Productivity and Prices in Europe: Micro-evidence for the period 1975 to 1990

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Abstract

In the absense of frictionless trade, domestic productivity will be a major determinant of prices. Using repeated cross-sections of absolute prices of individual goods across European countries, I find that products of an industry tend to be cheaper in countries with higher productivity in that industry. Similarly, countries with higher productivity in manufacturing have lower prices for products of that sector, and will have a lower price level as long as the manufacturing sector is sufficiently large.

Keywords: Balassa-Samuelson, productivity, real exchange rate, price level.
JEL Classification: E31, F3

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1. Introduction

What determines price differences across countries? In the presence of arbitrage costs, international price differences of individual goods and services within the implied "no-trade bounds" will be related to cross-country productivity differences. I investigate this implication using a unique micro-level dataset of absolute prices of goods and services across six European countries during the period 1975 to 1990.[1] The dataset used here is unique in that it enables exact international price comparisons[2] for most CPI items at a point in time. In utilizing this micro-level dataset, the paper deviates in an important dimension from the existing empirical literature on this topic, which has typically utilized aggregate time series price indices. This allows us to study the cross-sectional relation between the levels of prices and productivity.[3]

I show that products of an industry tend to be cheaper in countries with higher productivity in that industry. This is consistent with other empirical evidence on the failure of the law of one price (LOP). A growing body of the real exchange rate literature has refocused interest away from the use of price indices and towards microeconomic price data that allow investigation of the extent and determinants of LOP deviations. My paper is in line with this recent literature, which includes papers by Parsley and Wei (2001), Haskel and Wolf (2002), Lutz (2004) and Crucini, Telmer, and Zachariadis (2002).[4] The data also supports the prediction that countries with higher productivity tend to have lower prices of manufacturing goods.

A novel implication here is then that, depending on the relative size of the manufacturing sector, high productivity countries can have lower overall price levels. This contrasts markedly with the Balassa (1964) and Samuelson (1964) (thereby B-S) hypothesis but is consistent with the models of Benigno and Thoenissen (2003) and MacDonald and Ricci (2004). The B-S hypothesis states that countries with higher relative productivity for traded goods (manufactures) will have a higher price level than other countries. This is because higher productivity in the traded goods sector leads to higher wages and higher prices in the non-traded (services) sector which does not experience sufficient productivity gains to offset the higher wage cost. When the latter B-S effect is combined

[1] This is a subset of the data from Crucini, Telmer, and Zachariadis (2002).

[2] The price comparisons are always made for the same good sold in the same package (say 100 grams of round rice.) In many instances, we have prices of the same brand of a good across countries.

[3] Analysing exchange rates and purchasing power parity in a "no-arbitrage" or "real business cycle" context, Apte, Sercu, and Uppal (2004) propose that empirical work should use levels of variables rather than first differences.

[4] Early evidence on deviations from LOP using import unit values rather than absolute price levels of individual goods is also reported in Isard (1977) and Giovannini (1988).

with the assumption that LOP holds for traded goods, we get the B-S implication of a higher price level in the more productive countries.

In contrast to the B-S proposition, Benigno and Thoenissen (2003) propose a theoretical framework where an increase in the productivity of the traded goods sector results in a depreciation of the real exchange rate, offsetting the appreciation of the relative price of non-traded goods. Their model allows for non-traded goods and generates the standard positive B-S effect of tradeables productivity on the relative price of non-tradeables and on the real exchange rate. However, their model also allows for home bias in demand for domestically produced tradeables. Since the home bias implies domestically produced tradeables are a more important component of domestic consumption than of foreign consumption, an increase in the productivity of tradeables can lead to a lower domestic price level and a real exchange rate depreciation. The negative impact of productivity on the real exchange rate dominates in their calibrations of that model.

Similarly, in MacDonald and Ricci (2004), home bias in demand allows for a negative effect of tradeables productivity on prices that might offset the positive B-S effect. Again, higher domestic productivity in tradeables induces a positive B-S effect, via wages, on the relative price of non-tradeables and on the real exchange rate. The increase in domestic productivity also exerts downward pressure on the prices of domestically produced tradeables which in the presence of expenditure bias for domestic goods is greater for the domestic economy, inducing a fall in the real exchange rate. The latter effect of productivity on the real exchange rate dominates the B-S effect if the non-tradeables share of domestic spending is sufficiently small. Using a panel of aggregate price indices, MacDonald and Ricci (2004) find that, in fact, the B-S effect dominates so that changes in tradeables productivity have a positive effect on real exchange rate changes over time.

Dornbusch, Fischer, and Samuelson (1977), originally proposed a Ricardian model, where relative prices of home-produced to foreign produced goods depend inversely on relative productivities and positively on relative wages. This is consistent with the empirical specification we propose here, and with the findings regarding the negative impact of relative productivity and the positive impact of relative wages on prices.[5]

I also find that countries with higher productivity have higher price ratios of services relative to

[5] In Dornbusch etal (1977), the home and foreign countries produce different goods. Here, we could think of goods differentiated in one dimension, the location of production. That is, consumers with a preference bias for home-produced goods perceive these otherwise identical goods as differentiated. The LOP deviations we document here would then capture the extent of differentiation of these goods or, in other words, the extent of home bias in preferences.

manufactures. Comparing the impact of aggregate productivity on prices of manufacturing goods to the impact on prices for services, the relative price of services to manufactures appears to be increasing with productivity. This finding is consistent with a basic premise of the B-S hypothesis and with the findings of De Gregorio and Wolf (1994), Canzoneri, Cumby, and Diba (1999), Chinn and Johnston (1999), and MacDonald and Ricci (2004).[6] In all of these papers, this finding coincides with the finding of a positive productivity effect on the real exchange rate. Canzoneri, Cumby, and Diba (1999) also find that purchasing power parity does not hold for the manufacturing sector, contradicting the second component of the B-S hypothesis, but consistent with the LOP deviations for manufacturing goods we document here.

