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Abstract

Scale effects in per capita production are an outcome of many theoretical economic models like second generation growth models, models of the new trade theory or the new economic geography. The prediction is that larger economies should have a higher per capita production than smaller economies. However, in an open economy context the scale of the economy is less important because countries can participate in the scale of other countries through trade. This paper develops an open economy growth model of the second generation type which shows the relevance of the scale of the trading partners in technology goods for per capita production. This model is empirically tested using a cross section of 88 countries for the year 2000. The scale of these economies is measured by a weighted sum of scales of the G7 countries, since these are the countries spending most on R&D and are thus the main origin of technology. The results show that there is a significant effect of this scale variable on per capita production.

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1 Introduction

Jones (2004) discusses the issue of scale effects in growth models of the second generation type (e.g. Jones 1995, Kortum 1997, Segerstrom 1998, Young 1998). These models all exhibit a so called weak scale effect in per capita production, a larger economy should have a higher per capita production than a smaller. The reason for the weak scale effect to occur is simply due to the increasing returns in growth models caused by the non-rivalry of ideas which determine the state of technology. Once an idea has been discovered it can be used with no additional costs by as many production units as possible. With this setup, there exist fixed costs in setting up production, i.e. the costs of discovering the idea, and, as usual, the assumed constant marginal costs in production given the idea. This inevitably yields increasing returns to scale. Another feature of second generation models like Young (1998), Peretto (1998), Dinopoulos and Thompson (1998) and Howitt (1999) is, that the total number of ideas is tied to the scale of an economy. In the most simple case only labor is used as a traditional input factor in production and therefore the economy with the largest labor force has the highest stock of ideas which can be utilitized by the labor force.

Studies trying to find evidence for this weak scale effect include Backus, Kehoe and Kehoe (1992), Sala-i-Martin (1997), Romer and Frankel (1999), Hall and Jones (1999) and Alcala and Ciccone (2002). Although the studies use different methodologies, they have in common that they measure the scale of an economy by its own size, e.g. the population size or the extend of the work force. Significant positive effects of the scale onto per capita production are found by Frankel and Romer (1999) and Alcala and Ciccone. On a more regional level Ciccone and Hall (1996) and Ciccone (2002) find significant scale effects of per capita production on the county level for the US and the regional level for the EU 15 with respect to the county or regional population density. But again only the scale or density of the economic unit under consideration is used as an explanatory variable. The main argument developed in the theoretical part of this paper is that not only the own scale matters but also the scale of countries with which economic interaction exists. This argument gains in importance if one thinks about the strengthening economic integration of the world. Some of the aforementioned studies try to account for this by controlling in their empirical work for trade. This might be a step in the right direction but it seems more reasonable to account for economic interaction and integration by using the correct economic definition of the explanatory variables. It is important to correctly estimate these weak scale effects because these scale effects play an important role in explaining productivity differences between countries.

The paper adds to the existing literature by making a theoretical and an empirical contribution. It will be shown theoretically how the scale of economic partners of an open economy determines its per capita production. The empirical part of this paper consists of a cross sectional analysis for 88 countries for the year 2000. It will be shown that per capita GDP in these countries can be explained by the scale of technologically important partner countries, i.e. the G7 countries. A spatial scale variable will be constructed using also insights from the literature on technology diffusion (see Keller 2001), which serves to uncover the weak scale effect in an open economy context. The results indicate that this scale measure is significant in explaining variation in per capita GDP. This gives further support on Jones' (2004) conclusion that the weak scale effect in second generation growth models is more a feature than a bug.

The outline of the paper is as follows. Section 2 considers theoretical foundations of the scale effect in per capita production. A version of the second generation growth model of Young (1998) is used to illustrate the weak scale effect for the open economy. The empirical part of the paper is concentrated in section 4 where the data and methods used are described. Finally section 5 concludes.

