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International Integration and Regional Development in China

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Abstract

Concerns about the duration of China's growth and hence the question of a permanent significant contribution of China to world economic growth relate, amongst other things, to the problem of reducing regional disparity in China. While China's high average growth is driven by a small number of rapidly developing provinces, the majority of provinces have experienced more moderate development. To obtain broad continous growth it is important to identify the determinants of provincial growth. Therefore, we introduce a stylized model of regional development which is characterized by two pillars: (i) International integration indicated by FDI and/or trade lead to imitation of international technologies, technology spill overs and temporary dynamic scale economies, and (ii) domestic factors indicated by human and real capital available through interregional factor mobility. Using panel data analysis and GMM estimates our empirical analysis supports the predictions from our theoretical model of regional development. Positive and significant coefficients for FDI and trade support the importance of international integration and technology imitation. A negative and significant lagged GDP per capita indicates a catching up, non steady state process across China's provinces.Highly significant human and real capital identifies the importance of these domestic growth restricting factors. However, other potentially important factors like labor or government expenditures are (surprisingly) insignificant or even negative. Further, in contrast to implications from NEG models indicators for urbanization and agglomeration do not contribute significantly.

Keywords: international integration, regional development, FDI, China

JEL classification: J24, O14, O18, O33, O40, R55

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1 Introduction

For more than a decade the People's Republic of China experienced very successful development. An outstanding average growth in real GDP per capita [1], the unprecedented boom in foreign direct investment (FDI), and the sustained increase in trade are of impressive dimensions. This positive economic development caused an enormous improvement in China's standard of living and had an important impact on the global economy. However, the development of China is somehow deceptive considering that measured in GDP per capita, China still is a poor developing country[2]. Furthermore, China seems to be afflicted by growing regional disparities. The regional Gini coefficient increased from 0.35 in 1995 to 0.43 in 2004. Accelerated growth and increasing provincial inequality provoked great public interest and became a focus of numerous studies. Analyzing the economic development of the coast, the interior and the rural and urban provinces Kanbur and Zhang (2005), Huang, Kuo and Kao (2003), Li and Zhao (1999) and Wan (1998) find statistical evidence of increasing provincial disparities. Numerous studies try to analyze this rising inequality using the concept of σ- and β convergence. The dominant finding in the literature is that inequality measured by σ convergence has increased during the past decades (Chen and Fleisher 1996, Jian, Sachs and Warner 1996, Zhang, Liu and Yao 2001, Wang 2003 and Yao and Zhang 2001b). The question of regional disparity is not just a Chinese problem. Regional convergence can be regarded as an indicator of the continuity of the rapid growth process. A scenario of convergence indicates that China's average growth is not driven solely by a small number of rapidly developing regions and so it may be somewhat sustainable. Therefore, the question of the duration of Chinese growth and in turn, of China's permanent and significant contribution the world economy is the centres on the convergence of the Chinese regional growth process.

Chen and Fleisher (1996) find evidence of conditional convergence of per capita production from 1978 to 1993 when controlling for the variables of employment, physical capital, human capital, and coastal location. Further, Cai, Wang and Du (2002) support this finding for the period 1978 to 1998. Using panel data Choi and Li (2000) report convergence within China's provinces from 1978 to 1994. They argue that the poorer regions have higher convergence rates and hence catch up with the wealthier ones. This finding is also supported by Wu (1999). Results by Chen and Feng (2000), Jian, Sachs and Warner (1996), Yudong and Weeks (2003) also support the conditional convergence hypothesis, and Raiser (1998) and Gundlach (1997) report evidence even for absolute convergence.

However, using nonstationary panel techniques Pedroni and Yao (2006) argue that since 1978 per capita incomes in the majority of the provinces has appeared to be diverging. They show that this divergence process cannot be attributed to either the presence of geographically-oriented convergence clubs,

[1] Average growth of the last ten years is 8.01 percent, source: Penn World Table 6.2.

[2] With a GDP per capita (PPP) of \$6,300 the People's Republic of China was ranked 118^{th} of 232 countries in 2005; Source: The World Factbook 2006.

or to the fact that some provinces run open-door policies while others do not. Weeks and Judong (2003) indicate a system-wide divergence during the reform period, which in their opinion is a consequence of the technology gap between the coastal and the interior provinces. Yao and Zhang (2001a, 2001b, 2002), too, have found evidence of regional income divergence in the last decades, which is explained by an increase in the average income gap between the coast and the inland, rather than by an increase in the variance within either the coast or the inland regions. Overall, therefore, the convergence literature paints an inconsistent picture.

With respect to the determinants of the provincial growth process many studies focus on capital in form of physical and human capital, factors influencing openness, the government, and geographical location.

Physical capital stock persistently shows a significant impact on GDP growth in China (Yao 2006, Fleisher, Li and Zhao 2005, Yao and Zhang 2001a and 2002, Wang and Yao 2003 and Madariga and Poncet 2005).

With respect to human capital it can be observed that beside the rapid economic development and high economic growth in the last years, endowment of human capital especially in the eastern provinces of China is also improving steadily. Using the number of students enrolled in higher education as a proxy for human capital in a growth regression Yao (2006) and Chen and Feng (2000) estimate positive and significant coefficients. While Chen and Fleisher (1996) use university graduates/population, other studies by Fleisher, Li and Zhao (2005), Démurger (2001), Yao and Zhang (2001a) use secondary school enrollment as a proxy. All arrive at the conclusion that human capital contributes significantly to growth and welfare. Wang and Yao (2003) construct a new measure of human capital stock using average years of schooling and also find a positive effect. Arayama and Miyoshi (2004) argue that the contribution of human capital is rather substantial in the central and western regions.

Apart from capital and human capital there is a general view that economic integration is a strong factor of regional development in China. Since the start of the open door policy and the implementation of Special Economic Zones (SEZ) in the early 1980s China has made significant steps towards international integration and attracted many foreign direct investors. The importance of economic integration and openness for China's provinces is broadly aknowledged. Particularly the effects of FDI and trade on China's regional growth have been studied in a number of papers. While Chen and Feng (2000) and Yao and Zhang (2001a, 2002) identify positive effects for exports in the last decades, Chen and Fleisher (1996), Zhang and Song (2000) and recently Yao (2006) have pointed out that both exports and FDI have a strong and positive effect on economic growth. Based on an analysis of 196 Chinese cities from 1990 to 2002 Madariga and Poncet (2005) demonstrate that cities take advantages not only of their own financial openness but also of FDI flows received by neighboring provinces. Cheung and Lin (2004) argue that inward FDI can have beneficial effects on innovation activity and growth via various spillover channels such as reverse engineering, labor mobility, demonstration effects, supplier–customer relationships, and so on. They find evidence of positive spillover effects of FDI on the number of domestic patent applications for the period 1995-2000.

Another set of studies focuses on the impact of geographic factors on growth and disparities. The advantageous location of the coastal provinces is discussed in the context of lower transportation costs and a more successful open door policy. For example, Bao et al. (2002) argue that spatial and topographic advantages promote higher returns on capital investment in the coastal provinces, thus attracting more FDI and migrant labor to a region and causing growth. Madariga and Poncet (2005) and Bao et al. (2002) point out that geography that translates into international transaction costs is responsible for a significant part of successful growth of the coastal belt. Furthermore, Chen and Fleisher found that convergence is conditional on coastal location, among others, while Yao and Zhang (2001b and 2002) use an augmented Solow's growth model and construct diverging clubs to identify that remote regions cannot catch-up with their eastern counterparts due to the long distance to economic centers.

In this paper the economy is a small region integrated into the world economy. The region is located in a developing country and characterized by a technological gap compared to leading industrialized countries. In this stylized economy an international traded final good is produced with human capital and real capital and international mobile real foreign capital. All trading transactions are directed at world markets. Due to positive externalities, incoming FDI induces imitation and hence productivity growth. The regional government can influence the economy by changing international transaction costs (transport costs as well as barriers to international trade and investments), and providing the public infrastructure required for imitation.

The empirical part examines the determinants of per capita income growth for 28 Chinese provinces over the period 1991-2004. We apply two estimation techniques for dynamic panels: The difference GMM estimator developed by Arrelano and Bond (1991) and the system GMM estimator developed by Blundell and Bond (1998). With these econometric techniques we account for province-specific effects, we can include dependent variables as regressors and control for endogeneity of all explanatory variables, and hence can provide unbiased and efficient estimates. Our analysis is based on revised GDP and investment data from Hsueh and Li (1999).

2 A 3-equation model of regional development

For a developing country, access to relevant production factors, international spill-over and externalities through technologies and infrastructure are relevant determinants of growth and development.[3] While the idea of New Economic Geography basically works through increasing returns to scale, monopolistic competition, market size and pecuniary externalities, the idea in this paper is

[3]See e.g. Fujita/Thisse (2002 ch.11), or Kelly/Hageman (1999).

slightly different. Within a neoclassical model, we introduce technical and information externalities in the imitation process. The main reason why firms are located in a certain region is because they have access and proximity to international technologies and a pool of human capital. In the discussion of this process Glaeser et al. (1992) point to the distinction between Jacobs (1969) and MAR (Marshall-Arrow-Romer) externalities. MAR externalities focus on knowledge spill-over processes between firms in the same industries. MAR externalities were discussed first by Marshall (1890 [1920]) and Arrow (1962). Starting with Romer (1986) this kind of spill-over process plays a crucial role in many models of the new growth theory. Jacobs externalities are not industry specific but general. They occur between firms that do not need to be in the same industry cluster. From an empirical point of view both externalities seem to matter. Glaeser et al. (1992) found evidence of Jacobs externalities while Black/Henderson (1999a) and Kelly/Hagemann (1999) identified MAR externalities.

Taking these ideas of externalities and international spill-over as the point of departure, we develop a basically neoclassical model of growth for a single backward region. Externalities will lead to temporary dynamic scale economies and drive the technical imitation process. The dynamics of the model are driven not by accumulation but by technological catching up and imitation. The model will be stylized and simplified in such a way that a region can be modeled with three equations.

Final output: The final output sector of region i uses human capital H_i international capital flowing into the region as FDI $\mathcal{F}_i$ and domestic real capital K_i to produce a homogeneous final good. Hence, in this model the most important factors of production that might eventually drive the growth process are three different types of capital. We especially assume that domestic capital and international capital are different. The fundamental difference and the continued high degree of capital control segregates the market for domestic and international capital. Workers are assumed to be allocated to any production process at a subsistence level of income from a pool of surplus labor. Like in a *Lewis Economy,* labor is not a growth restricting factor. The Lewis turning point has not yet been reached. Hence, H_i, K_i and $\mathcal{F}_i$ can be regarded as the respective capital per unit labor. Based on the small economy assumption and the integration of regional goods markets into world markets, the per capita production of the final good y_i can be regarded as Findlay's *foreign exchange production function*[4]. Hence y_i is a production value function measured in international prices. With the concept of the *foreign exchange production function* the aggregate production value function stands for a continuum of industries characterized by different factor intensities valuated in given international prices. Each level of output value indicates a full specialization in the industry characterized by the corresponding factor intensity. A change in output value and hence factor

[4]See Findlay (1973, 1984).

intensity indicates a switch in specialization pattern towards another industry. Inflowing international capital F_i is fully depreciated during the period of influx. Production of the final good takes place under perfect competition and constant economies of scale and is described by

$$\begin{aligned} y_i &= A_i H_i^{\alpha} \mathcal{F}_i^{\beta} K_i^{1-\alpha-\beta}, \\ with \quad A_i &= \omega_i / A \end{aligned} \tag{1}$$

where A_i indicates the regional level of technology and ω_i is the region's relative technological position compared to the technology leader A which increases at a given rate n. As we will see later, domestic technology will be driven by ω_i. The domestic product is used for government expenditures which is the fraction γ_i of output, domestic consumption and exports.