More recently, Gali, Gertler, and Lopez-Salido (2001) consider a real marginal cost measure that accounts for the influence of productivity and wages on European inflation.[7] They show that the ratio of wages to labor productivity moves together with the inflation rate for the Euro area during the period 1970 to 1998. Here, I study the price impact of productivity and wage rates separately. My results support Gali etal (2001) by providing cross-sectional micro-evidence for a negative relation between productivity and prices and a positive relation between wage rates and prices in six European countries for the period 1975 to 1990. Moreover, the impact of wages is almost always stronger for services compared to manufactures and, similarly, GDP per capita has a positive impact on international price differences which is always stronger for the service sector.[8]

The framework considered here highlights the relevance of R&D as a determinant of productivity and, thus, prices. Models of R&D-induced growth as in Segerstrom, Anant and Dinopoulos (1990) or Aghion and Howitt (1992) predict that the intensity of innovation-related activity over time as measured by the stock of R&D, largely determines productivity levels. The latter implication is also in line with the Ricardian model of Eaton and Kortum (2002.) The strong positive relation between R&D and productivity has been empirically documented by Griliches (1980) and more recently by Keller (2002). However, there is no previous attempt to relate models of R&D-induced

[6] Canzoneri, Cumby, and Diba (1999) use aggregate time-series data across thirteen OECD countries and find that labor productivity in manufacturing relative to services appears to be cointegrated with the price of services relative to manufactures.

[7] They decompose the real marginal cost measure into a wage markup and an inefficiency wedge inversely related to productivity.

[8] There is strong evidence that richer countries have higher prices. This is in part due to the upward pressure that higher productivity in the manufacturing sector puts on wages in the service sector over time, and also due to differences in demand between rich and poor countries that might be more important for the service sector in the presence of non-homothetic preferences as in Bergstrand (1991.)

productivity to international price differences.

In the next section, I take a preliminary look at the data. In the third section, I examine the relationship of international price differences for individual goods and services with sectoral and industry-level productivity differences. The final section briefly concludes.

2. Data

I use Eurostat Survey prices of household goods and services for Germany, France, Italy, the U.K., the Netherlands, and Denmark, in 1975, 1980, 1985 and 1990. A detailed description of the price data is given in Crucini, Telmer, and Zachariadis (2002). In this dataset, manufactures are goods like "Video recorder" or "Selected Brand of Motor car: less than 1.2 l, 998 cc" and services are items like "cup of coffee at cafe" or "Ladies' hairdresser: shampoo and set." Exactly the same item (for example the same brand of the same car) is sampled across European capitals at the same point in time. I use a repeated cross-sections approach similar to Crucini, Telmer, and Zachariadis (2002) so as to include the maximum number of goods.[9] Considering bilateral price differences between the six countries gives 245 observations for services and 1305 for manufactures in 1975 (for 49 services and 261 manufacturing goods respectively), 230 and 1195 observations in 1980 (for 46 services and 239 manufactures,) 425 and 1840 observations in 1985 (for 85 services and 368 manufactures), and 270 and 1185 observations in 1990 (for 54 services and 237 manufactures.) For the industry-level application, I exclude Denmark because of data unavailability. This leaves me with 1324 observations for 331 products in 1975, 1080 observations for 270 products in 1980, 2128 observations for 532 products in 1985, and 1456 observations for 364 products in 1990.

The dependent variable I consider is each country's log deviations from German prices. That is, we consider $\log P_{GEit} - \log E_{GEkt} P_{kit}$ for each good i and country k for t=[1975, 1980, 1985, 1990]. In Figures 1 and 2, I present each country's log deviations from German manufacturing goods prices and services prices respectively for 1990. These deviations are presented in ascending order, so that points below the horizontal zero line indicate goods for which prices are lower in Germany. Germany is the country with the highest stock of R&D among the six countries in the sample throughout this period with the exception of 1975. Germany is also the country where the majority of manufacturing goods prices were lower than in other countries throughout this

[9] A dynamic panel approach would greatly limit the number of goods for any given year while introducing a source of measurement error due to intertemporal mismatching, since there is not always a direct match between goods sampled in different years.

period with the exception of 1975. The single year for which a majority of manufacturing goods in Germany had prices higher than in the other countries is 1975, for which the U.K. had the highest stock of R&D. In that same year, 76 percent of manufacturing goods prices in the U.K. were lower than in the other five countries providing preliminary evidence about the impact of R&D stocks on productivity and prices. For 1980, 1985, and 1990, 53, 60, and 56 percent of manufacturing goods were cheaper in Germany, and 64, 48, and 59 percent of services were more expensive there. Comparing the same-year price deviations for manufactures with those for services, the latter appear to be displaced upwards relative to those for manufactures.