2 The Model

The model employs the production technology familiar from Romer (1986, 1987) and combines it with the growth mechanism of Young (1998) to obtain a multi country growth model. At the first sight the model seems to be similar to the model in Spolaore and Wacziarg (2005) but there are important differences. First

Spolaore and Wacziarg (2005) do not account for steady state growth in there model. This is due to their assumption that technology is only given by the horizontal differentiation of production as in the first generation growth models (Romer 1986, 1987 or Grossman and Helpman 1991). Second, and more important, they assume in a multi country and multi region setup capital immobility between countries besides trade in goods between regions and countries. This assumption merely serves as a capacity constraint to obtain a result for level of technology. In the model to be presented below capital is allowed to move freely between regions, the necessary restriction to yield a solution for the level of technology is instead taken from the endogenous growth mechanism of the Young (1998) model which adds another dimension of growth through vertical innovations to the model. This gives a set of more economic plausible assumptions for a multi country growth model.

Households: The economies considered in the model are assumed to admit a representative household who maximizes lifetime utility given by

$$U = \sum_{t=0}^{\infty} \frac{\ln c_t}{(1+\rho)^t}, \tag{1}$$

where ρ is the rate of time preference. Time is discrete and the time subscript is suppressed in the following to simplify the notation. In general all figures correspond to the current time t period if not indexed otherwise. Maximizing (1) subject to an intertemporal budget constraint leads to the condition

$$\frac{c_{t+1}}{c} = \frac{1+r}{1+\rho}, \tag{2}$$

where r is the net interest rate of the economy.

Production: Country i, $i = 1, 2, ..., M$, is populated by L_i workers in period t supplying inelastically one unit of labor each. Labor can be used in production of final output and in R&D and can move freely between these two sectors, however labor is immobile between countries. The aggregate production function for this country is

$$Y_i = L_{i,p}^{\alpha} \int_0^N (\lambda_j x_j)^{1-\alpha} dj.$$

x_j is the input quantity and λ_j is the quality level of the jth variant of an intermediate input factor, $\alpha \in (0,1)$ determines the elasticity of production with respect to the input factors. N is the available set of intermediate input factors at time t and $L_{i,p}$ is the amount of labor used in production of the final good Y_i. $L_{i,p}$ is endogenous and it will become obvious later how it is related to the total exogenous labor supply L_i.

The intermediate input factors are produced by individual firms which have been engaged in the design of one particular variant. Therefore they are assumed to possess a competitive advantage in producing this variant and the production function for one of the variants for the original designer is

$$x_j = k_j,$$

where k_j is the input of capital goods used for production. It is assumed that capital goods can be produced from final output Y_i with a linear production technology with productivity equal to one under perfect competition.

The production function for a competitor who is not involved in the development of one particular variant is given by

$$x_j = \gamma^{-1} k_j,$$

where $\gamma > 1$ is a productivity parameter capturing the competitive advantage of the original developer in producing the particular variant.

Since the original developer has a competitive advantage in producing his particular variant of the intermediate input factor it is assumed that he sets a limit price $\gamma c_{i,j,k}$, where $c_{i,j,k}$ denotes the marginal cost for the inventor of the jth variant in country i delivering to country k, in order to prevent potential competitors from entering the market for intermediate input factors.

Trade It is assumed that capital goods produced from final output can be traded freely between the M economies. This implies that the user costs of capital $r_g = r+\delta$, where δ is the rate of depreciation, are equal across countries. This immediately implies that the price for capital goods p is the same across countries. Furthermore countries can trade in intermediate input factors but not frictionless. Transport costs are assumed to be of the "iceberg" type (Samuleson (1954)), i.e. country i has to ship $\tau_{ik} > 1$ units in order to deliver one unit to country k, $k \neq i$. Throughout the following discussion τ_{ik} is specific for a particular pair of countries ik, $\tau_{ik} = \tau_{ki}$ and $\tau_{ii} = 1$ for all i.

With this setup each intermediate input supplier in a specific country i faces demand from country i and from the remaining $M - 1$ economies. N therefore denotes the total set of intermediate input factors available in the world market.