FDI inflow and exports: Optimal capital inflow is derived from the firms' optimal factor demand. Due to the small country assumption, capital costs in a region for international capital $\mathcal{F}_i$ are determined by the exogenous world market interest factor r[5] and an ad valorem factor for region specific international transaction costs τ_i. τ_i may include a risk premium related to the specific region. Since we are also looking at trade policies we introduce τ_i^{ex} as a transaction cost parameter for exports. τ_i^{ex} may be an export tariff or the equivalent of bureaucratic transaction costs. τ_i and τ_i^{ex} are modeled as iceberg costs on exports. As we assume that returns on international capital investments in a region $\mathcal{F}_i$ will be fully repatriated, exports Ex must earn international interest rates and all international transaction costs. On the firm level $Ex_i(1-\tau_i^{ex}) = \tau_i r \mathcal{F}_i$. Solving the firms' optimization problem[6] we obtain the optimal influx of foreign capital

$$\mathcal{F}_i = \frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} y_i \tag{2}$$

and as a fraction φ_i of GDP

$$\varphi_i = \frac{\mathcal{F}_i}{y_i} = \frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r}.$$

To keep things simple, international borrowing or lending beyond FDI is excluded. Since international capital costs have to be paid by exports we can determine the export value necessary to cover international capital costs including all transaction costs:

$$Ex_i = \frac{\tau_i r}{(1-\tau_i^{ex})} \mathcal{F}_i, \qquad \frac{Ex_i}{y_i} = (1-\gamma_i)\beta.$$

Whereas the export share of GDP is simply determined by the elasticity of production of foreign capital β and the tax rate γ_i (2).

[5] The interest factor is one + interest rate.

[6] The firm has to determine optimal factor inputs by maximizing profits. Since all capital services have to be paid in terms of exports, the full capital costs include several components like government taxes on output γ_i or transaction costs for exports.

Determining the production level: Including optimal capital inflows in the production function leads to the production level [7]

$$Y_i = \omega_i{}^{\frac{1}{1-\beta}} H_i^{\frac{\alpha}{1-\beta}} (\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r})_i^{\frac{\beta}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}}$$

Production is now normalized for the international technology level. Hence, production is determined by regional factor endowments and the relative technology position of the region compared to the technological leader ω_i.

Technology and imitation: The developing region does not create new knowledge, but acquires technologies by decoding and imitating foreign designs from international technology leaders. In the present model growth through technological imitation and agglomeration is driven by three components:[8]

1) International knowledge spill-over and positive technological externalities from the influx of FDI were modelled by Markusen/Venables (1999). Here the effects of these externalities are included at a macro level of modeling.

2) In order to make spill-over from FDI effective for the host region, technology and firm-relevant public infrastructure must exist.[9]

3) As the focus lies on underdeveloped regions the case of innovations in this backward region is excluded. The imitation process is affected by the technology gap $(1-\omega)$ between the backward region and the industrialized world. If the domestic stock of technology is low (ω is small), it is relatively easy to increase the technology position by adopting foreign designs. However, the process becomes increasingly difficult as the technology gap narrows.[10] Therefore, in this approach technological progress in a backward economy is modeled as a process of endogenous catching-up relative to an exogenous growth path of a technology leader.

While the exogenous process is driven by international innovation growth, the endogenous process of imitation and participation in worldwide technical progress is determined by pure externalities from FDI $\mathcal{F}(t)$ and from domestic government investments $G(t)$ in the ability to imitate and improve productivity.[11] These externalities and the resulting relative increase in domestic

[7] $Y = yA^{-\frac{1}{1-\beta}}$. see also appendix 1e.

[8] There is a broad literature on international technology diffusion that has suggested various channels. Eaton/Kortum (1999) discuss trade as a channel of diffusion in a multi-country setting. See also Coe/Helpman (1995) who link the direction of technology diffusion to exports. Keller (1998) however has some doubts about the link between trade and diffusion.

[9] E.g. Martin (1999) has analyzed the effects of public policies and infrastructure to the growth performance of a regional economy.

[10] This idea draws back to the well-known Veblen-Gerschenkron hypothesis (Veblen (1915) and Gerschenkron (1962)). Later Nelson/Phelps (1966), Gries/Wigger (1993), Gries/Jungblut (1997) and Gries (2002) further developed these ideas in the context of catching-up economies. The catching-up hypothesis has been tested successfully and robustly by Benhabib/Spiegel (1994), de la Fuente (2002), and Engelbrecht (2003).

[11] Note that $\mathcal{F}(t)$ and $G(t)$ are normalized values transformed by an international technology index factor $A(t)^{\frac{1}{1-\beta}}$, and A is growing at a given constant rate n. See also appendix 1e.

technologies by imitation are the elements that allow us to depart from neoclassics. Externalities in the imitation process generate temporary dynamic scale economies. As scale economies are the driving element in the models introduced by the *New Economic Geography* (NEG), there is a link to NEG even if the market structure is not monopolistic competition. While pure size and pecuniary externalities are permanently positive in NEG models in this approach we focus on the underlying factors of technical externalities from factors of production and the resulting transitory dynamic scale economies,[12]

$$\dot{\omega}_i(t) = G(t)_i^{\delta_G} F(t)_i^{\delta_F} - \omega(t). \tag{3}$$

The externalities from FDI and government infrastructure are assumed to have a rather limited effect on imitation such that $\delta_G + \delta_F = \delta < 1$ and δ is small.

As described above, government expenditures are restricted by government tax income. We abstract from government borrowing or lending and interregional transfers. Hence the government budget constraint is

$$G_i = \gamma_i y_i \tag{4}$$

The three equations (1), (2), and (3) capture the model of regional development for one region. The solution to (1), (2), and (3) is a differential equation determining the growth of the relative stock of technology available to the region (catching-up in technology) during the period of transition to the steady state.[13] In this period we observe additional technological catching up with the steady state productivity growth. As this acceleration process is driven by additional factors flowing into the region, the economy can realize temporary dynamic scale economies during this catching up and adjustment period. While $\dot{\omega}_i(t)$ is positive during transition, it converges to zero when approaching the steady state path. Equation (5) suggests a decreasing speed of growth with a rising income level as a result of increasing difficulties in the imitation process.[14]

$$\dot{\omega}_i(t) = \gamma_i^{\delta_G} \varphi_i^{\left(\delta_F + \frac{\beta}{1-\beta}\right)} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \right]^{\delta} \omega(t)_i^{\frac{\delta}{1-\beta}} - \omega(t), \qquad \text{with} \quad \frac{d\dot{\omega}_i(t)}{d\omega(t)} < 0. \tag{5}$$

Not only the speed of technological catching up $\dot{\omega}_i(t)$ is determined by the factor endowments K_i, H_i and the fractions γ_i and φ_i. For each endowment we can determine the steady state position ω_i^* of the region. For $\dot{\omega}_i(t) = 0$[15] we

[12] For the dynamic catching-up-spill-over equation we assume that G and $\mathcal{F}$ are sufficiently large for positive upgrading.

[13] See appendix 1f.

[14] The dynamic catching-up-spill-over equation contains a scaling problem if H and K are taken as absolute values. As the region is assumed to remain backward, the values of γ, φ, H and K are assumed to be sufficiently small. See appendix 2 for the derivatives.

[15] We assume that the contribution of FDI to production β as well as the externality effect of FDI on technology δ are sufficiently small. This also reflects the already mentioned assumption of a rather limited spill-over effect of FDI on the relative catching up process.

obtain

$$\begin{aligned}
\omega^* &= \gamma_i^{\delta_G \frac{(1-\beta)}{(1-\beta-\delta)}} \varphi_i^{\frac{\delta_F(1-\beta)+\delta\beta}{(1-\beta-\delta)}} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}} && (6)\\
\frac{\partial \omega_i^*}{\partial K_i} &= \frac{\delta(1-\beta-\alpha)}{1-\beta-\delta}\omega^* K_i^{-1} > 0, \quad \frac{\partial \omega_i^*}{\partial H_i} = \frac{\delta\alpha}{1-\beta-\delta}\omega^* H_i^{-1} > 0, && (7)\\
\frac{\partial \omega_i^*}{\partial \tau_i} &= -\frac{(1-\beta)\,\omega_i^*}{(1-\beta-\delta)}\left[\delta_F + \frac{\beta}{1-\beta}\delta\right]\tau_i^{-1} < 0 && (8)\\
\frac{\partial \omega_i^*}{\partial \tau_i^{ex}} &= -\frac{(1-\beta)\,\omega_i^*}{(1-\beta-\delta)}\left[\delta_F + \frac{\beta}{1-\beta}\delta\right](1-\tau_i^{ex})^{-1} < 0 && (9)\\
\frac{\partial \omega_i^*}{\partial \gamma_i} &= \frac{(1-\beta)\,\omega_i^*}{(1-\beta-\delta)}\left[\delta_G\gamma_i^{-1} - \left(\delta_F + \frac{\beta}{1-\beta}\delta\right)(1-\gamma_i)^{-1}\right] \gtreqless 0 && (10)
\end{aligned}$$

The essential determinants of the speed of convergence and the final relative convergence position are the endowment of capital K_i and human capital H_i, technology relevant government expenditure indicated by γ_i, and international (and domestic) transaction costs connected to exports τ_i^{ex} and FDI τ_i and hence the share of FDI φ_i.

The economic story is rather simple. Reducing τ_i will reduce the costs of international capital and increase the input of international capital. As more FDI or government investments enter the region, spill-over and positive externalities will accelerate imitation and technology convergence and in turn improve the final relative technology position of the region. Similarly, with a larger endowment of human capital or human capital, capital productivity will increase such that additional FDI speeds up imitation and the final position of the region improves.

Optimal level of government activity: The steady state reaction of ω_i^* resulting from a change in government expenditures is ambiguous and depends on the present state of government policy. With respect to the potential goal of maximizing the regions' steady state position we can determine an optimum tax rate[16] and hence an optimum value of government expenditures for technology related infrastructure

$$\max_{\gamma_i} \quad \omega^* \qquad \Rightarrow \gamma_i^* = \frac{\delta_G}{\left(\delta_F + \frac{\beta}{1-\beta}\delta + \delta_G\right)}.$$

Therefore, there is a range $\gamma_i < \gamma_i^*$ where an increase in γ positively affects ω_i^*. Beyond the optimal value γ_i^* (for $\gamma_i > \gamma_i^*$) an increasing taxes and increasing government expenditures reduce ω_i^*.

$$\frac{\partial \omega^*}{\partial \gamma_i} \begin{cases} > 0 & & \gamma_i < \gamma_i^* & \text{underinvestment} \\ = 0 & \text{for} & \gamma_i = \gamma_i^* & \text{GDP maximizing spending} \\ < 0 & & \gamma_i > \gamma_i^* & \text{overinvestment} \end{cases} \qquad (11)$$

[16]In appendix 3 we show that the government can maximize the final development position of the economy and the speed of growth by choosing an optimal level of govenment expenditure for public infrastructure.