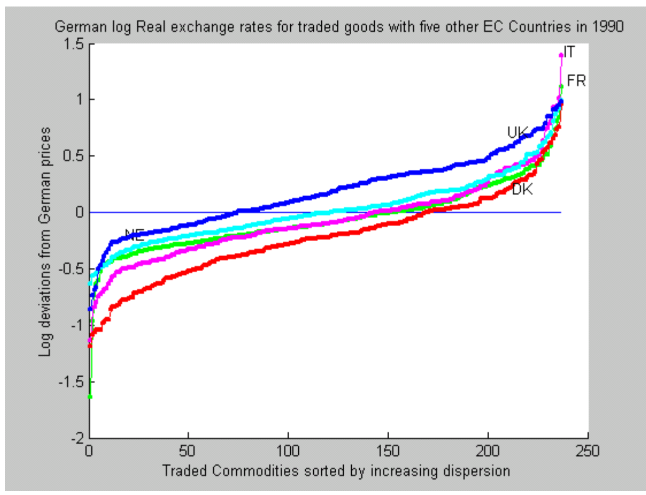

Figure 1: Manufacturing goods

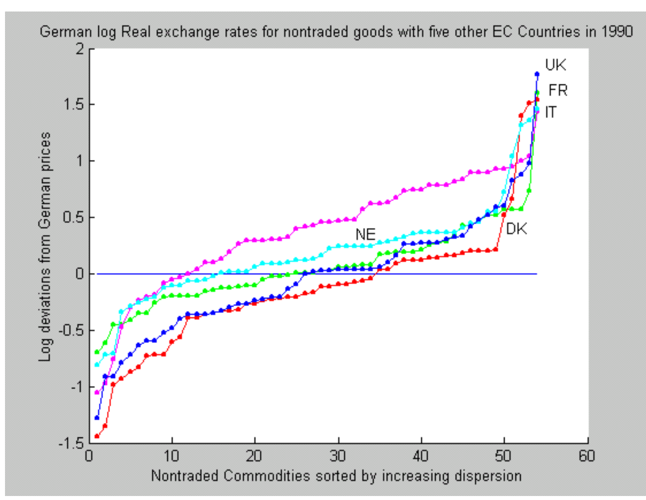

Figure 2: Services

In addition to the price data, I use the 1997 ANBERD data from the OECD. This provides R&D expenditures at current prices in national currencies from 1973 onwards. I use the 1994 OECD STAN data to construct deflators from value-added output for each industry and country, and use these to obtain R&D expenditures in constant 1985 prices. Finally, I use US dollar exchange rates to convert R&D expenditures in constant 1985 prices to a common currency.

The R&D capital stock is constructed using ten percent as the rate of depreciation, based on the findings of Nadiri and Prucha (1993.) The accumulation equation is $H(R_{jl,t}) = R_{jl,t} + (1 - 0.1) \times H(R_{jl,t-1})$, with $R_{jl,t}$ standing for R&D expenditures in constant prices and $H(R_{jl,t})$ standing for the implied stock of knowledge in country j and sector or industry l at time t. The benchmark value for this stock is obtained by assuming a steady state for the benchmark year. This implies $H(R_{jl,0}) = \frac{R_{jl,0}}{0.12}$, where the denominator is the sum of the assumed rate of depreciation and the growth rate. I construct industry-specific R&D stocks for a group of sixteen two-digit industries and for the aggregate manufacturing sector. The sixteen industries are Food, beverages and tobacco, Textiles, apparel and footwear, Paper products and printing and publishing, Chemicals, products and drugs and medicines, Products of petroleum and coal, Rubber and plastic, Pottery, china, earthware, glass and glass products, Iron, steel and non-ferrous metal basic industries, Fabricated metal products except machinery, Manufacture of machinery except electrical, Office, computing and accounting machinery, Electrical machinery, apparatus and appliances, Radio, tele. and communications equipment, Motor vehicles, Professional, scientific, measuring and control, and Services. Below, I present a histogram with the R&D stocks for the Manufacturing sector, the Service sector, and the overall economy for 1990. From the figure, it is clear that the Manufacturing sector was responsible for the bulk of R&D expenditures for the period under study.

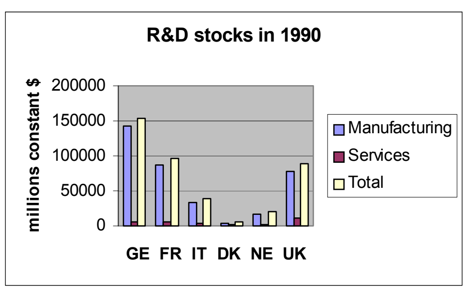

Figure 3

A note regarding the treatment of Manufacturing versus the service sector is in order here. The previous literature has widely treated manufactures as “traded” and services as “non-traded”. In fact, all commodities are better characterized by a certain degree of non-tradeability. There is a non-traded domestic component in the production of any good or service.[10] Thus, non-tradedness is not necessarily the defining characteristic of services relative to manufactures. In the current paper, I emphasize the tendency of manufactures to be intensive in R&D relative to services, and focus on this rather than frictionless trade as the defining characteristic of manufacturing.

Wages and employment data used to construct wage rates as the ratio of total wages and salaries to total employment for the two-digit industries were obtained from the 1994 OECD Sectoral Database. GDP per Capita in constant $US, degree of openness, and population data for each country are obtained from the 1992 Penn World Tables.

3. The relation between productivity and prices

Are international productivity differences important for the determination of international relative prices? To answer this question, I consider next the impact of aggregate productivity and, following that, the impact of industry productivity on international price differences of goods and services.

Aggregate Productivity

Following, I present a model that motivates the link between productivity and international price differences. This link will be exact within the no-trade bounds determined by arbitrage costs. Within the no-trade bounds prices would be exactly determined by the domestic cost of production but productivity differences will never lead to price differences greater than the size of the transportation cost since in that case goods would be imported in the less productive country which would forego domestic production.[11] Crucini and Lee (2004) model arbitrage costs explicitly and show that international price differences will be equal to or less than the size of the transportation cost depending on whether goods are traded or not. The model of Crucini and Lee (2004) considers an endowment economy. If we interpret relative endowments to be broadly captured by relative R&D stocks then that model would imply a relation of these with relative prices similar to what

[10] In this spirit, Crucini, Telmer, and Zachariadis (2002) use a ratio of exports and imports over output ("trade share"), and a measure of local input content ("input share") to capture the degree of tradedness for commodities produced in any industry. Electricity, Gas, and Water (ISIC 4150), commonly treated as a "non-traded" service industry, has a trade share of 72 percent and an input share of 26 percent, whereas Printing and Publishing (ISIC 3420) and Products of Petroleum and Coal (ISIC 3540), both of which are commonly treated as "traded", had respective trade shares of 15 and 40 percent and input shares of 24 and 14 percent respectively.

[11] Presumably, imperfect information regarding foreign produced tradeables would allow price differences to differ by more than the size of transportation costs or broader trade costs, due to productivity differences.

we estimate here.[12]

Models of R&D-induced growth like Aghion and Howitt (1992) predict that the intensity of innovation-related activity over time as measured by the stock of R&D, largely determines productivity levels. I utilize this theoretical framework to link R&D-induced productivity to prices. I allow for the presence of a non-R&D performing service sector and an R&D performing manufacturing sector. This is motivated by the empirical observation that the great majority of R&D is performed in the manufacturing sector. The presumption is that countries with higher R&D stocks are more productive relative to countries with lower stocks of R&D. Thus, productivity differences between countries will exist as long as domestic stocks of knowledge do not diffuse completely across countries. The prediction is that prices of manufacturing goods will be lower and prices of services higher in the most productive country. This is so because productivity gains from R&D benefit the production of goods in the manufacturing sector and, as a result of inter-sectoral labor mobility within countries, exert upward pressure on the prices of services which do not experience sufficient productivity gains to offset this wage cost. Price differences across countries are maintained in the presence of exogenously given arbitrage costs which create bands of "inaction" or "no trade."