R&D and Growth: It is clear from the production function (**??**) that output will increase, ceteris paribus, in the number of intermediate input factors. However, growth can be caused in this model not only through the channel of an increasing set N of available variants of input factors, but as well through an increase in the quality levels λ_j over time.

To model growth in the quality level the idea of Young (1998) is utilized. Assume that before production of one variant of the intermediate input factors can take place, a quasi-fixed cost of R&D has to be incurred in order to be able to produce with a certain level of quality. The real cost function for R&D is given by

$$F_j = \begin{cases} f e^{\mu \lambda_j / \bar{\lambda}_{t-1}} & \text{if } \lambda_j \geq \bar{\lambda}_{t-1}, \\ f e^{\mu} & \text{otherwise,} \end{cases} \tag{3}$$

with $\bar{\lambda}_{t-1} = \frac{1}{N_{t-1}} \int_0^{N_{t-1}} \lambda_{j,t-1} dj$ as the average quality level in period $t-1$. This real cost function is identical for all countries. Developers of intermediate input factors can benefit from past quality improvements through a *standing on shoulders* argument; past improvements make future improvements cheaper. f and μ are exogenously given productivity parameters. As noted above (3) gives a real cost function in terms of the quantity of a specific production factor used to cover these fixed costs. In the following it will be assumed that merely labor is used in R&D so that F_j denotes the number of workers employed in R&D by one specific input-factor producer. Hence, labor market clearing requires $L_{i,p} + L_{i,r} = L_i$, where $L_{i,r} = \int_0^{N_i} F_j dj$ and N_i denotes the set of intermediate input factors produced in country i.

The individual intermediate input factor producer of variant j in country i chooses his quality level in order to maximize profits $\pi_{i,j}$ given by

$$\pi_{i,j} = (\gamma - 1)c_{i,j}x^d_{i,j} - w_i F_j, \tag{4}$$

$$x^d_{i,j} = \sum_{k=1}^{M} \left(\frac{\gamma c_{i,j,k}}{p}\right)^{-\frac{1}{\alpha}} (1-\alpha)^{\frac{1}{\alpha}} \lambda_j^{\frac{1-\alpha}{\alpha}} L_{k,p} \tag{5}$$

where w_i is the wage rate in country i. $x_{i,j}$ is the demand for variant j from all economies obtained from equating its price with its marginal product in all M economies. The marginal costs for the producer of variant j are heterogenous with respect to the countries of origin and destination. In particular $c_{i,jk} = \tau_{ik} r_g$ due to the "iceberg" transport cost and the fact that intermediate input factors are produced from capital goods which must be rented by the producer from the household sector at a gross interest rate of r_g.

To find the optimum profits one sets the first derivative of this profit function with respect to λ_j equal to zero. Taking account of the R&D cost function (3) this yields the following rule for the development of the quality level

$$\frac{\lambda_j}{\bar{\lambda}_{t-1}} = \frac{1}{\mu}\frac{1-\alpha}{\alpha}, \tag{6}$$

which is very similar to the result in Young (1998). From (6) it is immediately clear that all producers of intermediate input factors choose the same quality level $\lambda_j = \bar{\lambda}$ and that $\bar{\lambda}$ grows at a constant rate given by exogenous parameters.

What still needs to be determined is the equilibrium number of intermediate input factors N_i produced in every country. For this it is assumed that entry into the market for intermediate input factors occurs until profits given by (4) are driven down to zero. The mechanism leading to shrinking profits due to additional market entry operates via the wage rate w_i. As new variants enter the market, labor productivity in final good production increases, driving up wages and therefore increase the R&D costs. From the marginal product condition for labor in final production one easily derives $w_i = \alpha \frac{Y_i}{L_{i,p}}$. The marginal product condition for intermediate input factors delivers the production function for final output in reduced form as

$$Y_i = (1-\alpha)^{\frac{1-\alpha}{\alpha}} \gamma^{-\frac{1-\alpha}{\alpha}} \bar{\lambda}^{\frac{1-\alpha}{\alpha}} r_g^{-\frac{1-\alpha}{\alpha}} L_{i,p} \left(\sum_{k=1}^{M} N_k \tau_{ik}^{-\frac{1-\alpha}{\alpha}} \right), \tag{7}$$

