy of the past are key factors driving the rise of the service economy. This would explain why, in industry and transport (the sectors with a high energy intensity of production), productivity increases are in real terms significantly higher than in the commercial service sector (with low energy intensity). The divergence that occurred between the sectors' labor productivity induced not only a migration of employment from the industry to the commercial service sector. It also generated lasting cost differentials, epitomized by Baumol's cost disease of the service sector. The differentials seem to have largely been compensated by a price level rising faster for commercial services than for industrial products and transport services. In nominal terms, productivity differences between the sectors were thus erased and, by the same token, the value added share of commercial services inflated.

To test our hypotheses empirically, we analyzed the existence of a cointegration relationship among labor productivity and the variables derived from our model by means of the Autoregressive Distributed Lags (ARDL) bounds test developed by Pesaran and Shin (1999) and Pesaran et al. (2001). We found evidence of cointegration only in the sectors industry and transport, implying that the development of labor productivity in the commercial sector is independent of energy-related parameters.

If our explanation of the role of energy for sectoral change is correct, the analysis holds some interesting implications for the future. Since the turn of the millennium energy prices have been rapidly rising. If they continue to do so, it may be inferred from our findings that the apparently incessant growth of the service economy in terms of value added and employment will be difficult to maintain. The incentives to further substitute energy for labor are likely to fade out. On the other hand, the incentives to develop, and to invest into, a more energy-efficient capital stock in the energy-intensive sectors will grow. However, the success of the corresponding efforts is limited by thermodynamic constraints. The net effect of changing incentives and technical progress on labor productivity in these sectors is difficult to anticipate.

In the commercial services sector, we have shown, energy-for-labor substitution did not play much of a role in the past. For this reason, the development of labor productivity (in real terms) is likely to be less affected by rising energy prices. Consequently, the productivity growth differential between what were "progressive" and "stagnant" sectors may decline or even disappear as would, in that case, Baumol's cost disease. Productivity growth would then slow down economy-wide. At the same time, it is doubtful whether the relative decline in the price level of manufactured goods is going to continue. Depending on the development of their relative price levels, the sector's value added shares could even develop in the reverse direction in the future. With respect to employment these developments would mean that labor migration from the industrial sector to commercial services would hardly continue as in the past. To the contrary, the industrial sector may absorb labor laid off elsewhere, provided a decrease in the sector's labor productivity would be tolerated. Unless the patterns of private or public spending on services and industrial products change exogenously, concerns seem justified that the "service economy" may run into difficulties in a future with heavily increasing energy costs.

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