I assume that both final goods sectors are perfectly competitive, and that the non-R&D performing service sector uses only labor inputs while the R&D performing manufacturing sector uses both labor and capital. Alternatively, one could allow for labor and capital to be used in both sectors and assume the service sector to be labor intensive. Labor flows freely across sectors and capital flows freely across countries[13] so that wages are equalized across the sectors of the domestic economy and the interest rate is equalized across countries.

The framework considered here is a variant of the endogenous productivity growth framework of Aghion and Howitt (1992). The innovation process uses only the manufacturing sector's final output to produce inventions which can be thought of as new forms of capital services that benefit the domestic manufacturing sector. As a result, the productivity level of the manufacturing sector is increasing over time while the productivity level of services remains constant. Alternatively, one could assume that both sectors benefit from the accumulation of R&D but the manufacturing sector benefits more so than the service sector. Thus, aggregate productivity is determined by the accumulation of R&D performed in the domestic manufacturing sector. Indeed, OECD data

[12] The latter model offers then an alternative way to motivate our empirical specification. We choose to focus instead on a model that explicitly links productivity to prices, treating arbitrage costs as exogenously determined.

[13] This means that supply is so elastic that demand has no effect on the relative price of services.

suggest that about 80 percent of R&D is performed in the manufacturing sector. Finally, there are no international spillovers of knowledge[14] and there is a scale effect so that countries with higher accumulation of R&D have higher levels of productivity.

The production functions for manufactures and services in each country are given respectively by $Y_{Mt} = (A_{Mt}L_{Mt})^{1-\alpha}K_{Mt}^{\alpha}$ and $Y_{St} = A_S L_{St}$, where Y_{Mt} (Y_{St}), A_{Mt} (A_S), L_{Mt} (L_{St}), and K_{Mt} stand for output, technology level, labor input, and capital input, and the subscripts M and S indicate the Manufactures and Service sectors respectively. The aggregate level of technology grows at the rate $\mathrm{g}_t = (1-\beta)\frac{\dot{A}_{Mt}}{A_{Mt}}$ where $(1-\beta)$ is the output share of the manufacturing sector in the domestic economy. The rate of technological progress in the manufacturing sector is $\frac{\dot{A}_{Mt}}{A_{Mt}} = \sigma\lambda\frac{R_{Mt}}{A_{Mt}}$, where σ stands for innovation size and λ stands for research productivity both assumed to be time-invariant. I assume constant returns to R&D so that technological progress is proportional to R&D-intensity, and the level of technology is proportional to the stock of knowledge implied by the accumulated stock of R&D expenditures. The level of technology in the manufacturing sector as of period t is thus given by

$$A_{Mt} = \int_{s=0}^{t} \dot{A}_{Ms} ds = \sigma\lambda \int_{s=0}^{t} R_{Ms} ds \tag{1}$$

The first order conditions from profit maximization in each of the two sectors are

$$P_{Mt}\alpha A_{Mt}^{1-\alpha} k_{Mt}^{\alpha-1} = r_t \tag{2}$$

$$P_{Mt}(1-\alpha)A_{Mt}^{1-\alpha} k_{Mt}^{\alpha} = w_{Mt} \tag{3}$$

$$P_{St}A_S = w_{St} \tag{4}$$

where $k_{Mt} = K_{Mt}/L_{Mt}$ is the capital-labor ratio in manufacturing.

Solving equation (2) for k_M gives $k_{Mt} = (r_t/P_{Mt})^{\frac{1}{\alpha-1}}\alpha^{\frac{1}{1-\alpha}}A_{Mt}$. Substituting for k_{Mt} in equation (3) gives $w_{Mt} = \Gamma A_{Mt}P_{Mt}$, where $\Gamma \equiv (1-\alpha)\alpha^{\frac{\alpha}{1-\alpha}}(r_t/P_{Mt})^{\frac{\alpha}{\alpha-1}}$. Assuming international mobility of capital equalizes the real return of capital across countries, and that the share of capital, α, is the same across countries, then equation (4) implies $\frac{P_{Mt}}{E_t P_{Mt}^*} = \frac{A_{Mt}^*}{A_{Mt}}\frac{w_{Mt}}{E_t w_{Mt}^*}$ so that international differences

[14] Keller (2002) shows that for a group of advanced OECD countries 80 percent of R&D-induced productivity gains are due to domestic R&D accumulation.

in prices of manufactures are positively related to international wage differences, and inversely related to international productivity differences as in the basic Ricardian model of Dornbusch etal (1977). Using the latter condition along with (1) and assuming that innovation size and research productivity are identical across countries so that $\sigma = \sigma^*$, and $\lambda = \lambda^*$, we get

$$\frac{P_{Mt}}{E_t P^*_{Mt}} = \left(\frac{\int_{s=0}^{t} R_{Ms} ds}{\int_{s=0}^{t} R^*_{Ms} ds} \right)^{-1} \left(\frac{w_{Mt}}{E_t w^*_{Mt}} \right) \tag{5}$$

Thus, price differences across countries will be inversely related to differences in R&D stocks and positively related to differences in wages. An implicit assumption here is that these price differences are maintained in the presence of trade costs for final goods which create "bands of inaction" where domestic productivity will determine prices as long as prices do not hit the arbitrage bands. B-S assume instead that manufacturing goods flow freely and thus have identical prices across countries. Alternatively, deviations from LOP could arise if consumers perceive the goods to be differentiated in one dimension, the location of production. This would occur in the presence of a preference bias for home produced goods.