after integrating over all variants of intermediate input factors. With this result the wage rate in country i becomes

$$w_i = \alpha(1-\alpha)^{\frac{1-\alpha}{\alpha}} \gamma^{-\frac{1-\alpha}{\alpha}} \bar{\lambda}^{\frac{1-\alpha}{\alpha}} r_g^{-\frac{1-\alpha}{\alpha}} \left(\sum_{k=1}^{M} N_k \tau_{ik}^{-\frac{1-\alpha}{\alpha}} \right). \tag{8}$$

Now setting the profits (4) equal zero and using (6) and (8) gives a system of M equations in the M unknowns N_i which has the solution[1]

$$N_i = \frac{1-\alpha}{\alpha} \frac{\gamma-1}{\gamma} f^{-1} e^{-\frac{1-\alpha}{\alpha}} L_{i,p}. \tag{9}$$

Per Capita Production: Equation (9) produces the scale effect mentioned in the introduction. The extent of the set of intermediate input factors is direct proportional to the extent of the work force employed in final production what directly influence productivity and hence per capita production. However per capita production is heterogenous between countries because every country i has individual access to intermediate input factors due to the differences in the composition of the τ_{ik}.

With the results obtained so far the allocation of workers between final production

[1] A necessary condition for this solution is that the $M \times M$ matrix T with typical element $\tau_{ik}^{\frac{1-\alpha}{\alpha}}$ is invertible.

and R&D can now be computed. With the real R&D cost (3), the optimality condition (6) and the set of variants of intermediate input factors (9) the work force employed in R&D, $L_{i,r}$ is given by

$$L_{i,r} = N_i f e^{\frac{1-\alpha}{\alpha}} = \frac{1-\alpha}{\alpha}\frac{\gamma-1}{\gamma} L_{i,p}, \tag{10}$$

and therefore

$$L_{i,r} = \frac{(1-\alpha)(\gamma-1)}{\alpha+\gamma-1} L_i, \tag{11}$$

$$L_{i,p} = \frac{\alpha\gamma}{\alpha+\gamma-1} L_i. \tag{12}$$

Using (7), (9) and (12), per capita production in country i is then given by

$$\frac{Y_i}{L_i} = \eta \bar{\lambda}^{\frac{1-\alpha}{\alpha}} r_g^{-\frac{1-\alpha}{\alpha}} \left(\sum_{j=1}^{M} \tau_{ij}^{-\frac{1-\alpha}{\alpha}} L_j \right). \tag{13}$$

$$\eta = (1-\alpha)^{\frac{1-\alpha}{\alpha}} \gamma^{-\frac{1-\alpha}{\alpha}} f^{-1} e^{-\frac{1-\alpha}{\alpha}} \times \times \left(\frac{\alpha\gamma}{\alpha+\gamma-1} \right)^2 \frac{\gamma-1}{\gamma} \frac{1-\alpha}{\alpha}.$$

Equation (13) shows clearly that in an open economy both, the scale of the considered economy is important as well as the scale of the trading partner countries. Their scale enters weighted with a function of the transportation costs. With this result it is also obvious that wages do not equalize between countries which is simply due to the trade frictions assumed by the heterogeneity in the transport costs.

Equation (13) is the main result of this section and serves as the motivation for the empirical analysis below. Note that this a special case for the weak scale effect. Due to the assumptions about the production function for the open economy case the elasticity of production per worker with respect to the scale given by $\sum_{j=1}^{M} \tau_{ij}^{-\frac{1-\alpha}{\alpha}} L_j$ is equal to one. In the empirical section a more general relationship will be explored.