From the discussion of the adjustment and the steady state we can turn to the general dynamic behavior of the region's income path over time. At any point in time t_0 the income path can be described by a Taylor approximation :

$$\ln Y(t_0) = \ln Y(t_0) + \frac{Y'(t_0)}{Y(t_0)}(t - t_0) + \frac{1}{2}\frac{Y''(t_0)y(t_0) - Y'(t_0)^2}{Y(t_0)^2}(t - t_0)$$

From this path we can derive the general rule of motion which describes the speed of the process defined by the growth rate.[17]

$$\begin{aligned} \frac{\Delta \ln Y(t_0)}{\Delta t} &= \frac{Y'(t_0)}{Y(t_0)} + \frac{Y''(t_0)y(t_0) - Y'(t_0)^2}{Y(t_0)^2}(t - t_0) + \frac{1}{2}... \\ &= \frac{Y'}{Y} + \frac{Y''}{Y} - \left(\frac{Y'}{Y}\right)^2 = \frac{Y'}{Y} + \frac{Y''}{Y}. \end{aligned}$$

Using the model specification we obtain equation (12) for the development of each region.[18] Equation (12) will be transformed into the estimation equation later on.

$$\frac{d\ln Y(t_0)}{dt} = \frac{\dot{\omega}}{\omega}(G, F, \omega) + \alpha\frac{\dot{H}}{H} + \left(\beta + \frac{\partial^2 y}{\partial \omega^2}\frac{\partial \dot{\omega}}{\partial F}\right)\frac{\dot{F}}{F} + (1 - \alpha - \beta)\frac{\dot{K}}{K} + \frac{\partial^2 y}{\partial \omega^2}\frac{\partial \dot{\omega}}{\partial G}\frac{\dot{G}}{G} \tag{12}$$

3 Panel data analysis and GMM estimations

In this paper we suggest applying a panel data analysis and GMM estimations. We prefer dynamic panel estimators mainly for two reasons.

Firstly, from a theoretical point of view we should assume that a number of individual factors exist that can not be captured in conditioning set X_i, as different provinces exhibit different technological or geographical endowments. The dynamic panel procedure allows us to control for these specific effects whereas the OLS estimator assumes that the intercept that captures the effect of all omitted and not observable variables is the same for all provinces. This individual effect must be considered to correlate with the included explanatory variables, hence omission of the individual effect would become part of the error term, which would lead to a bias in the estimates.

[17] Since $\left(\frac{y'}{y}\right)^2$ is rather small we can approximate the process.

[18] To simplify we consider only linear and log linear processes.

Secondly, some of the variables in conditioning set X_i must be considered not strictly exogenous and determined simultaneously with growth. In consideration of these problems, panel procedures enable a calculation of consistent and efficient estimates.

With regard to the first point, panel data estimations can take a region's heterogeneity explicitly into account by allowing for individual steady-state positions (individual specific effects) using fixed effects. In comparison to the standard fixed effect estimator, GMM estimation additionally circumvents the bias associated with the inclusion of a lagged dependent variable as a regressor. Additionally, by combining the time series dimension with the cross-sectional dimension, the panel data gives a richer set of information to exploit the relationship between the dependent and independent variables, reduce the collinearity among the explanatory variables, increase the degrees of freedom and give more variability and efficiency.[19]

More specifically, our point of departure is a simple fixed effects model of the form

$$y_{i,t} - y_{i,t-1} = \theta y_{i,t-1} + \beta X'_{i,t} + u_{i,t} \tag{13}$$

where $y_{i,t}$ is the logarithm of real per capita GDP so that $y_{i,t} - y_{i,t-1}$ is the growth rate of per capita GDP, X_i is a conditioning set of explanatory variables. This method allows for an inclusion of individual effects for each province. Hence $u_{it} = \eta_i + \varepsilon_{it}$ denotes the disturbance term that is composed of the individual effect η_i and stochastic white noise disturbance ε_{it}.We can now rewrite equation (13) and obtain

$$y_{i,t} = \widetilde{\theta} y_{i,t-1} + \beta X'_{i,t} + \eta_i + \varepsilon_{i,t} \tag{14}$$

whereas $\widetilde{\theta} = \theta + 1$. The errors are assumed to be uncorrelated

$$E(\varepsilon_{i,t}; \varepsilon_{i,s}) = 0, \qquad \text{for } s \neq t, \tag{15}$$

the individual effect captures the province specific characteristics and might correlate with the explanatory variables

$$E(X'_{i,t}; \eta_i) = 0.$$

To get consistent results we have to assume that the error term is orthogonal to all explanatory variables. At this point a problem arises as the lagged endogenous variable used as a regressor correlates with the error term

$$E(y_{i,t-1} \varepsilon_{i,t}) \neq 0. \tag{16}$$

If we do not take this correlation structure into account, and estimate (14) by a common least squares estimator, our estimators will be biased and inefficient (Nickell 1981).

[19] See Gujarati (2003) p.637.

Anderson and Hsiao difference estimator: Anderson and Hsiao (1982) suggested to take differences of the original equation to eliminate the individual fixed effect.

$$y_{i,t} - y_{i,t-1} = \theta(y_{i,t-1} - y_{i,t-2}) + \beta(X'_{i,t} - X'_{i,t-1}) + \varepsilon_{i,t} - \varepsilon_{i,t-1} \tag{17}$$

This can be simplified in

$$\triangle y_{i,t} = \theta \triangle y_{i,t-1} + \beta \triangle X'_{i,t} + \triangle\varepsilon_{i,t} \tag{18}$$

where $\triangle$ is the first difference. However, using differences does not eliminate the problematic relationship between $\triangle y_{i,t-1}$and $\triangle\varepsilon_{i,t}$, since $y_{i,t-1}$ and $\varepsilon_{i,t}$ are contained in these terms. So a new correlation problem arises that again leads to a coefficient bias, as the difference of the lagged endogenous variable correlates with the new error term

$$E(\triangle y_{i,t-1}; \triangle\varepsilon_{i,t}) \neq 0. \tag{19}$$

To deal with this problem of correlation between the independent variable and the error term, we introduce a dynamic panel procedure and use instrumental variables (IV). This technique also controls for the potential endogeneity of all explanatory variables that may also correlate with the error term. Starting with the problem of correlation between the regressor and the error term in (19), bias can be avoided using an instrumental variable Z that strongly correlates with the explanatory variables $\triangle y_{i,t-1}$ in the equation but does not correlate with the error term $\triangle\varepsilon_{i,t}$. So a valid instrument is characterized by the following assumptions

$$E(\triangle y_{i,t-1}; Z) \neq 0, \tag{20}$$

$$E(Z; \triangle\varepsilon_{i,t}) = 0. \tag{21}$$

The structure of the error term contains the periods t and $t-1$, so assuming no serial correlation in the errors, variables from the period $t-2$ do not correlate with $\triangle\varepsilon_{i,t}$. Anderson and Hsiao (1982) recommend using either the lagged observation ($y_{i,t-2}$) or the lagged difference ($\triangle y_{i,t-2}$) as instruments for the differenced lagged explanatory variable. Both correlate with the explanatory variable but not with the error term

$$E(y_{i,t-2}; \triangle\varepsilon_{i,t}) = 0, \tag{22}$$

$$E(\triangle y_{i,t-2}; \triangle\varepsilon_{i,t}) = 0. \tag{23}$$

Arellano (1989) shows that in models with an autoregressive exogenous variable instruments in levels are better suited. In contrast to the estimator that use differenced instruments the estimator with level instruments has no singularities and much smaller variances.

Arellano and Bond difference estimator: Though the method recommended by Anderson and Hsiao (1982) provides consistent results, Arellano and Bond (1991) show that the Anderson-Hsiao estimator is not necessary efficient since it does not make use of all available moment restrictions. Following Arellano and Bond (1991) all lagged observations should be used as instruments. The corresponding moment condition can be expressed as follows

$$E(y_{i,t-s}; \triangle\varepsilon_{i,t}) = 0 \qquad \text{for } s \geq 2; \qquad t = 3, ..., T. \tag{24}$$

This moment condition can be checked using the Sargan statistic that tests the validity of the instruments. Using the lagged levels dated $t-2$ and earlier as instruments for the equation in first differences, we obtain consistent and efficient parameter estimates. We refer to the GMM estimator based on these conditions as the difference estimator. Simulations by Judson and Owen (1996) and Arellano and Bond (1991) suggest significant efficiency gains of the difference GMM estimator relative to that of the Anderson-Hsiao type in the form of smaller variances of the estimated coefficients.

Blundell and Bond system estimator: However, Blundell and Bond (1998) argue that this difference estimator has poor finite sample properties in terms of bias and imprecision when the lagged levels of the variables are weak instruments for the equations in first differences. This is the case when the time series are persistent or have near unit root properties. They propose using additional instruments in levels. In a system GMM estimator they combine the regression in differences with the regression in levels. The regression equation in differences is given by (18), the additional regression equation in levels is

$$y_{i,t} = \theta y_{i,t-1} + \beta X'_{i,t} + \eta_i + \varepsilon_{i,t}, \tag{25}$$

where differences are used as instruments. Blundell and Bond (1998) consider an additional stationarity assumption

$$E(\triangle y_{i,2}\eta_i) = 0 \qquad i = 1, ..., N. \tag{26}$$

The moment restriction for the regression equation in differences is the same as above. Indicating that the differences do not correlate with the error term for the regression equation in levels, the following moment restrictions are used

$$E(\triangle y_{i,t-s}u_{i,t}) = 0 \qquad \text{for } s = 1; \qquad t = 3, ..., T. \tag{27}$$

The Difference Sargan test can be used to test the additional assumptions and the validity of the additional instruments. Using the moment conditions in (24) and (27), we construct a GMM estimator that yields consistent and efficient values for the parameters. It combines the equations in differences with suitably lagged levels as instruments with the set of equations in levels with suitably lagged first-differences. Bond, Hoeffler and Temple (2001) compare the difference and the system GMM estimator and show that in an estimation of an empirical growth model, the system GMM estimator returns more reasonable results. Blundell, Bond and Windmeijer (2000) report similar improvements for a typical growth model with a lagged dependent variable and additional right-hand-side variables. Furthermore, Monte Carlo simulations[20] on the finite sample properties of the GMM estimator for dynamic panel data models demonstrate a significant improvement in performance of the system estimator to the regular difference GMM estimator.

4 Specification of the model and data

To analyze the determinants of growth and the convergence process within China it is necessary to use regional data to take the regions' heterogeneity into account. Our data set covers the period 1991-2004[21] and contains annual data for 28 Chinese provinces, autonomous regions, and municipalities. These are Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Shanxi, Jilin, Heilongjiang, Anhui, Jiagxi, Henan, Hubei, Hunan, Inner Mongolia, Guangxi, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang. The provinces Tibet and Hainan are excluded because of missing values. In constructing our data set, we have used new income and investment data reported by Hsueh and Li (1999) and various sources of Chinese official statistics provided by the National Bureau of Statistics (NBS). They are the China Statistical Yearbook (CSY) from 1996-2004 and the China Compendium of Statistics 1949-2004. In the following the variables are accurately described.

Our estimation equations are directly derived from the theoretical model presented above. The general equation of motion for the above model *(12)* translates into the estimation equations (28) and (29) with the following specification

$$\begin{aligned} \triangle y_{i,t} &= \beta_1 y_{i,t-1} + \beta_2 \triangle K_{i,t} + \beta_2 \triangle POP_{i,t} + \beta_4 \triangle HC_{i,t} \\ &\quad + \beta_5 \triangle FDI_{i,t} + \beta_6 \triangle GOV1_{i,t} + \beta_7 \triangle GOV2_{i,t} \\ &\quad + \beta_8 POPKM2_{i,t} + \beta_9 URBAN_{i,t} + \triangle \varepsilon_{i,t} \end{aligned} \tag{28}$$

and an alternative version where trade is assumed to have positive technology spill-over

[20] Monte Carlo results on the finite sample properties of the GMM estimator for dynamic panel data models have been reported by Arellano and Bond (1991), Kiviet (1995), Ziliak (1997), Blundell and Bond (1998) and Alonso-Borrego and Arellano (1999), amongst others.