The relation between international price differences and cross-country differences in accumulated R&D expenditures of the manufacturing sector can be expressed in logarithmic form as:

$$\log P_{Mt} - \log E_t P^*_{Mt} = \xi[\log(H(R_M)/w_{Mt}) - \log(H(R^*_M)/E_t w^*_{Mt})] \tag{I}$$

where $H(R_{Mt}) = \sum_{s=0}^{t} R_{Ms}$ is the accumulated stock of R&D in discrete time, P is the local currency price, w is the wage rate, E is the nominal exchange rate, and subscripts M and S stand for manufacturing and services respectively. The coefficient ξ is negative according to equation (5). I estimate this relation for manufacturing as specification (I). I also decompose the effect of the knowledge stock and the wage rate to consider:

$$\log P_{Mt} - \log E_t P^*_{Mt} = \zeta[\log(H(R_M) - \log H(R^*_M)] + \gamma[\log w_{Mt} - \log w^*_{Mt}] \tag{II}$$

where ζ is negative and γ positive according to equation (5). I estimate this relation (with and without the wage component) for manufacturing as specification (II), initially using GDP per capita to proxy for the wage rate.

Wage equalization across sectors implies that an increase in the productivity of the manufacturing sector brings about higher wage rates and prices for services. Assuming wage equalization across sectors, substituting for w_{St} in equation (4) and rearranging, we get $\frac{P_{St}}{P_{Mt}} = \Gamma \frac{A_{Mt}}{A_S}$, so that the relative price ratio of services to manufactures is positively related to the productivity of manufacturing and inversely related to that of services. The latter expression can be used to express the domestic to foreign price ratio of services to manufactures as, $\left(\frac{P_{St}}{P_{Mt}}\right) / \left(\frac{EP^*_{St}}{EP^*_{Mt}}\right) = \frac{A_{Mt}}{A_S} / \frac{A^*_{Mt}}{A^*_S}$. Utilizing equation (1) and assuming that innovation size and research productivity are identical across countries so that $\sigma = \sigma^*$, and $\lambda = \lambda^*$, we get

$$\left(\frac{P_{St}}{P_{Mt}}\right) / \left(\frac{EP^*_{St}}{EP^*_{Mt}}\right) = \left(\frac{\int_{s=0}^{t} R_{Ms} ds / A_S}{\int_{s=0}^{t} R^*_{Ms} ds / A^*_S}\right) \tag{6}$$

Assuming that the level of technology for services is similar across countries[15] so that $A_S = A^*_S$ then we get

$$\log P_{St} - \log E_t P^*_{St} = \varphi(\log H(R_M) - \log H(R^*_M)) \tag{II\_S}$$

with φ negative according to equation (6). We estimate this relation as specification (II) for services. Relaxing the assumption $A_S = A^*_S$, then we get

$$\log P_{St} - \log E_t P^*_{St} = \psi(\log H(R_M)/H(R_S) - \log H(R^*_M)/H(R^*_S)) \tag{III}$$

with ψ negative according to equation (6). We estimate this as specification (III).

We note that the model implies that the price level for any one country is given by weighting manufactures and services prices as follows, $P_t = P^{\beta}_{St} P^{1-\beta}_{Mt}$, where β stands for the output share of the service sector in the economy. Thus, a large Manufacturing sector (small β) could in theory sustain a lower overall price level in the more productive country.

Estimation and Results

Specifications (I), (II), and (III) are assumed to hold for every good or service i and country pair jk (where j will always denote Germany) so that: $s_{ijk} = \zeta h_{jk} + \gamma x_{jk} + u_{ijk}$, where s_{ijk} =log(p_{ij})-log(p_{ik}) with p_{ij} and p_{ik} the prices of product i in country j and k respectively converted to US dollars, and u_{ijk} is an error term. For specification (I) $h_{jk} = \log(H(R_M)/w_{Mt}) - \log(H(R^*_M)/E_t w^*_{Mt})$ is the cross-country difference of R&D stock to wage rate ratios, for (II) h_{jk} =log$H(R_{Mj})$-log$H(R_{Mk})$ are cross-country differences in R&D stocks, and for (III) $h_{jk} = \log H(R_M)/H(R_S) - \log H(R^*_M)/H(R^*_S)$ are cross-country differences of ratios of R&D stocks in

[15] One of the postulates of the Balassa model is that international productivity levels for non-tradeables are closer than those for tradeables. Indeed, the mean of absolute differences across countries for R&D stocks in manufacturing was much smaller for services (1.35 compared to 0.89 in 1985.)

manufacturing relative to the service sector. The parameter ζ captures the effect of differences in R&D-induced productivity on international price differences.

I perform robustness checks by including a set of explanatory variables x_{jk} on the right hand side of the regression equation. The framework under study implies that wages play a role in the determination of prices so I consider a specification with GDP per capita as a proxy for wage differences. As an additional robustness check, I include the degree of a country's openness. Finally, I re-estimate specifications (II) and (III) by replacing GDP per capita with wages. The intend here is to assess the extent and direction of the impact of productivity and other country-specific variables on prices of individual goods and services. This will help us assess the relevance of each of the two implications of the B-S hypothesis discussed in the introduction.[16] I perform separate OLS regressions for price differences of manufacturing goods and services, correcting the standard errors for heteroskedasticity.[17] I report estimates and t-statistics in Table 1 for manufactures and Tables 2 and 3 for services.

Table 1: Explaining cross-country price differences for Manufactures

	specification (I)			specification (II)			(II) with wages		
1975									
R&D-stock	-.025 (-5.24)*	-.022 (-4.63)*	-.069 (-9.29)*	-.018 (-3.62)*	-.021 (-4.29)*	-.067 (-9.04)*	-.018 (-3.62)*	-.015 (-3.08)*	-.059 (-8.25)*
GDP-per-capita[1]		.776 (8.03)*	.875 (9.11)*		.829 (8.54)*	1.039 (10.37)*		.346 (9.28)*	.412 (10.63)*
Openness			-.324 (-9.36)*			-.315 (-9.22)*			-.310 (-9.04)*
$\bar{R}^2$ in percent	6.1	5.5	10.7	5.3	5.2	10.2	5.3	6.6	11.6
1980									
R&D-stock	-.035 (-5.62)*	-.047 (-7.11)*	-.074 (-7.83)*	-.029 (-4.86)*	-.049 (-7.17)*	-.069 (-7.56)*	-.029 (-4.86)*	-.039 (-6.28)*	-.088 (-8.69)*
GDP-per-capita[1]		.583 (4.69)*	.676 (5.35)*		.710 (5.38)*	.828 (6.13)*		.192 (4.26)*	.393 (6.96)*
Openness			-.198 (-4.46)*			-.158 (-3.80)*			-.341 (-6.67)***
$\bar{R}^2$ in percent	3.6	4.4	5.7	3.1	4.5	5.4	3.1	3.6	6.4

[16] However, we note that as shown in Crucini, Telmer, and Zachariadis (2000), about ninety percent of the variation in the data goes beyond country-specific effects so that an aggregative model cannot hope to explain much of the variation in this highly disaggregated data.