Balanced growth: On the balanced growth path consumption expenditure of the households grows with the same rate as output. Output growth with a stationary population is determined by growth in the quality level of intermediate input factors and together with (6) the optimality condition (2) states that

$$\frac{c_{t+1}}{c_t} = \frac{1+r_t}{1+\rho} = \left(\frac{1}{\mu}\frac{1-\alpha}{\alpha}\right)^{\frac{1-\alpha}{\alpha}}, \tag{14}$$

which implies a net interest rate

$$r = (1+\rho)\left(\frac{1}{\mu}\frac{1-\alpha}{\alpha}\right)^{\frac{1-\alpha}{\alpha}} - 1. \tag{15}$$

It can be shown that the model has the usual saddle path properties. Note also that the zero profit condition for the firms producing intermediate input factors is identical with a trade balance condition on intermediate input factor trade, i.e. trade in these factors is always balanced between countries. Equilibrium in the market for final goods finally forces the net balance of trade in capital goods to be zero as well.

3 Empirical Analysis

3.1 Review of the Literature

As mentioned in the introduction there are some studies dealing empirically with the weak scale effect in per capita production. All of these studies focus on the influence of the scale of one particular country on its productivity.

Frankel and Romer (1999) analyze two cross sections, one of 150 countries and one of the 98 countries considered in Mankiw, Romer and Weil (1992), in 1985. They regress the logarithm of per capita income on the trade share, the logarithm of population and the logarithm of the country area. Due to the possible endogeneity of trade, they use as instruments for trade the geographical characteristics of the trading partners to construct predicted values for trade. The final estimation is done by OLS and the authors find a significant positive impact of the population variable on per capita income with elasticities ranging from 0.12 to 0.35.

Hall and Jones (1999) estimate the relationship between output per worker and the social infrastructure in the particular country in 1988 for 127 countries. Social infrastructure is measured by an aggregate of an index of government anti-diversion policies and an index measuring the openness to trade. The measure of social infrastructure is instrumented by geographical characteristics. As an additional variable they add the country's population to the regression and obtain an estimated elasticity of 0.05, which is statistically insignificant at any considerable level of significance. Backus, Kehoe and Kehoe (1992) are searching for effects of trade on growth. They find them in an extended empirical model where they regress the growth rate of production per capita in manufacturing and the average growth rate of GDP per capita between 1970 and 1985 on a trade index and among other control variables the average growth rate of the population from 1970 to 1985. Experimenting with different trade indices they estimate various elasticities of per capita production with respect to the population. They are all negative, in the case of the manufacturing sector they are not significant at the 10 percent level of significance, and range from -1.6 to -1.2.

Finally Alcala and Ciccone (2002) estimate the effect of trade, the scale of production and institutional quality on per capita GDP using IV regression techniques separately for 1985 and 1990. As instruments they use, among others, geographical characteristics of the considered countries. They consider like Frankel and Romer (1999) two sets of countries, one with 150 and one with 98 countries. The estimated elasticities of per capita GDP with respect to the workforce range from 0.14 to 0.46 and are all statistically significant.

None of the studies mentioned accounted for the possible role of the scale of the trading partners in the determination of per capita production.

Concerning the link to the existing empirical literature it must be noted that this paper borrows to some extent from the literature concerned with technology diffusion. Studies trying to measure knowledge or technology diffusion generally construct variables that should measure world wide available technology. This is usually done by computing R&D stocks from historical investments in R&D or by historical patent behavior of sectors and countries. One influential study is Coe and Helpman (1995) who explain total factor productivity for the OECD countries and Israel with home and foreign R&D stocks which the compute via the perpetual inventory method from historical R&D investments. The foreign R&D stock is thereby a weighted sum of country specific R&D stocks. As weights Coe and Helpman (1995) use bilateral import shares between the home and foreign countries to compute the aggregated foreign R&D stock.

There is a number of studies building on the work of Coe and Helpman (1995) trying to refine their methodology (for a survey of the literature see Keller 2001a). Most of this literature is working on finding better weights as e.g. in Lichtenberg und Pottelsberghe de la Potterie (1996), where FDI is used to obtain weights or in Xu and Wang (1999) where bilateral import shares in capital intensive goods are used. Xu (2000) uses data on multinational enterprises to construct weights. Keller (1999) uses the original Coe and Helpman (1995) methodology but applies it to different sectors of the G7 countries instead on the whole economy. Keller (2002b) uses a technology flow matrix to account for technology diffusion between sectors and bilateral industry specific import shares for diffusion between countries in order to analyze total factor productivity on the sector level for the OECD countries.