[21] The choice of the period makes sense for two reasons. First, the early 1990s saw the latest wave of international integration policy in China. Also in the early 1990s the Chinese government started to prepare for WTO accession and a further opening up of the economy. Second, with respect to some important indicators some provinces would have had to be excluded if the time period had been expanded to earlier years.

$$\begin{aligned}\triangle y_{i,t} &= \beta_1 y_{i,t-1} + \beta_2 \triangle K_{i,t} + \beta_2 \triangle POP_{i,t} + \beta_4 \triangle HC_{i,t} \\ &+\beta_5 \triangle T_{i,t} + \beta_6 \triangle GOV1_{i,t} + \beta_7 \triangle GOV2_{i,t} \\ &+\beta_8 POPKM2_{i,t} + \beta_9 URBAN_{i,t} + \triangle\varepsilon_{i,t} \quad .\end{aligned} \tag{29}$$

where $y_{i,t}$ denotes GDP per capita, $K_{i,t}$ denotes provincial capital stock, $POP_{i,t}$ measures the population, $HC_{i,t}$ is the proxy for human capital, $FDI_{i,t}$ refers to FDI and $T_{i,t}$ to trade, $GOV1_{i,t}$ and $GOV2_{i,t}$ are the shares of government expenditure in GDP, $POPKM2_{i,t}$ is the proxy for aggregation and $URBAN_{i,t}$ the proxy for urbanization.

The notation of the estimation equation translates as follows:

Real GDP per capita: $y_{i,t}$ $y_{i,t}$ denotes the log of real GDP per labor unit and $\Delta y_{i,t}$ gives growth rate $y_t - y_{t-1}$ over time period $t-(t-1)$. We obtained provincial level output data from Hsueh and Li (1999) covering the period 1978-1995 and from various issues of the Statistical Yearbook of China for 1996-2004. GDP expressed in current prices (yuan) has been deflated with 1995 as the base year. The number of employed persons is taken from the China Compendium of Statistics 1949-2004.

Real capital stock: K_i K_i denotes the log of real capital stock per unit labor in each province i. The real physical capital stock for all provinces is estimated using the standard perpetual inventory approach. It is accumulated according to

$$\mathcal{K}_{t+1} = I_t + (1-\delta)\mathcal{K}_t \tag{30}$$

where $\mathcal{K}_t$ and $\mathcal{K}_{t+1}$ is the capital stock of year t and $t+1$, I_t denotes investment, and δ the depreciation rate. The investment series used is gross fixed capital formation and is taken at current prices, it is taken from Hsueh and Li (1999) and the Chinese Statistical Yearbooks. We assume that the depreciation rate δ is 5 percent for all provinces as in Miyamoto and Liu (2005). For the initial capital stocks for each province we use the average ratio of provincial GDP to national GDP for each province over the period 1952-1977 as the weight. Following Wang and Yao (2003) we assume their estimate of 26609.67 billion yuan as the initial real capital stock for 1977 at the national level. By multiplying this initial capital stock with the provincial weights we derive the initial capital stock for each province. To calculate the real capital stock we use a new investment deflator provided by Hsueh and Li (1999) for the period 1978-1995 combined with the price index for fixed asset investment for the period 1996-2004. Again we use the number of employed persons to calculate the real capital stock per employee.

Population: $POP_i:$ POP_i denotes the population in a province. The population data is obtained from the China Compendium of Statistics 1949-2004.

Human capital: H_i : Enrollment in higher education as log of the share in the total employed population is the proxy for human capital H_i. We obtained the data from the China Compendium of Statistics 1949-2004.

FDI: FDI_i : We use the log of foreign direct investment per employee as a measure for economic integration. Because FDI data is available only in yuan we transform the data into US dollars using the national exchange rate for each year reported by the National Bureau of Statistics.

Trade: T_i : The second variable measuring the economic integration is trade. It is the log of the sum of imports and export taken from the China Compendium of Statistics 1949-2004 divided by the number of employed persons.

Government: $GOV2$, $GOV2$: Two variables can indicate the effect of government expenditure on economic growth. The first is the the share of local government general expenditure in administration ($GOV1$) and the second is the ratio of local government general expenditure in culture, education, science and public health to GDP ($GOV2$). Again, the source of the data is the China Compendium of Statistics 1949-2004.

Agglomeration: $POPKM2$: Agglomeration is not formally modeled in the above theoretical model. However, models introduced by New Economic Geography (NEG) emphasize the relevance of agglomeration on growth. Population density measured in the provincial population per square kilometer is used as a proxy for the degree of agglomeration in a province. The data are obtained from the China Compendium of Statistics 1949-2004.

Urbanization: $URBAN$: Urbanization is the second variable addressing the hypothesis of positive agglomeration effects on growth from NEG. Urbanization is measured by the ratio of the urban employed population to total population. The data were sourced from the China Compendium of Statistics 1949-2004.

5 Estimate results

The results of the estimates are summarized in table 1 and table 2. Table 1 shows the results for the Arellano and Bond estimator reported as GMM-DIFF and the Blundell and Bond estimator denoted as GMM-SYS for the period 1991-2004. The estimates are based on the specified model in (28)[22].

[22] We use the Hausman test to check for unobserved heterogeneity between the provinces. If the null hypothesis is significant a simple OLS estimator is consistent and efficient, whereas the GMM estimator is consistent in all cases. For our model the null hypothesis is rejected so that the GMM estimation should be favored.

Table 1 GMM Growth regressions with FDI (1991-2004)
Dependant variable: $\triangle y_{i,t}$

	GMM-DIFF		GMM-SYS	
	coeff.	Std. Err.	coeff.	Std. Err.
$y_{i,t-1}$	-0.186***	(0.099)	-0.117***	(0.000)
$\triangle K_{i,t}$	1.066***	(0.359)	0.744**	(0.302)
$\triangle POP_{i,t}$	0.832	(1.443)	-0.019	(1.375)
$\triangle HC_{i,t}$	0.377***	(0.100)	0.376***	(0.120)
$\triangle FDI_{i,t}$	0.029**	(0.012)	0.030**	(0.014)
$\triangle GOV1_{i,t}$	-0.029	(0.072)	-0.148	(0.147)
$\triangle GOV2_{i,t}$	-0.311***	(0.100)	-0.244**	(0.123)
$POPKM2$	-0.001	(0.001)	0.000	(0.000)
$URBAN$	-0.438	(0.294)	-0.146	(0.411)
m1	0.005		0.001	
m2	0.982		0.853	
Hansen	0.524		0.275	

Note: *, ** and *** denote significance at the 10%, 5% and 1% level.

Table 2 accordingly presents the results for the alternative specification in (29). We avoid including both FDI and trade in one model because of multicollinearity problems[23]. To verify GMM consistency, we have to make sure that the instruments are valid. We use the Hansen test of over-identifying restrictions to test the validity of the instrumental variables which is a general specification test. The hypothesis assumes that the othogonality conditions of the instrumental variables are satisfied. In the case of the difference estimator the test indicates that the instruments appropriately do not corralate with the error term. The validity of lagged levels combined with lagged first differences is lower in both models while the p-values stay satisfactory.

Looking at table 1 and 2, most explanatory variables enter with the sign predicted from the model, except government expenditures and the proxies for agglomerations and urbanization. Hence, the major findings of the estimates suggest that there are two sources for the Chinese growth process: external sources available due to international integration, and domestic sources:

[23] We also checked for multicolinearity of all other variables.

Table 2 GMM Growth regressions with trade (1991-2004)
Dependant variable: $\triangle y_{i,t}$

	GMM-DIFF		GMM-SYS	
	coeff.	Std. Err.	coeff.	Std. Err.
$y_{i,t-1}$	-0.221***	(0.099)	-0.181***	(0.000)
$\triangle K_{i,t}$	0.958***	(0.172)	0.746***	(0.143)
$\triangle POP_{i,t}$	0.754	(1.110)	0.781	(1.148)
$\triangle HC_{i,t}$	0.239**	(0.105)	0.300***	(0.095)
$\triangle T_{i,t}$	0.066***	(0.023)	0.048**	(0.019)
$\triangle GOV1_{i,t}$	-0.045	(0.095)	-0.172**	(0.078)
$\triangle GOV2_{i,t}$	-0.185	(0.117)	-0.141	(0.130)
$POPKM2$	-0.000	(0.001)	0.000	(0.000)
$URBAN$	0.268	(0.375)	0.409	(0.312)
m1	0.005		0.002	
m2	0.982		0.896	
Hansen	0.524		0.440	

Note: *, ** and *** denote significance at the 10%, 5% and 1% level.

1. *Development and International Integration:*

    - Controlling for other explanatory variables the coefficient for *lagged GDP per capita* is negative and significant. This result indicates a non stationary process. Some sort of non linear catching up or adjustment process seems to be characteristic of China's provinces. In other words, on the conditioning set of all other explanatory variables initially poorer provinces tend to have higher growth rates. This finding is predicted by the above model. During the period of rapid catching up and non stationary growth and non linear temporary dynamic scale economies are additional driving forces of development. In the model this process is driven by technological imitation and spill overs originally entering China through international integration.
    - *Foreign Direct Investment* is significant at the 5% level and also shows a positive effect on growth. This result supports the underlying theory that FDI creates technology spillover through imitation. At least part of the technological catching up process is driven by international integration via FDI.
    - In the alternative model where *trade* is included instead of FDI we likewise demonstrate a positive significant effect. Learning to produce for the international market seems to be another growth driving mechanism through international integration. In the theory model above FDI and exports are two sides of the same coin.

2. *Domestic sources of development*

   - The coefficient for *physical capital* is significant and shows the strongest positive impact on output growth in absolute terms for both the GMM-DIFF and the GMM-SYS independent of whether FDI or trade are included in the model. This result indicates that the growth process in China is not only a phenomenon caused by foreign firms investing in a poor country. The growth process has strong and important domestic components. However, while the theoretical model does not address the origin of domestic capital in each province, this question seems crucial. If provincial real capital is accumulated via savings in each province there is no inter-provincial growth conflict. If the source of capital in successful provinces is an inter-provincial capital flow, these provinces may grow at the expense of other provinces. In this case, inter-provincial capital flows may be a source of growth but also of divergence.
   - *Human capital* (measured in secondary or higher education enrollment) enters positively and is highly significant. As expected this result suggests that better education at the secondary level improves the process of industrialization. Qualified workers with intermediate skill level have the ability to work in production plants with high productivity. Hence increasing human capital per capita affects economic output in the sense that it leads to higher productivity.

3. *No significant sources of development*

   - In all cases *population* shows an insignificant effect.[24] Following the ideas of surplus labor introduced by Lewis (1954) this result is not surprising as long as China has not reached the Lewis turning point. In other words, as long as pure labor is not a growth restricting factor China still seems to have surplus labor in the rural sector that can be added to the growth restricting factors as needed. Pure labor can be added to or withdrawn from a region without affecting output.
   - The coefficient for *government* administration expenditure and the expenditures in culture, education, science and public health shows, if anything, a significant negative impact on growth. With respect to the theoretical model this result suggests that we have an overinvestment in this kind of government activities. From the theory we know that provincial governments may cause positive effects if activities decrease international transaction costs or help to improve technology spill over from international technologies. However, if taxes become too high, potential positive effects are overcompensated and the financed government activities must be regarded as overinvestment. Our findings suggest that there is an overinvestment in certain

[24] Using employees instead of population leads also to insignificant results.

fields of government spending. Government expenditure needs to be adjusted and optimized to drive the growth process more efficiently.