[17] As shown in Crucini, Telmer, and Zachariadis (2000), it is necessary to correct the standard errors for heteroskedasticity in this specific context, where we use aggregative values of the explanatory variable to explain a highly disaggregated dependent variable. This creates a heteroskedastic pattern in the variance of the regression term as shown in the earlier paper. This type of aggregation also makes goodness of fit measures difficult to interpret, so that the low R^2's reported here should be taken with caution.

1985									
R&D-stock	-.052	-.058	-.077	-.049	-.057	-0.073	-.049	-.047	-0.092
	(-11.98)*	(-12.69)*	(-14.76)*	(-11.98)*	(-12.97)*	(-14.68)*	(-11.98)*	(-9.26)*	(-12.14)*
GDP-per-capita[1]		.374	.559		.445	.618		-.049	.444
		(3.51)*	(5.32)*		(4.13)*	(5.79)*		(-0.76)	(4.97)*
Openness			-.216			-.196			-.295
			(-8.94)*			(-8.31)*			(-8.79)*
$\bar{R}^2$ in percent	2.4	3.4	6.3	2.5	3.8	6.3	2.5	2.5	5.7
1990									
R&D-stock	-.043	-.069	-.090	-.038	-.068	-.084	-.038	-.068	-.126
	(-7.51)*	(-9.26)*	(-10.52)*	(-7.09)*	(-9.15)*	(-10.21)*	(-7.09)*	(-9.16)*	(-12.59)*
GDP-per-capita[1]		.921	1.224		1.031	1.305		.429	.995
		(5.78)*	(7.53)*		(6.13)*	(7.62)*		(5.84)*	(10.58)*
Openness			-.189			-.166			-.372
			(-6.05)*			(-5.45)*			(-9.52)*
$\bar{R}^2$ in percent	6.7	7.2	9.6	6.4	7.1	8.9	6.4	6.6	12.4

Notes: * the estimate is statistically significant beyond the one percent level. [1] The coefficient estimates in the last three columns are for actual relative wages.

In the first three columns of Table 1, I report results for manufactures adjusting R&D stocks with the wage rate as implied by specification (I). Higher productivity countries are shown to have lower prices of manufacturing goods. Correcting for differences in GDP per capita, and degree of openness, price elasticities for R&D range from -6.9 percent in 1975 to -9 percent in 1990. Since the productivity ratio utilized in specification (I) is adjusted by relative wages, the additional price impact of GDP per capita in specification (I) could be attributed to a non-wage channel. Considering the second row of Table 1, comparing the coefficient estimates for the price impact of GDP per capita (in the third column of Table 1) to that of wages (in the ninth column,) the former appears to be about twice as large as the latter, suggesting again a price impact of GDP per capita over and above the supply-side wage effect considered here.[18]

In columns four to six of Table 1, I report estimates for specification (II). The results from specification (II) reported in Table 1 are similar to the estimates for specification (I), with higher productivity countries exhibiting a tendency to have lower prices of manufactures. Correcting for differences in GDP per capita and the degree of openness, price elasticities for R&D now range from -6.7 percent in 1975 to -8.4 percent in 1990. There is no qualitative change in the results when we replace GDP per capita with actual wage rate differences. These results are shown in columns seven to nine of Table 1. Controlling for differences in the degree of openness, price elasticities for R&D now range from -5.9 percent in 1975 to -12.6 percent in 1990.

[18] Such us a demand-side channel through which GDP per capita can effect prices in the presence of non-homothetic preferences

Turning now to the impact of aggregate productivity on the prices of services, we see that the estimates are quite different. In columns one to three of Tables 2 and 3, I report estimates for specification (II). These estimates do not exhibit the negative tendency we saw for manufactures. In most cases, the impact of productivity on prices of services is either positive or statistically indistinguishable from zero. Controlling for differences in GDP per capita and openness in Table 2, the price elasticities of R&D range from 4.5 percent in 1980 to -5.3 percent in 1990, and controlling for differences in wage rates and the degree of openness in Table 3 these elasticities range from 5.2 percent in 1980 down to 0.4 percent, statistically indistinguishable from zero, in 1975.

In columns four to six of Tables 2 and 3, I present estimates for specification (III). This specification considers dependence of international price differences on the R&D stock of manufacturing relative to the R&D stock in the service sector (the relative productivity across the two sectors,) relaxing the assumption that productivity-enhancing R&D is accumulated only in manufacturing. Controlling for differences in GDP per capita and openness, the price elasticities of productivity reported in Table 2 range from 8.6 percent in 1980 down to -11.7 percent in 1990. Controlling for differences in wage rates and openness, the price elasticities reported in Table 3 range from 20.5 percent in 1980 down to 8.4 percent in 1985, and are positive and statistically significant beyond the one percent level for every cross-section in this fifteen year period.

Comparing the results using GDP per capita in Table 2 to those using wage rates in Table 3, the latter provide stronger support for a positive relation between R&D-induced productivity and the prices of services. The evidence from Table 2 for specifications (II) and (III) alike, suggests that when we control for the impact of GDP per capita on services, productivity can in certain cases have a negative impact on prices of services. This possibility would arise if services benefit from productivity gains in manufacturing which would be likely if (a) disembodied technology (knowledge) flows from manufacturing sector R&D to services, or (b) if services embody manufacturing goods as an input and as a result benefit from productivity gains in manufacturing. Point (b) is realistic if we think of services as a composite of both tradeable and non-tradeable inputs so that a drop in the price of the tradeable input component leads to downward pressure in the price of services as a result of productivity gains in tradeables.