A more modern approach emerged from the work in Keller (2002a), where the technology available to a country is modelled again by a weighted sum R&D stocks but the weights were estimated instead of deterministically computed from the data. Keller (2002a) uses in a nonlinear regression analysis parameterized exponential functions in the geographical distance between countries to model technology diffusion between sectors of the OECD countries. Keller (2001b) extends this approach by including not only geographical distance in the weight functions but also sector specific trade measures, FDI and communication channels to explain differences in total factor productivity.

In the empirical analysis in this paper different ways of computing the theoretical scale variable mentioned above will be implemented, thereby making use of the methods developed for measuring the pure diffusion of technology. The main difference between this paper and the cited papers concerned with pure technology diffusion is that this paper reduces technology to its model oriented origin, the extent of the work force. Articles dealing with technology diffusion generally do not go that far, but try to measure technology by using expenditures for technological purposes.

3.2 Data

For testing equation (13) empirically, data on per capita production, the scale of the technological important trading partners of the considered economies as well as on the transport costs are needed. For the cross section of countries the sample in Hall and Jones (1999) serves as a starting point.

The data used for per capita production is per capita GDP for the year 2000 taken from the Penn World Tables 6.1. The variable used is RGDPCH which is measured at purchasing power parity in 1996 US Dollars using a chain index. This makes the per capita GDP comparable across countries (see Summers and Heston 1991).

Finally, data on transport costs are needed. Since there are no data available for the considered cross section of countries for a longer time horizon, a proxy is used. It is well known that trade patterns follow geographical patterns, i.e. trade between neighboring countries is stronger than between countries that are separated by large distances (see e.g. Frankel and Romer 1999). It is therefore natural to assume that trading costs are tied to the distance between trading partners. As a proxy for transportation costs in the subsection below, functions of the great circle distances between the capital cities of the countries considered in the analysis and the G7 countries are used.

Data availability on GDP per capita in the Penn World tables restricts the original 120 country sample from Hall and Jones (1999). Furthermore city states like Hong Kong or Singapore were deleted from the sample, because they are assumed to be outliers. This results in a cross section of 88 countries listed in table 2 in the appendix.

3.3 Methodology and Results

The computation of the scale variable is of great importance for the empirical analysis in this section. From the theoretical point of view the scale of the economies is given by their own work force and the work force of the trading partners. Inspection of trade statistics reveals that almost every country in the world trades to some extent with every other country. Therefore it might seem reasonable to include the scales of all countries in some way in the scale variable for one particular economy under consideration. However there are good reasons to deviate here a little bit from theory. 94% of all business enterprise R&D expenditure in the OECD countries is conducted by the G7 countries Canada, France, Germany, Italy, Japan, UK and USA (see e.g. Keller (2001)). From the theory of the last section it became clear that the scale effect operates via technology which is determined by the work force of the countries performing R&D. A plausible way of calculating the necessary scale variable is therefore to proxy for scale by the extent of the populations in the G7 countries.

Another important point is the weighting scheme in the scale variable. From equation (13) it can be seen that the scale variable is a weighted sum of population sizes; functions in the transport costs determine the weights. From the above cited literature on technology diffusion two approaches can be adopted, the parametric and the non-parametric way of calculating such a scale variable. E.g. Coe and Helpman (1995) use import trade shares as weights while Keller (2002a) uses exponential functions in the geographical distance as weights.