- Even if we did not include *agglomeration* in our theoretical model, NEG strongly suggests a positive correlation between agglomeration and growth of economic activities. NEG models emphasize that an agglomeration has a positive impact on the economy. We use population density measured in population per square kilometer as a proxy for the agglomeration process. Surprisingly density has no significant effect on growth.
- Agglomeration can also be measured even more directly by the degree of urbanization. However, as for density, *urbanization* measured as the ratio of the employed urban population to total population has no significant effect on growth. These results suggest that agglomerations do not seem to generate the growth driving positive externalities sometimes proposed. Agglomerations host the growth driving factors and the most important ingredients for growth. Therefore, the estimate identifies these growth factors but no pure externality from agglomeration and density.

To sum up the empirical findings: We show that based on the theoretical model all three kinds of capital, namely domestic physical capital, human capital and foreign capital, enter positively and significantly. To a large extent, these factors are responsible for the development of China's provinces and hence of China as a whole. With regard to the tremendous success story of the coastal belt during the sample period the hypothesis that international integration has had an enormous effect is supported by the positive effect of FDI and trade. However, we also identify a group of variables that has no or even a negative effect on growth - these include population, government expenditure and the proxies for agglomeration and urbanization. These two surprising results contradict the NEG. They propose that pure agglomeration and urbanization do not favor economic growth, and they emphasize the importance of fundamental production factors like domestic, foreign and human capital. Since we included these factors in our analysis there is no additional effect that could come from pure agglomeration or urbanization.

6 Summary and conclusion

In the last decade the People's Republic of China experienced a very impressive development. However, the country is characterized by increasing inequality. To ensure the China's successful development can be maintained, it seems important to identify the determinants of provincial success.

To address this question we introduce a stylized model of regional development. Growth and development is driven by two sources. 1. International integration indicated by FDI and trade promotes imitation from international technologies and leads to a technological upgrading of a region. 2. The domestic capital endownment in terms of real and human capital and government investments into growth relevant infrastructure represent domestic sources of growth.

Using panel data analysis and GMM estimates, our empirical analysis supports the predictions of our theoretical model of growth. International integration indicated by foreign direct investment and trade is significant and shows the predicted positive effects on growth. This result supports the underlying theory that these factors create technology spillover effects and promote productivity growth. Controlling for other explanatory variables we find a non stationary non linear adjustment process across China's provinces, which suggests that poorer provinces are catching up. The domestic capital endowment in terms of real and human capital enters with the expected positive signs, verifying the importance of these production factors and suggesting that a better educated population affects economic output through a higher productivity.[25]

However, other factors also expected to contribute positively to development such as government expenditure and labor do not promote growth. According to the theory the negative effect of government expenditure can be regarded as over-investment in certain fields of government activities. The insignificant labor effect supports Lewis' idea of surplus labor, and suggests that China has not yet reached the Lewis turning point.

According to NEG, agglomerations and urbanization are factors driving growth. Although not included in the theoretical model we proxy these factors to examine their importance. However, the result of these two variables contradict the NEG and enter insignificantly, suggesting that pure agglomeration and urbanization do not drive eocomic growth.

References

[1] Alonso-Borrego, C.; Arellano, M. (1999), Symmetrically Normalized Instrumental-Variable Estimation Using Panel Data, Journal of Business and Economic Statistics, Vol. 17 , Issue 1 , pp. 36-49 .

[2] Anderson, T. W.; Hsiao, C. (1981), Estimation of Dynamic Models with Error Components, Journal of the American Statistical Association, Vol. 76, Issue 375, pp. 598-606.

[3] Arayama, Y.; Miyoshi, K. (2004) Regional Diversity And Sources Of Economic Growth in China.

[4] Arellano, M. (1989), A Note on the Anderson-Hsiao Estimator for Panel Data, Economic Letters, 31, pp. 337-341.

[25] Using secondary school enrollment instead of enrollment in higher education leads to the same results.

[5] Arellano, M.; Bover, (1995), Another Look at the Instrumental Variable Estimation of Error-Components Models, Journal of Econometrics 68, pp. 29-51.

[6] Arrow, K.J. (1962), The Economic Implications of Learning-by-Doing, Review of Economic Studies 29, No. 1, pp. 155-173.

[7] Bao, S.; Chang, G.H.; Sachs, J.D.; Woo, W.T. (2002), Geographic Factors and China's Regional Development under Market Reforms, 1978-1998, China Economic Review, Vol. 13, pp. 89-111.

[8] Benhabib, J.; Spiegel, M.M. (1994) The Role of Human Capital in Economic Development - Evidence from Aggregate Cross-Country Data, Journal of Monetary Economics, Vol. 34, pp. 143-173.

[9] Black, D.; Henderson, V. (1999b), A Theory of Urban Growth, Journal of Political Economy, 107, pp. 252-284.

[10] Blundell, R.; Bond, S. (1998), GMM Estimation with Persistent Panel Data: An Application to Production Functions, IFS Working Papers W99/04, Institute for Fiscal Studies.

[11] Blundell, R.; Bond, S.; Windmeijer, F. (2000), Estimation in Dynamic Panel Data Models: Improving on the Performance of the Standard GMM Estimator, IFS Working Papers W00/12, Institute for Fiscal Studies.

[12] Bond, S.; Hoeffler, A.; Temple, J. (2001), GMM Estimation of Empirical Growth Models, CEPR Discussion Paper No. 3048, Centre for Economic Policy Research.

[13] Chen, B.; Feng, Y. (2000), Determinants of Economic Growth in China: Private Enterprise, Education, and Openness, China Economic Review, Vol. 11, pp. 1-15.

[14] Chen, J.; Fleisher, B.M. (1996), Regional Income Inequality and Economic Growth in China, Journal of Comparative Economics, Vol. 22, Issue 15, pp. 141-164.

[15] Cheung, K.; Lin, P. (2004), Spillover Effects of FDI on Innovation in China, Evidence from the Provincial Data, China Economic Review, Vol. 15, pp.25-44.

[16] Cai, F.; Wang, D.; Du, Y. (2002), Regional Disparity and Economic Growth in China. The Impact of Labor Market Distortions, China Economic Review, Vol. 13, pp.197–212.

[17] Choi, H.; Li, H. (2000), Economic Development and Growth Convergence in China, The Journal of International Trade and Economic Development, 9(1), pp.37–54.

[18] Coe, D.T.; Helpman, E. (1995), International R & D spillovers, European Economic Review, v. 39, iss. 5, pp. 859-887.

[19] de la Fuente, A. (2002), On the Sources of Convergence: a Close Look at the Spanish Regions, European Economic Review, 46, pp. 569-599.

[20] Démurger, S. (2001), Infrastructure Development and Economic Growth: An Explanation for Regional Disparities in China. Journal of Comparative Economics, Vol. 29, Issue 1, pp. 95-117.

[21] Eaton, J.; Kortum, S. (2001), Technology, Trade and Growth: A Unifed Framework, European Economic Review, v. 45, iss. 4-6, pp. 742-755.

[22] Engelbrecht, H.-J. (2003), Human Capital and Economic Growth: Gross Section Evidence for OECD, The Economic Record, v.79, special issue, pp. 40-51.

[23] Findlay, R. (1973), International Trade and Development Theory, Columbia University Press, New York.

[24] Findlay, R. (1984), Growth and Development in Growth Models, in: Jones, R.W.; Kenen, P.B. (eds.), Handbook of International Economics, 1, North Holland, pp. 185-236.

[25] Fleisher, B.M.; Li, H.; Zhao, M.Q. (2005), Regional Inequality and Productivity Growth in China: The Role of Foreign Direct Investment, Infrastructure, and Human Capital. Working Paper: Ohio State University.

[26] Fujita, M.; Thisse, J. (2002), Economics of Agglomeration, Cambridge University Press.

[27] Gerschenkron, A. (1962) Economic Backwardness in Historical Perspective, Harvard University Press, Cambridge MA.

[28] Glaeser, E.L.; Kallal, H.D.; Scheinkman, J.; Schleifer, A. (1992), Growth in Cities, Journal of Political Economy, 100, pp. 1126-1152.

[29] Gries, T. (2002), Catching-up, Falling Behind and the Role of FDI: A Model of Endogenous Growth and Development, South African Journal of Economics, v. 70, iss. 4, pp.588-611.

[30] Gries, T.; Jungblut, S. (1997), Catching-up and Structural Change, Economia Internazionale, v. 50, iss. 4, pp. 561-82.

[31] Gries, T.; Wigger, B. (1993), The Dynamics of Upgrading or How to Catch Up: Imitation and Growth of Newly Industrialized Countries, Economia Internazionale, v. 46, iss. 4, pp.377-87.

[32] Grossman, G.M.; Helpman, E. (1991), Innovations and Growth in Global Economy, MIT Press, Cambridge, Mass.

[33] Gujarati, D.N. (2005), Basic Econometrics, 4ed., Boston: McGraw-Hill.

[34] Gundlach, E. (1997) Regional Convergence of Output per Worker in China - A Neoclassical Interpretation, Asian Economic Journal, Vol. 11 No. 4, pp. 423-442.

[35] Hsueh, T.; Li, Q. (1999), China's National Income 1952-1995, Westview Press, Collorado, Oxford.

[36] Huang, J; Kuo, C; Kao, A. (2005), The Inequality of Regional Economic Development in China between 1991 and 2001, Journal of Chinese Economic and Business Studies, Vol. 1, No. 3, pp. 273–285.

[37] Jacobs, J. (1969), The Economy of Cities, Vintage Books, New York.

[38] Jian, T.; Sachs, J.D.; Warner, A.M. (1996), Trends in Regional Inequality in China, China Economic Review, 7(1), pp.1-21.

[39] Judson, R. A.; Owen, A. L. (1996), Estimating Dynamic Panel Data Models: A Practical Guide for Macroeconomists, Economics Letters, Vol. 65, No. 1, pp. 9-15.

[40] Kanbur, R.; Zhang, X. (2005), Fifty Years of Regional Inequality in China a Journey through Central Planning, Reform, and Openness, Review of development Economics, 9(1), pp. 87-106.

[41] Keller, W. (1998), Are International R&D Spillovers Trade-related? Analyzing Spillovers among Randomly Matched Trade Partners, European Economic Review, 42, pp.1469-1481.

[42] Kelly, M.; Hageman, A. (1999), Marshallian Externalities in Innovation, Journal of Economic Growth, 4, pp. 39-54.

[43] Kiviet, J. F. (1995), On bias, inconsistency, and efficiency of various estimators in dynamic panel data models, Journal of Econometrics, Elsevier, Vol. 68, No. 1, pp. 53-78.

[44] Li, S.; Zhao R. (1999), On China's Income Distribution again, Economic Research Journal, April, 3-17.

[45] Lin, J.Y.; Wang, G.; Zhao, Y. (2004), Regional Inequality and Labor Transfers in China, The University of Chicago.

[46] Lewis, M. A. (1954), Economic development with unlimited surplus of labor, The Manchester School Economic and Social Studies, Vol. 22, pp. 139-191.

[47] Madariaga, N.; Poncet, S. (2005), FDI Impact on Growth - Spatial Evidence from China, Working Paper, CEPII research center.

[48] Markusen, J.R., Venables, A.J. (1999), Foreign Direct Investment as a Catalyst for Iindustrial Development, European Economic Review, 43, pp. 335-356.

[49] Marshall, A. (1920), Principles of Economics, Macmillan, London.

[50] Martin, P.; Ottaviano, G.I.P. (1999), Growing locations in a model of endogenous growth, European Economic Review, 43, pp. 281-302.