A comparison of the impact of aggregate R&D on prices of manufactures to the impact on non-R&D performing services, suggests that the relative price of services to manufactures appears to increase with productivity. This is so since higher productivity is almost always associated with a bigger fall in the prices of manufactures than in the prices of services. In many instances, higher productivity is associated with absolutely (not just relative to manufactures) higher prices for services. Within the framework considered here, the latter result no longer implies a higher overall price level for more productive countries since the prices of manufactures are lower in these countries. Indeed, the most robust result here is that higher R&D stocks are associated with lower prices for manufactures. Thus, the overall impact of productivity on the price level depends on the relative size of the manufacturing and service sectors. A large enough manufacturing sector can sustain lower prices in the more productive country.

Table 2: Explaining cross-country price differences for Services

	specification(II)			specification(III)		
1975						
R&D-stock	.009 (.59)	.001 (.04)	-.038 (-1.63)	.109 (5.21)*	.025 (1.07)	-.004 (-.12)
GDP-per-capita		2.183 (7.89)*	2.357 (8.19)*		1.981 (6.00)*	2.281 (5.84)*
Openness			-.259 (-2.66)*			-.138 (-1.71)***
$\bar{R}^2$ in percent	6.3	12.8	14.3	0.4	12.0	12.5
1980						
R&D-stock	.071 (3.69)*	.026 (1.27)	.045 (1.59)	.138 (5.41)*	.076 (1.90)***	.086 (2.04)**
GDP-per-capita		1.636 (4.64)*	1.530 (4.33)*		1.039 (2.11)**	.956 (1.93)***
Openness			.142 (1.11)			.072 (.72)
$\bar{R}^2$ in percent	0.4	3.8	3.9	3.5	5.4	4.9
1985						
R&D-stock	.010 (.87)	-.007 (-.62)	-0.007 (-.51)	.028 (1.32)	-.019 (-.88)	-.019 (-.82)
GDP-per-capita		1.047 (3.34)*	1.041 (3.39)*		1.131 (3.39)*	1.123 (3.43)*
Openness			.007 (.09)			.011 (.18)
$\bar{R}^2$ in percent	.02	3.3	3.1	.1	3.2	2.9
1990						
R&D-stock	.025 (1.41)	-.049 (-2.12)**	-.053 (-2.03)**	.039 (1.55)	-.117 (-3.02)*	-.117 (-3.03)*
GDP-per-capita		2.555 (4.98)*	2.608 (4.87)*		3.268 (5.56)*	3.265 (5.57)*
Openness			-.032 (-.35)			.076 (.89)
$\bar{R}^2$ in percent	.9	7.2	6.9	2.5	8.9	8.9

Notes: *, **, *** the estimate is statistically significant beyond the one/five/ten percent level respectively.

In Tables 1, 2 and 3 we also see that differences in GDP per capita have a strong positive impact on cross-country price differences for manufacturing goods and for services. This confirms the well known empirical regularity that price levels are positively related to real per capita incomes. Moreover, the estimates for the impact of differences in GDP per capita on cross-country price differences for services are always higher than for manufactures. To understand this result we need to step beyond the "supply-side" theoretical framework and note that, assuming non-homothetic preferences, differences in GDP per capita are consistent with different demand elasticities across countries. Different demand elasticities combined with some market segmentation imply a role for price discrimination across locations.[19] If markets are more segmented for services than for manufactures, we should expect such effects to be stronger for services prices as evidenced in the results. Alternatively, if as assumed in Bergstrand (1991) services are luxuries while traded (manufacturing) goods are more likely to be necessities, then income will have a greater impact on the prices of services via this "demand-side" channel.

We also note that wage rates have a positive impact on prices and that this is almost always stronger for services. Openness has a negative impact on the prices of manufactures. Its impact on services is much weaker.[20]

Table 3: Explaining cross-country price differences for Services, controlling for wage rates.

	specification(II)			specification(III)		
1975						
R&D-stock	.009 (.59)	.039 (2.45)*	.004 (.19)	.109 (5.21)*	.149 (7.09)*	.141 (6.51)*
Wages		.715 (7.99)*	.765 (8.15)*		1.852 (5.48)*	2.194 (5.37)*
Openness			-.254 (-2.58)*			-.141 (-1.73)***
$\bar{R}^2$ in percent	6.3	13.96	15.5	.04	9.8	10.2
1980						
R&D-stock	.071 (3.69)*	.069 (3.70)*	.052 (1.93)***	.138 (5.41)*	.197 (5.69)*	.205 (5.79)*
Wages		.513 (4.58)*	.595 (4.46)*		1.09 (2.72)*	1.436 (2.96)*
Openness			-.162 (-1.09)			-.146 (-1.26)
$\bar{R}^2$ in percent	.04	5.6	5.6	3.5	6.7	6.8

[19] Differences in demand elasticities and price discrimination are allowed for, in addition to non traded goods and home bias in demand, in the model of Benigno and Thoenissen (2003).

[20] If we think of both goods and services as composites of traded and non-traded inputs and allow for services to have a lower degree of traded inputs, then we would expect openness to have a greater impact (in absolute terms) on the prices of manufactures, which is what we find here.

1985						
R&D-stock	.010	.012	0.006	.028	.077	.084
	(0.87)	(0.99)	(0.50)	(1.32)	(2.67)*	(2.91)*
Wages		.299	.370		.625	.769
		(2.67)*	(3.15)*		(3.20)*	(3.75)*
Openness			-.094			-.109
			(-1.30)			(-1.64)
$\bar{R}^2$ in percent	.02	1.8	1.9	.1	2.9	3.1
1990						
R&D-stock	.025	.031	.029	.039	.087	.096
	(1.41)	(1.78)***	(1.61)	(1.55)	(2.77)*	(2.89)*
Wages		.422	.449		.502	.590
		(3.07)*	(2.92)*		(2.48)*	(2.62)*
Openness			-.039			-.078
			(-.37)			(-.78)
$\bar{R}^2$ in percent	.9	1.4	1.1	2.5	.9	.7

Notes: *, **, *** the estimate is statistically significant beyond the one/five/ten percent level respectively

Industry-level productivity

The previous section documents a relation between aggregate productivity and prices across countries. Here, I extend the empirical model to consider industry-level R&D stocks.