In this section both the non-parametric and the parametric approach will be explored to yields estimates of the weak scale effect in per capita production. The general model to be estimated is

$$\ln y_i = \alpha_0 + \alpha_1 \ln s_i + \beta x_i + \varepsilon_i, \tag{16}$$

where y_i is per capita GDP of country i, s_i denotes the scale variable to be defined below and x_i is a vector of controls. α_0, α_1 are parameters and β is a parameter vector to be estimated. ε_i is a usual error term. The scale variable is defined as

$$s_i = \begin{cases} \sum_{l=1}^{7} d_{il}^{-1} pop_l & \text{non-parametric,} \\ \sum_{l=1}^{7} e^{-\alpha_2 d_{il}} pop_l & \text{parametric,} \end{cases} \tag{17}$$

where l indicates the G7 countries, d_{il} is the great circle distance between country i measured in kilometers and the G7 country, pop_l is population in the G7 country and α_2 is a parameter to be estimated in the parametric case. In the non-parametric case the inverse of the distance is used as a weight as is often done in spatial econometrics (see e.g. Anselin (1988)). As the G7 countries are themselves part of the cross section the distances d_{ll} is set equal to one half of the square root of the land area of country l to approximate for transport costs within the country.

In the control vector x_i distance from the equator and regional dummies are included for: Africa, Asia, Australia/New Zealand, Central America, the EU, Near East, South America and the Indian subcontinent; North America is the control group. The geographical controls mainly serve to account for spatial autocorrelation in per capita production not caused by spatial scale effects. Additional control variables were omitted because of several reasons. First equation (13) is a reduced form of the production function per capita. Thus it accounts for scale effect after all other variables like the physical or human capital have adjusted, in the latter case via the knowledge incorporated in the set of available intermediate input factors determined by the extent of the population. This reduced form is exactly what is to be estimated. There might be other factors not included in the theoretical model influencing per capita production like social of economic infrastructure. These variables are likely to be endogenous and useful instruments might be hard to come by. However, the regional controls might be good proxies for these variables and last but not least it is very unlikely that the scale variable defined in (17) is correlated with them.

Estimation of (16) is done by non-linear least squares in the parametric and OLS in the non-parametric case. Table 2 (in the appendix) provides the results. Heteroskedastic consistent standard errors were computed using the White covariance estimator in its non-linear and linear version[2]. In the parametric case the parameters of interest are clearly α_1 and α_2. The estimates for both coefficients in the first column of table 1 show the expected signs and are of magnitude 0.249 and -0.000268. However, looking at the estimated standard errors, both coefficients seem to be in-

[2] In case of the non-linear estimation robust standard errors could also be computed by bootstrapping. This gives similar results.

significant. Inspecting the data this seems to be merely a problem of collinearity. The correlation of the gradients of the regression function with respect to α_1 and α_2 at the estimated parameter values is 0.94, thus it is likely that the scale variable as defined above is nevertheless a significant determinant of per capita production. To explore this issue further two additional regression were estimated (column 2 and 3 in table 1). The first is a conditional estimation based on the point estimate of -0.000268 for α_2. This gives a statistical conditional significant estimate of the parameter α_1 showing that using a weight of $e^{-0.000268 d_{il}}$ the scale variable explains a significant part of the variation of per capita GDP in the cross section. The second estimate is the non-parametric model with inverse distances as weights. The coefficient of estimate 0.294 for α_1 is slightly higher than in the parametric specification but is again highly significant. Together these results strongly indicate that per capita GDP in this 88 country sample is influenced by a scale variable determined by the scale of the G7 countries as predicted by the theoretical model in section 2. Besides the studies of Frankel and Romer (1999) and Alcala and Ciccone (2002) this gives further support to the existence of scale effects in per capita production but this time using a different scale variable founded by a reasonable endogenous growth multi-country model.

4 Conclusion

The weak scale effect is one of the effects observed in growth models of the second generation type. This paper has shown, using a version of the Young (1998) model, how these scale effects come into existence. The larger the economy considered, the more quasi fixed costs of R&D can be covered and the more technologically advanced is an economy. But through trade in intermediate or technology goods an open economy can participate in the scale of countries producing these technology goods. Thus the scale of an open economy is not constrained to its own resources, e.g. the population or the workforce, but is determined by the scale of its trading partners as well as by its own. If trading costs are low, the scale of an economy is almost given by the own scale extended by the scale of the trading partners.