[51] Martin, R. (1999), Public Policies, Regional Inequalities and Growth, Journal of Public Economics, 73, pp. 85-105.

[52] Miyamoto, K., Liu, H. (2005), An Analysis of the Determinants of Provincial Level Performance in China's Economy, Comparative Economic Studies, 47 (3), pp.520-542.

[53] NBS (2005), China Compendium of Statistics 1949-2004, Beijing: China Statistical Press.

[54] NBS (various years), China Statistical Yearbook, Beijing: China Statistical Publishing House.

[55] Nelson, R.R.; Phelps, E.S. (1966), Investment in Humans, Technological Diffusion, and Economic Growth, Cowles Foundation Paper 236, Reprinted from American Economic Review, 56, No. 2, pp. 69-75.

[56] Nickel, S. (1981), Biases in Dynamic Models with Fixed Effects, Econometrica, Vol. 46, Issue 6, pp. 1417-1426.

[57] Pedroni, P.; Yao, J.Y. (2006), Regional Income Divergence in China, Journal of Asian Economics, Vol. 17 No. 2, pp. 294-315.

[58] Raiser, M. (1998), Subsidising Inequality: Economic Reforms, Fiscal Transfers and Convergence across Chinese Provinces, Journal of Development Studies, Vol. 34, pp. 1-26.

[59] Romer, P.M. (1986), Increasing Returns and Long-run Growth, Journal of Political Economy, 94, No 5, pp. 1002-1037.

[60] Romer, P.M. (1990), Endogenous Technological Change, Journal of Political Economy, 98(5) part 2, pp. 71-102.

[61] Veblen, T. (1915), Imperial Germany and the Industrial Revolution, London.

[62] Wan, G. (1998) An Empirical Analysis of Inhabitants' Income Differential among China's Rural Areas and its Changes, Economic Research Journal, pp. 36-41.

[63] Wang, Z. (2003) WTO Accession, The "Greater China" Free Trade Area, and Economic Integration across the Taiwan Strait, China Economic Review, Vol. 14, pp. 316– 349.

[64] Wang, Y.; Yao, Y. (2003), Sources of China's Economic Growth 1952–1999: Incorporating Human Capital Accumulation. China Economic Review, Vol. 14, pp. 32–52.

[65] Wu, Y. (1999), Income Disparity and Convergence in China's Regional Economies, University of Western Australia Discussion Paper 9915.

[66] Yao, S.; Zhang, Z. (2001a), Regional Growth in China Under Economic Reforms, Journal of Development Studies. Volume 38, No. 2, pp. 167-186.

[67] Yao, S.; Zhang, Z. (2001b), On Regional Inequality and Diverging Clubs - A Case Study of Contemporary China, Journal of Comparative Economics , Vol. 29, pp. 466-484.

[68] Yao, S., Zhang, Z. (2002), Economic Growth and Diverging Clubs - A Case Study of the Chinese Regions, Applied Economic Letters, Vol. 9, pp.833-836.

[69] Yao, S. (2006), On Economic Growth, FDI and Exports in China. Applied Economics, Vol. 38, No. 3, pp. 339-351.

[70] Yudong, Y.; Weeks, M. (2003), Provincial Income Convergence in China, 1953-1997: a Panel Data Approach, Econometric Reviews 1/2003, Vol. 22 , Issue 1, pp. 59-77.

[71] Ziliak, J.P. (1997), Efficient Estimation with Panel Data When Instruments Are Predetermined: An Empirical Comparison of Moment-Condition Estimators, Journal of Business & Economic Statistics, American Statistical Association, Vol. 15, No.4, pp. 419-431.

[72] Zhang, Z.; Liu, A.; Yao, S. (2001), Convergence of China's Regions Incomes 1952-1997, China Economic Review, Vol. 12, pp. 243-258.

[73] Zhang, K. H.; Song, S. (2000), Promoting Exports: The Role of Inward FDI in China, China Economic Review, Vol. 11, 385-396.

7 Appendix

Appendix 1: determining the aggregate production level of the region:

$$
\begin{aligned}
y_i &= A_i H_i^{\alpha} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} y_i \right)^{\beta} K_i^{1-\alpha-\beta} \\
y_i &= A_i{}^{\frac{1}{1-\beta}} H_i^{\frac{\alpha}{1-\beta}} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \right)^{\frac{\beta}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \\
Y_i &= \frac{y_i}{A^{\frac{1}{1-\beta}}} \quad \text{hence} \quad Y_i = \omega_i{}^{\frac{1}{1-\beta}} H_i^{\frac{\alpha}{1-\beta}} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \right)^{\frac{\beta}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}}
\end{aligned}
$$

Appendix 2: Steady state determination and reactions of ω_i^* when H_i, K_i, τ_i, τ_i^{ex} and γ are changing:

Solve for $\dot{\omega}$ by plugging in:

$$\dot{\omega}_i(t) = G(t)_i^{\delta_G} F(t)_i^{\delta_F} - \omega(t),$$

$$\dot{\omega}_i(t) = \gamma^{\delta_G} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \right)^{\delta_F} y(t)_i^{\delta} - \omega(t)$$

$$y_i = \omega_i^{\frac{1}{1-\beta}} H_i^{\frac{\alpha}{1-\beta}} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \right)^{\frac{\beta}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}}$$

$$\dot{\omega}_i(t) = \gamma^{\delta_G} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \right)^{\delta_F} \left[\omega(t)_i^{\frac{1}{1-\beta}} H_i^{\frac{\alpha}{1-\beta}} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \right)^{\frac{\beta}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \right]^{\delta} - \omega(t)$$

$$\dot{\omega}_i(t) = \gamma^{\delta_G} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \right)^{\delta_F + \frac{\beta}{1-\beta}\delta} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \right]^{\delta} \omega(t)_i^{\frac{\delta}{1-\beta}} - \omega(t).$$

$$\frac{d\dot{\omega}_i(t)}{d\omega(t)} = \frac{\delta}{1-\beta} \Psi_i \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \right]^{\delta} \omega(t)_i^{\frac{\delta-1+\beta}{1-\beta}} - 1 < 0$$

as H_i and K_i are assumed to be sufficiently small

To simplify, this equation is rewritten as

$$\dot{\omega}_i(t) = \Psi_i \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \right]^{\delta} \omega(t)^{\frac{\delta}{1-\beta}} - \omega(t) \qquad \text{see} \qquad (5)$$

$$\text{with} \quad \Psi_i := \gamma^{\delta_G} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \right)^{\delta_F + \frac{\beta}{1-\beta}\delta}. \qquad (31)$$

solve for the steady state position:

$$0 = \dot{\omega}_i(t) = \Psi_i \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \right]^{\delta} \omega^{\frac{\delta}{1-\beta}} - \omega$$

$$\omega = \Psi_i \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \right]^{\delta} \omega^{\frac{\delta}{1-\beta}}$$

$$\omega^* = \Psi_i^{\frac{(1-\beta)}{(1-\beta-\delta)}} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}}$$

$$\Psi_i^{\frac{(1-\beta)}{(1-\beta-\delta)}} = \left[\gamma_i^{\delta_G} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \right)^{\delta_F + \frac{\beta}{1-\beta}\delta} \right]^{\frac{(1-\beta)}{(1-\beta-\delta)}}$$

$$= \gamma_i^{\delta_G \frac{(1-\beta)}{(1-\beta-\delta)}} (\varphi_i)^{\frac{\delta_F(1-\beta)+\delta\beta}{(1-\beta-\delta)}}$$

$$\omega_i^* = \gamma_i^{\delta_G \frac{(1-\beta)}{(1-\beta-\delta)}} (\varphi_i)^{\frac{\delta_F(1-\beta)+\delta\beta}{(1-\beta-\delta)}} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}} \qquad \text{see} \qquad (6)$$

Steady state reactions $\frac{\partial \omega_i^*}{\partial K_i}$:

$$\omega_i^* = \Psi_i^{\frac{(1-\beta)}{(1-\beta-\delta)}} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}}$$

$$\frac{\partial \omega_i^*}{\partial K_i} = \frac{\delta(1-\beta)}{1-\beta-\delta} \frac{1-\beta-\alpha}{1-\beta} \Psi_i^{\frac{1-\beta}{1-\beta-\delta}} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}-1} K_i^{\frac{1-\beta-\alpha}{1-\beta}-1} H_i^{\frac{\alpha}{1-\beta}}$$

$$= \frac{\delta(1-\beta-\alpha)}{1-\beta-\delta} \omega_i^* \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{-1} K_i^{\frac{-\alpha}{1-\beta}} H_i^{\frac{\alpha}{1-\beta}}$$

$$= \frac{\delta(1-\beta-\alpha)}{1-\beta-\delta} \omega_i^* K_i^{\frac{-1+\beta+\alpha-\alpha}{1-\beta}}$$

$$\frac{\partial \omega_i^*}{\partial K_i} = \frac{\delta(1-\beta-\alpha)}{1-\beta-\delta} \omega_i^* K_i^{-1} > 0, \quad \text{see} \quad (\mathbf{??})$$

Steady state reactions $\frac{\partial \omega_i^*}{\partial \tau_i}$:

$$\frac{\partial \omega_i^*}{\partial \tau_i} = \frac{(1-\beta)}{(1-\beta-\delta)} \Psi_i^{\frac{\delta}{(1-\beta-\delta)}} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}} \frac{\partial \Psi_i}{\partial \tau_i}$$

$$\frac{\partial \Psi_i}{\partial \tau_i} = -\left[\delta_F + \frac{\beta}{1-\beta}\delta\right] \gamma^{\delta_G} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r}\right)^{\delta_F + \frac{\beta}{1-\beta}\delta - 1} \frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \tau_i^{-1}$$

$$= -\left[\delta_F + \frac{\beta}{1-\beta}\delta\right] \gamma^{\delta_G} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r}\right)^{\delta_F + \frac{\beta}{1-\beta}\delta} \tau_i^{-1} = -\left[\delta_F + \frac{\beta}{1-\beta}\delta\right] \Psi_i \tau_i^{-1}$$

$$\frac{\partial \omega_i^*}{\partial \tau_i} = -\frac{(1-\beta)}{(1-\beta-\delta)} \Psi_i^{\frac{\delta}{(1-\beta-\delta)}} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}} \left[\delta_F + \frac{\beta}{1-\beta}\delta\right] \Psi_i \tau_i^{-1}$$

$$= -\left[\frac{(1-\beta)}{(1-\beta-\delta)}\right] \left[\delta_F + \frac{\beta}{1-\beta}\delta\right] \Psi_i^{\frac{1-\beta}{(1-\beta-\delta)}} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}} \tau_i^{-1}$$

$$= -\left[\frac{(1-\beta)}{(1-\beta-\delta)}\right] \left[\delta_F + \frac{\beta}{1-\beta}\delta\right] \omega^* \tau_i^{-1} < 0 \qquad \text{see} \qquad (7)$$

Steady state reactions $\frac{\partial \omega_i^*}{\partial \tau_i^{ex}}$:

$$\frac{\partial \omega_i^*}{\partial \tau_i^{ex}} = \frac{(1-\beta)}{(1-\beta-\delta)} \Psi_i^{\frac{\delta}{(1-\beta-\delta)}} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}} \frac{\partial \Psi_i}{\partial \tau_i^{ex}}$$

$$
\begin{aligned}
\frac{\partial \Psi_i}{\partial \tau_i^{ex}} &= -\left[\delta_F + \frac{\beta}{1-\beta}\delta\right] \gamma^{\delta_G} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r}\right)^{\delta_F + \frac{\beta}{1-\beta}\delta - 1} \frac{\beta}{\tau_i r} \\
&= -\left[\delta_F + \frac{\beta}{1-\beta}\delta\right] \Psi_i (1-\tau_i^{ex})^{-1}
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial \omega_i^*}{\partial \tau_i^{ex}} &= -\frac{(1-\beta)}{(1-\beta-\delta)} \Psi_i^{\frac{\delta}{(1-\beta-\delta)}} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}} \left[\delta_F + \frac{\beta}{1-\beta}\delta\right] \Psi_i (1-\tau_i^{ex})^{-1} \\
&= -\frac{(1-\beta)}{(1-\beta-\delta)} \left[\delta_F + \frac{\beta}{1-\beta}\delta\right] \omega_i^* (1-\tau_i^{ex})^{-1} \qquad \text{see} \qquad (9)
\end{aligned}
$$