For every manufacturing good or service i and country pair jk (country j relative to Germany) I estimate $s_{ijk} = \zeta h_{ljk} + \gamma x_{jk} + u_{ijk}$. Now, h_{ljk} =log($H(R_{lj})$)-log($H(R_{lk})$) is the cross-country difference between R&D stocks in industry l for countries j and k, and x_{jk} includes log differences in the degree of a country's openness, population size, and GDP per capita. Population size is included here to check whether the link between R&D stocks and prices is due to a scale effect rather than a productivity effect. Finally, country-specific and industry-specific dummies are included to capture omitted country and industry-specific factors with impact on international price differences. For example, country effects control for monetary policy differences[21], and industry effects for differences in market structure among industries. Standard errors are corrected for heteroskedasticity.

Table 4 presents the results. We note again that we use aggregative values of the explanatory variable to explain a highly disaggregated dependent variable. As shown in Crucini, Telmer, and Zachariadis (2000), this type of aggregation makes goodness of fit measures difficult to interpret, so that the low R^2's reported here should be taken with caution.[22] Controlling for differences in GDP per capita and openness, a product is cheaper in the country with the higher industry stock of

[21] Likely to be important in the case of Italy and the U.K. for part of this period.

[22] Due to the unavailability of good-specific information, we use aggregate (industry-level) explanatory variables. Aggregation implies we are piling up disaggregated price observations at each industry-specific value of the explanatory variable, thus masking the strong relationship between industry productivity and prices.

R&D, with price elasticities for R&D ranging from -2.3 percent in 1980 to -11.4 percent in 1990.[23] We note that there is no qualitative change when population size is included. Population size is meant to capture scale effects related to the size of the domestic market whose omission might bias the estimate of our R&D stock measure upwards as these scale effects are erroneously attributed to the impact of R&D induced productivity. In general, the estimates for the impact of R&D-induced productivity on prices are robust across the different cross-sections and specifications. Moreover, estimates of price elasticities with industry productivity are very similar to, albeit typically somewhat smaller than, those with aggregate productivity. The predominant conclusion is once again that relative productivity relates negatively to relative prices across European countries. We also see that countries with higher GDP per capita (or higher industry wage rates) have higher prices, and that a greater degree of openness exerts downward pressure on prices.

4. Conclusion

We have compared micro-prices across Europe for the period 1975 to 1990 and have shown that products of an industry tend to be cheaper in countries with higher stocks of R&D in that industry, and that a higher R&D stock in a country is associated with lower prices for manufacturing goods. We conclude that productivity plays a role in determining prices in these countries and that the law of one price fails even for manufactures. This reverses the usual B-S result of a higher overall price level for countries with higher productivity. The overall impact of productivity on the price level will depend on the relative size of the two sectors. A large productive sector can sustain lower prices in the most productive international location, as predicted in the recent theoretical contributions of Benigno and Thoenissen (2003) and MacDonald and Ricci (2004).

[23] There is no qualitative change when we replace GDP per capita with industry wage rates. Correcting for differences in GDP per capita and openness, price elasticities for R&D-induced productivity now range from -1.5 percent in 1985 to -6.9 percent in 1975. The complete table of results is available upon request.

Table 4: Explaining cross-country price differences using industry-level R&D stock differences

Real Exchange Rates explained by:	Ind. R&D stock	GDPperCapita	Openness	$\bar{R}^2$%
1990 (364 goods,1456 obss)				
	-.017 (-2.87)*			3.9
	-.099 (-10.27)*	1.72 (10.40)*		6.9
	-.114 (-11.03)*	1.898 (10.98)*	-.112 (-4.23)*	7.9
with population[-.067(-1.38)]	-.112 (-10.78)*	2.206 (7.75)*	-.213 (-2.76)*	7.9
with industry dummies	-.078 (-6.02)*	1.645 (8.23)*	-.077 (-2.73)*	9.7
with country dummies	-.112 (-9.97)*			7.8
country&industry dummies	-.047 (-2.78)*			10.1
1985 (532 goods,2128 obss)				
	-.009 (-1.77)***			0.1
	-.019 (-2.57)*	.213 (1.65)***		0.3
	-.026 (-3.35)*	.283 (2.21)**	-.095 (-4.66)*	1.0
with population[-.071(-2.05)**]	-.021 (-2.64)*	.489 (2.88)*	-.202 (-3.59)*	1.0
with industry dummies	-.019 (-2.19)**	.174 (1.26)	-.091 (-4.46)*	2.8
with country dummies	-.050 (-4.89)*			2.1
country&industry dummies	-.072 (-5.42)*			4.5
1980 (270 goods, 1080 obss)				
	-.006 (-.81)			0.3
	-.017 (-2.16)**	.632 (5.48)*		1.8
	-.023 (-2.53)*	.634 (5.49)*	-.055 (-1.68)***	2.0
with population[.002 (.04)]	-.023 (-2.49)*	.631 (4.70)*	-.051 (-.64)	1.9
with industry dummies	.005 (.47)	.715 (5.12)*	-.026 (-.79)	6.7
with country dummies	-.074 (-6.49)*			7.1
country&industry dummies	-.061 (-4.65)*			10.2
1975 (331 goods, 1324 obss)				
	-.054 (-7.11)*			3.1
	-.055 (-7.84)*	.979 (10.60)*		6.0
	-.069 (-9.19)*	1.064 (11.41)*	-.202 (-9.00)*	8.9
with population[-.053 (-1.89)***]	-.067 (-8.96)*	1.094 (11.55)*	-.293 (-5.19)*	9.2
with industry dummies	-.065 (-8.11)*	.988 (9.81)*	-.185 (-7.70)*	13.3
with country dummies	-.045 (-5.15)*			10.0
country&industry dummies	-.025 (-2.28)**			14.9

Notes: * the estimate is statistically significant beyond the one percent level

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