Empirically the question was addressed, whether such scale effects are indeed present in the real world or whether they are just an artifact of special kinds of theoretical growth models. The results for are cross section of countries indicates that a scale variable composed of the scales of the G7 countries, the origin of most of the available technology, is a significant variable in explaining GDP per capita. These results give further support to the existence of weak scale effects in per capita production. and the corresponding assumptions in the second generation growth models seem reasonable.

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Appendix

Table 1: Country List

1	Argentina	31	Guatemala	61	Panama
2	Australia	32	Guinea	62	Paraguay
3	Austria	33	Honduras	63	Peru
4	Bangladesh	34	Iceland	64	Philippines
5	Belgium	35	India	65	Portugal
6	Benin	36	Indonesia	66	Rwanda
7	Bolivia	37	Iran	67	Senegal
8	Brazil	38	Ireland	68	South Africa
9	Burkina Faso	39	Israel	69	Spain
10	Burundi	40	Italy	70	Sri Lanka
11	Cameroon	41	Jamaica	71	Swaziland
12	Canada	42	Japan	72	Sweden
13	Chad	43	Jordan	73	Switzerland
14	Chile	44	Kenya	74	Syria
15	Colombia	45	Korea, South	75	Tanzania
16	Congo	46	Lesotho	76	Thailand
17	Costa rica	47	Madagascar	77	Togo
18	Cote d'Ivoire	48	Malawi	78	Trinidad and Tobago
19	Denmark	49	Malaysia	79	Tunisia
20	Dominican Republic	50	Mali	80	Turkey
21	Ecuador	51	Mexico	81	Uganda
22	Egypt	52	Morocco	82	UK
23	El salvador	53	Mozambique	83	USA
24	Ethiopia	54	Nepal	84	Uruguay
25	Finland	55	Netherlands	85	Venezuela
26	France	56	New Zealand	86	Yemen
27	Gambia	57	Niger	87	Zambia
28	Germany	58	Nigeria	88	Zimbabwe
29	Ghana	59	Norway		
30	Greece	60	Pakistan		

Table 2: Estimation Results

Dependent variable: Log of GDP per capita

Model:	parametric[a]	conditional[b]	non-parametric[c]
Log Scale	0.249	0.249	0.294
	(0.971)	(0.114)	(0.103)
Distance	-0.000268	-0.000268	-
	(0.000969)		
Dist. equator	2.960	2.960	2.742
	(0.489)	(0.477)	(0.487)
Africa	-1.957	-1.957	-1.930
	(0.284)	(0.283)	(0.305)
Asia	-0.290	-0.290	-0.331
	(0.448)	(0.317)	(0.309)
Australia/New Zealand	0.484	0.484	0.395
	(0.519)	(0.395)	(0.352)
Central America	-0.791	-0.791	-0.722
	(0.329)	(0.324)	(0.346)
EU	-0.620	-0.620	-0.620
	(0.228)	(0.225)	(0.255)
Near East	-1.793	-1.793	-1.691
	(0.294)	(0.289)	(0.324)
South America	-0.673	-0.673	-0.630
	(0.279)	(0.277)	(0.297)
Sub Indian cont.	-1.727	-1.727	-1.676
	(0.393)	(0.392)	(0.405)
Constant	5.900	5.900	7.396
	(12.671)	(1.409)	(0.615)
Observations	88	88	88
R^2	0.889	0.889	0.890

[a]Scale variable with parametric weights (exponential functions) for the population sizes of the G7 countries. Estimation by non-linear least squares, heteroskedasticity consistent standard errors (in parentheses) computed using the non-linear version of the White covariance estimator.

[b]Scale variable with exponential functions in the distance as weights for the populations of the G7 countries. Distance parameter fixed at the value from the parametric model. Estimation by OLS, heteroskedasticity consistent standard errors (in parentheses) computed by the White covariance estimator.

[c]Scale variable with inverse distance as weights for the populations of the G7 countries. Estimation by OLS, heteroskedasticity consistent standard errors (in parentheses) computed by the White covariance estimator.