Steady state reactions $\frac{\partial \omega_i^*}{\partial \gamma_i}$:

$$
\begin{aligned}
\frac{\partial \omega_i^*}{\partial \gamma_i} &= \frac{(1-\beta)\,\omega_i^*}{(1-\beta-\delta)} \Psi_i^{-1} \frac{\partial \Psi_i}{\partial \gamma_i} \\
\frac{d\Psi_i}{d\gamma_i} &= \delta_G \gamma_i^{\delta_G - 1} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r}\right)^{\delta_F + \frac{\beta}{1-\beta}\delta} \\
&\quad - \left(\delta_F + \frac{\beta}{1-\beta}\delta\right) \gamma_i^{\delta_G} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r}\right)^{\delta_F + \frac{\beta}{1-\beta}\delta - 1} \frac{(1-\tau_i^{ex})\beta}{\tau_i r} \\
&= \delta_G \gamma_i^{-1} \Psi_i - \left(\delta_F + \frac{\beta}{1-\beta}\delta\right) \Psi_i (1-\gamma_i)^{-1} \\
&= \Psi_i \left[\delta_G \gamma_i^{-1} - \left(\delta_F + \frac{\beta}{1-\beta}\delta\right)(1-\gamma_i)^{-1}\right] \\
\frac{\partial \omega_i^*}{\partial \gamma_i} &= \frac{(1-\beta)\,\omega_i^*}{(1-\beta-\delta)} \left[\delta_G \gamma_i^{-1} - \left(\delta_F + \frac{\beta}{1-\beta}\delta\right)(1-\gamma_i)^{-1}\right] \quad \textit{see} \quad (10)
\end{aligned}
$$

Appendix 3: Optimal level of government activities:

$$
\begin{aligned}
\max_{\gamma_i} \quad \omega^* &= \Psi_i^{\frac{(1-\beta)}{(1-\beta-\delta)}} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}} \qquad \Psi_i := \gamma_i^{\delta_G} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r}\right)^{\delta_F + \frac{\beta}{1-\beta}\delta} \\
\frac{\partial \omega_i^*}{\partial \gamma_i} &= \frac{(1-\beta)\,\omega_i^*}{(1-\beta-\delta)} \Psi_i^{-1} \frac{\partial \Psi_i}{\partial \gamma_i} \\
\frac{d\Psi_i}{d\gamma_i} &= \Psi_i \left[\delta_G \gamma_i^{-1} - \left(\delta_F + \frac{\beta}{1-\beta}\delta\right)(1-\gamma_i)^{-1}\right] = 0 \\
\delta_G &= \gamma_i \left(\delta_F + \frac{\beta}{1-\beta}\delta\right)(1-\gamma_i)^{-1} \\
\delta_G &= \gamma_i \left(\delta_F + \frac{\beta}{1-\beta}\delta + \delta_G\right)
\end{aligned}
$$

$$
\gamma_i^* = \frac{\delta_G}{\left(\delta_F + \frac{\beta}{1-\beta}\delta + \delta_G\right)}
$$

$$\frac{\partial \omega_i^*}{\partial \gamma_i} = \frac{\omega_i^*}{1-\delta}\Psi_i^{-1}\frac{\partial \Psi_i}{\partial \gamma_i} \quad \text{with}$$

$$\frac{\partial \Psi_i}{\partial \gamma_i} \begin{cases} > 0 & \gamma_i < \gamma_i^* \quad \text{underinvestment, undertaxation} \\ = 0 \quad \text{for} & \gamma_i = \gamma_i^* \quad \text{growth maximizing tax rate} \\ < 0 & \gamma_i > \gamma_i^* \quad \text{overinvestment, overtaxation} \end{cases}$$

8 Annotation

These annotation include all detailled steps of calculation for the convinience of the referee.

Appendix 1: determining the aggregate production level of the region:

$$\begin{aligned}
y_i &= A_i H_i^{\alpha} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} y_i \right)^{\beta} K_i^{1-\alpha-\beta} \\
y_i^{1-\beta} &= A_i H_i^{\alpha} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \right)^{\beta} K_i^{1-\alpha-\beta} \\
y_i &= A_i{}^{\frac{1}{1-\beta}} H_i^{\frac{\alpha}{1-\beta}} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \right)^{\frac{\beta}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \\
Y_i &= \frac{y_i}{A^{\frac{1}{1-\beta}}} \quad \text{hence} \quad Y_i = \omega_i{}^{\frac{1}{1-\beta}} H_i^{\frac{\alpha}{1-\beta}} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \right)^{\frac{\beta}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}}
\end{aligned}$$

Appendix 2: Steady state determination and reactions of ω_i^* when H_i, K_i, τ_i, τ_i^{ex} and γ are changing:

Solve for $\dot{\omega}$ by plugging in:

$$\begin{aligned}
\dot{\omega}_i(t) &= G(t)_i^{\delta_G} F(t)_i^{\delta_F} - \omega(t), \\
\dot{\omega}_i(t) &= (\gamma y(t)_i)^{\delta_G} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} y(t)_i \right)^{\delta_F} - \omega(t) \\
\dot{\omega}_i(t) &= \gamma^{\delta_G} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \right)^{\delta_F} y(t)_i^{\delta_G+\delta_F} - \omega(t) \\
\dot{\omega}_i(t) &= \gamma^{\delta_G} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \right)^{\delta_F} y(t)_i^{\delta} - \omega(t)
\end{aligned}$$

$$y_i = \omega_i^{\frac{1}{1-\beta}} H_i^{\frac{\alpha}{1-\beta}} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \right)^{\frac{\beta}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}}$$

$$\begin{aligned}
\dot{\omega}_i(t) &= \gamma^{\delta_G} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \right)^{\delta_F} \\
&\quad \left[\omega(t)_i^{\frac{1}{1-\beta}} H_i^{\frac{\alpha}{1-\beta}} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \right)^{\frac{\beta}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \right]^{\delta} - \omega(t) \\
\dot{\omega}_i(t) &= \gamma^{\delta_G} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \right)^{\delta_F} \\
&\quad \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \right)^{\frac{\beta}{1-\beta}\delta} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \right]^{\delta} \omega(t)_i^{\frac{\delta}{1-\beta}} - \omega(t)
\end{aligned}$$

$$\dot{\omega}_i(t) = \gamma^{\delta_G}\left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r}\right)^{\delta_F+\frac{\beta}{1-\beta}\delta}\left[H_i^{\frac{\alpha}{1-\beta}}K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\delta}\omega(t)_i^{\frac{\delta}{1-\beta}}-\omega(t).$$

$$\frac{d\dot{\omega}_i(t)}{d\omega(t)} = \frac{\delta}{1-\beta}\Psi_i\left[H_i^{\frac{\alpha}{1-\beta}}K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\delta}\omega(t)_i^{\frac{\delta-1+\beta}{1-\beta}}-1<0$$

as H_i and K_i are assumed to be suff. small

To simplify, this equation is rewritten as

$$\dot{\omega}_i(t) = \Psi_i\left[H_i^{\frac{\alpha}{1-\beta}}K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\delta}\omega(t)^{\frac{\delta}{1-\beta}}-\omega(t) \qquad \text{see} \qquad (5)$$

$$\text{with} \quad \Psi_i \quad : \quad =\gamma^{\delta_G}\left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r}\right)^{\delta_F+\frac{\beta}{1-\beta}\delta}. \qquad \text{see} \qquad (32)(32)$$

solve for the steady state position:

$$\begin{aligned}
0 &= \dot{\omega}_i(t)\\
0 &= \Psi_i\left[H_i^{\frac{\alpha}{1-\beta}}K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\delta}\omega^{\frac{\delta}{1-\beta}}-\omega\\
\omega &= \Psi_i\left[H_i^{\frac{\alpha}{1-\beta}}K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\delta}\omega^{\frac{\delta}{1-\beta}}\\
\omega^{1-\frac{\delta}{1-\beta}} &= \Psi_i\left[H_i^{\frac{\alpha}{1-\beta}}K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\delta}\\
\omega^{\frac{1-\beta-\delta}{1-\beta}} &= \Psi_i\left[H_i^{\frac{\alpha}{1-\beta}}K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\delta}\\
\omega^* &= \Psi_i^{\frac{(1-\beta)}{(1-\beta-\delta)}}\left[H_i^{\frac{\alpha}{1-\beta}}K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}}
\end{aligned}$$

$$\begin{aligned}
\Psi_i^{\frac{(1-\beta)}{(1-\beta-\delta)}} &= \left[\gamma_i^{\delta_G}\left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r}\right)^{\delta_F+\frac{\beta}{1-\beta}\delta}\right]^{\frac{(1-\beta)}{(1-\beta-\delta)}}\\
&= \gamma^{\delta_G\frac{(1-\beta)}{(1-\beta-\delta)}}\left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r}\right)^{\left(\delta_F+\frac{\beta}{1-\beta}\delta\right)\frac{(1-\beta)}{(1-\beta-\delta)}}\\
&= \gamma^{\delta_G\frac{(1-\beta)}{(1-\beta-\delta)}}\left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r}\right)^{\delta_F\frac{(1-\beta)}{(1-\beta-\delta)}+\frac{\beta}{1-\beta}\delta\frac{(1-\beta)}{(1-\beta-\delta)}}\\
&= \gamma_i^{\delta_G\frac{(1-\beta)}{(1-\beta-\delta)}}(\varphi_i)^{\frac{\delta_F(1-\beta)+\delta\beta}{(1-\beta-\delta)}}
\end{aligned}$$

$$\omega_i^* = \gamma_i^{\delta_G\frac{(1-\beta)}{(1-\beta-\delta)}}(\varphi_i)^{\frac{\delta_F(1-\beta)+\delta\beta}{(1-\beta-\delta)}}\left[H_i^{\frac{\alpha}{1-\beta}}K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}} \qquad \text{see} \qquad (6)$$

Steady state reactions $\frac{\partial \omega_i^*}{\partial K_i}$:

$$\omega_i^* = \Psi_i^{\frac{(1-\beta)}{(1-\beta-\delta)}} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}}$$

$$\begin{aligned}
\frac{\partial \omega_i^*}{\partial K_i} &= \frac{\delta(1-\beta)}{1-\beta-\delta} \frac{1-\beta-\alpha}{1-\beta} \Psi_i^{\frac{1-\beta}{1-\beta-\delta}} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}-1} K_i^{\frac{1-\beta-\alpha}{1-\beta}-1} H_i^{\frac{\alpha}{1-\beta}} \\
&= \frac{\delta\,(1-\beta-\alpha)}{1-\beta-\delta} \Psi_i^{\frac{1-\beta}{1-\beta-\delta}} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}-1} K_i^{\frac{-\alpha}{1-\beta}} H_i^{\frac{\alpha}{1-\beta}} \\
&= \frac{\delta(1-\beta-\alpha)}{1-\beta-\delta} \Psi_i^{\frac{1-\beta}{1-\beta-\delta}} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}-1} K_i^{\frac{-\alpha}{1-\beta}} H_i^{\frac{\alpha}{1-\beta}}
\end{aligned}$$

$$\begin{aligned}
&= \frac{\delta(1-\beta-\alpha)}{1-\beta-\delta} \omega_i^* \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \right]^{-1} K_i^{\frac{-\alpha}{1-\beta}} H_i^{\frac{\alpha}{1-\beta}} \\
&= \frac{\delta(1-\beta-\alpha)}{1-\beta-\delta} \omega_i^* K_i^{-\frac{1-\beta-\alpha}{1-\beta}} K_i^{\frac{-\alpha}{1-\beta}} \\
&= \frac{\delta(1-\beta-\alpha)}{1-\beta-\delta} \omega_i^* K_i^{\frac{-1+\beta+\alpha-\alpha}{1-\beta}} \\
&= \frac{\delta(1-\beta-\alpha)}{1-\beta-\delta} \omega_i^* K_i^{-\frac{1-\beta}{1-\beta}} \\
&= \frac{\delta(1-\beta-\alpha)}{1-\beta-\delta} \omega_i^* K_i^{-1} > 0, \quad \text{see} \quad (\textbf{??})
\end{aligned}$$

Steady state reactions $\frac{\partial \omega_i^*}{\partial \tau_i}$:

$$\frac{\partial \omega_i^*}{\partial \tau_i} = \frac{(1-\beta)}{(1-\beta-\delta)} \Psi_i^{\frac{\delta}{(1-\beta-\delta)}} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}} \frac{\partial \Psi_i}{\partial \tau_i}$$

$$\begin{aligned}
\frac{\partial \Psi_i}{\partial \tau_i} &= -\left[\delta_F + \frac{\beta}{1-\beta}\delta \right] \gamma^{\delta_G} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\,\beta}{\tau_i r} \right)^{\delta_F + \frac{\beta}{1-\beta}\delta - 1} \frac{(1-\tau_i^{ex})(1-\gamma_i)\,\beta}{\tau_i r} \tau_i^{-1} \\
&= -\left[\delta_F + \frac{\beta}{1-\beta}\delta \right] \gamma^{\delta_G} \left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\,\beta}{\tau_i r} \right)^{\delta_F + \frac{\beta}{1-\beta}\delta} \tau_i^{-1} = -\left[\delta_F + \frac{\beta}{1-\beta}\delta \right] \Psi_i \tau_i^{-1}
\end{aligned}$$

$$
\begin{aligned}
\frac{\partial \omega_i^*}{\partial \tau_i} &= -\frac{(1-\beta)}{(1-\beta-\delta)}\Psi_i^{\frac{\delta}{(1-\beta-\delta)}}\left[H_i^{\frac{\alpha}{1-\beta}}K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}}\left[\delta_F+\frac{\beta}{1-\beta}\delta\right]\Psi_i\tau_i^{-1} \\
&= -\left[\frac{(1-\beta)}{(1-\beta-\delta)}\right]\left[\delta_F+\frac{\beta}{1-\beta}\delta\right]\Psi_i^{\frac{\delta+1-\beta-\delta}{(1-\beta-\delta)}}\left[H_i^{\frac{\alpha}{1-\beta}}K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}}\tau_i^{-1} \\
&= -\left[\frac{(1-\beta)}{(1-\beta-\delta)}\right]\left[\delta_F+\frac{\beta}{1-\beta}\delta\right]\Psi_i^{\frac{1-\beta}{(1-\beta-\delta)}}\left[H_i^{\frac{\alpha}{1-\beta}}K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}}\tau_i^{-1} \\
&= -\left[\frac{(1-\beta)}{(1-\beta-\delta)}\right]\left[\delta_F+\frac{\beta}{1-\beta}\delta\right]\Psi_i^{\frac{1-\beta}{(1-\beta-\delta)}}\left[H_i^{\frac{\alpha}{1-\beta}}K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}}\tau_i^{-1} \\
&= -\left[\frac{(1-\beta)}{(1-\beta-\delta)}\right]\left[\delta_F+\frac{\beta}{1-\beta}\delta\right]\omega^*\tau_i^{-1}<0 \qquad \text{see} \qquad (7)
\end{aligned}
$$

Steady state reactions $\frac{\partial \omega_i^*}{\partial \tau_i^{ex}}$:

$$
\begin{aligned}
\frac{\partial \omega_i^*}{\partial \tau_i^{ex}} &= \frac{(1-\beta)}{(1-\beta-\delta)}\Psi_i^{\frac{\delta}{(1-\beta-\delta)}}\left[H_i^{\frac{\alpha}{1-\beta}}K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}}\frac{\partial \Psi_i}{\partial \tau_i^{ex}} \\
\omega_i^* &= \Psi_i^{\frac{(1-\beta)}{(1-\beta-\delta)}}\left[H_i^{\frac{\alpha}{1-\beta}}K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}}
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial \Psi_i}{\partial \tau_i^{ex}} &= -\left[\delta_F+\frac{\beta}{1-\beta}\delta\right]\gamma^{\delta_G}\left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r}\right)^{\delta_F+\frac{\beta}{1-\beta}\delta-1}\frac{\beta}{\tau_i r} \\
&= -\left[\delta_F+\frac{\beta}{1-\beta}\delta\right]\gamma^{\delta_G}\left(\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r}\right)^{\delta_F+\frac{\beta}{1-\beta}\delta-1}\frac{(1-\tau_i^{ex})(1-\gamma_i)\beta}{\tau_i r} \\
&= -\left[\delta_F+\frac{\beta}{1-\beta}\delta\right]\Psi_i(1-\tau_i^{ex})^{-1}
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial \omega_i^*}{\partial \tau_i^{ex}} &= -\frac{(1-\beta)}{(1-\beta-\delta)}\Psi_i^{\frac{\delta}{(1-\beta-\delta)}}\left[H_i^{\frac{\alpha}{1-\beta}}K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}}\left[\delta_F+\frac{\beta}{1-\beta}\delta\right]\Psi_i(1-\tau_i^{ex})^{-1} \\
&= -\frac{(1-\beta)}{(1-\beta-\delta)}\Psi_i^{\frac{\delta}{(1-\beta-\delta)}+1}\left[H_i^{\frac{\alpha}{1-\beta}}K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}}\left[\delta_F+\frac{\beta}{1-\beta}\delta\right](1-\tau_i^{ex})^{-1} \\
&= -\frac{(1-\beta)}{(1-\beta-\delta)}\Psi_i^{\frac{\delta}{(1-\beta-\delta)}+\frac{(1-\beta-\delta)}{(1-\beta-\delta)}}\left[H_i^{\frac{\alpha}{1-\beta}}K_i^{\frac{1-\beta-\alpha}{1-\beta}}\right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}}\left[\delta_F+\frac{\beta}{1-\beta}\delta\right](1-\tau_i^{ex})^{-1} \\
\frac{\partial \omega_i^*}{\partial \tau_i^{ex}} &= -\frac{(1-\beta)}{(1-\beta-\delta)}\left[\delta_F+\frac{\beta}{1-\beta}\delta\right]\omega_i^*(1-\tau_i^{ex})^{-1} \qquad \text{see} \qquad (9)
\end{aligned}
$$

Steady state reactions $\frac{\partial \omega_i^*}{\partial \gamma_i}$:

$$
\begin{aligned}
\frac{\partial \omega_i^*}{\partial \gamma_i} &= \frac{(1-\beta)\,\omega_i^*}{(1-\beta-\delta)} \Psi_i^{-1} \frac{\partial \Psi_i}{\partial \gamma_i} \\
\frac{d\Psi_i}{d\gamma_i} &= \delta_G \gamma_i^{\delta_G - 1} \left(\frac{(1-\tau_i^{ex})\,(1-\gamma_i)\,\beta}{\tau_i r} \right)^{\delta_F + \frac{\beta}{1-\beta}\delta} \\
&\quad - \left(\delta_F + \frac{\beta}{1-\beta}\delta \right) \gamma_i^{\delta_G} \left(\frac{(1-\tau_i^{ex})\,(1-\gamma_i)\,\beta}{\tau_i r} \right)^{\delta_F + \frac{\beta}{1-\beta}\delta - 1} \frac{(1-\tau_i^{ex})\beta}{\tau_i r} \\
&= \delta_G \gamma_i^{-1} \Psi_i - \left(\delta_F + \frac{\beta}{1-\beta}\delta \right) \Psi_i \,(1-\gamma_i)^{-1} \\
&= \Psi_i \left[\delta_G \gamma_i^{-1} - \left(\delta_F + \frac{\beta}{1-\beta}\delta \right) (1-\gamma_i)^{-1} \right] \\
\frac{\partial \omega_i^*}{\partial \gamma_i} &= \frac{(1-\beta)\,\omega_i^*}{(1-\beta-\delta)} \left[\delta_G \gamma_i^{-1} - \left(\delta_F + \frac{\beta}{1-\beta}\delta \right) (1-\gamma_i)^{-1} \right] \quad \textit{see} \quad (10)
\end{aligned}
$$

Appendix 3: Optimal level of government activities:

$$
\begin{aligned}
\max_{\gamma_i} \quad \omega^* &= \Psi_i^{\frac{(1-\beta)}{(1-\beta-\delta)}} \left[H_i^{\frac{\alpha}{1-\beta}} K_i^{\frac{1-\beta-\alpha}{1-\beta}} \right]^{\frac{\delta(1-\beta)}{(1-\beta-\delta)}} \qquad \Psi_i := \gamma_i^{\delta_G} \left(\frac{(1-\tau_i^{ex})\,(1-\gamma_i)\,\beta}{\tau_i r} \right)^{\delta_F + \frac{\beta}{1-\beta}\delta} \\
\frac{\partial \omega_i^*}{\partial \gamma_i} &= \frac{(1-\beta)\,\omega_i^*}{(1-\beta-\delta)} \Psi_i^{-1} \frac{\partial \Psi_i}{\partial \gamma_i} \\
\frac{d\Psi_i}{d\gamma_i} &= \Psi_i \left[\delta_G \gamma_i^{-1} - \left(\delta_F + \frac{\beta}{1-\beta}\delta \right) (1-\gamma_i)^{-1} \right] = 0 \\
\delta_G &= \gamma_i \left(\delta_F + \frac{\beta}{1-\beta}\delta \right) (1-\gamma_i)^{-1} \\
(1-\gamma_i)\,\delta_G &= \gamma_i \left(\delta_F + \frac{\beta}{1-\beta}\delta \right) \\
\delta_G - \gamma_i \delta_G &= \gamma_i \left(\delta_F + \frac{\beta}{1-\beta}\delta \right) \\
\delta_G &= \gamma_i \left(\delta_F + \frac{\beta}{1-\beta}\delta + \delta_G \right)
\end{aligned}
$$

$$
\gamma_i^* = \frac{\delta_G}{\left(\delta_F + \frac{\beta}{1-\beta}\delta + \delta_G \right)}
$$

$$
\frac{\partial \omega_i^*}{\partial \gamma_i} = \frac{\omega_i^*}{1-\delta} \Psi_i^{-1} \frac{\partial \Psi_i}{\partial \gamma_i} \quad \text{with}
$$

$$
\frac{\partial \Psi_i}{\partial \gamma_i} \begin{cases} > 0 & \gamma_i < \gamma_i^* \quad \text{underinvestment, undertaxation} \\ = 0 \quad \text{for} & \gamma_i = \gamma_i^* \quad \text{growth maximizing tax rate} \\ < 0 & \gamma_i > \gamma_i^* \quad \text{overinvestment, overtaxation} \end{cases}
$$