Human capital and growth:
What can we learn from micro-data?
Evidence from Taiwan (1976-95)[1]

Sylvie Démurger
CERDI-IDREC, CNRS-Université d'Auvergne
S.Demurger@cerdi.u-clermont1.fr

Martin Fournier
CERDI-IDREC (Université d'Auvergne), CREST-INSEE and DELTA
M.Fournier@cerdi.u-clermont1.fr

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Abstract: This paper uses micro-data to define aggregate human capital stock indicators and proposes various specifications to test for the role of human capital accumulation on economic growth. An empirical evaluation on the Taiwanese experience over the 1975-96 period suggests that: *(i)* the use of alternative human capital measures does not allow for the identification of significant differences with usual indicators when estimating the direct contribution of human capital accumulation to economic growth, *(ii)* specifying indirect channels through which human capital accumulation may affect economic growth allows for a clear identification of external effects arising through intersectoral interactions.

Keywords: economic growth, human capital, experience, externality, Taiwan.

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Résumé : Cet article utilise l'information disponible dans les bases de données micro-économiques pour définir des indicateurs agrégés de stock de capital humain et propose diverses spécifications afin d'évaluer le rôle de l'accumulation de capital humain dans la croissance économique. Une évaluation empirique sur l'expérience taiwanaise au cours de la période 1975-96 suggère que : *(i)* l'utilisation de mesures alternatives de capital humain ne permet pas d'identifier de différence significative par rapport aux indicateurs usuels dans l'estimation de la contribution directe de l'accumulation de capital humain à la croissance économique, *(ii)* la spécification des canaux indirects par lesquels l'accumulation de capital humain peut influer sur la croissance économique permet une identification claire d'effets d'externalité provenant de l'interaction entre les secteurs industriels.

Mots-clés : croissance économique, capital humain, expérience, externalités, Taiwan.

1. Introduction

Recent developments in growth theory give an important place to human capital as one of the main factors of economic growth. From a theoretical point of view, both its impact on rising productivity and on the development of innovation/imitation activity are stressed. However, contrasted results found in the empirical literature[2] tend to raise the question of the definition and measurement of human capital variables[3] as well as that of the specification of the estimated relation[4]. Indeed, three main issues seem to call for more attention in evaluation procedures: *(i)* What are the underlying hypotheses implied by usual human capital variables? *(ii)* What other dimensions than education should enter human capital measures? *(iii)* What are the channels through which human capital accumulation can affect economic growth? This paper attempts to evaluate potential biases arising from usual human capital indicators and potential improvements which may be derived from the 3 points mentioned above.

If one accepts the hypothesis of perfect adequation between education and human capital, setting aside measurement issues, the question of how to construct this variable remains open. Indeed, taking the average level of schooling in the whole population (or in the working population) has strong theoretical implication. It implies that schooling years can be summed across individuals: in the absence of a weighting scheme, any individual observed with four years of schooling will be strictly equivalent to two individuals with two years of schooling. The use of the average schooling years observed in the population thus results in making a very strong *ad hoc* hypothesis concerning the existing underlying link between education and productivity at the individual level. Moreover, educational expansion usually

[2] See for instance Benhabib and Spiegel (1994), Islam (1995) and Pritchett (1996).

[3] Gurgand (1998).

[4] Berthélemy, Dessus and Varoudakis (1997).

induces strong effects on the distribution of education among the population which effect cannot be taken into account by changes in the average education level.

The question of the composition of human capital variables is seldom raised and most macro-economic analyses of growth consider that human capital stocks can be represented by the observed education level of the population. Even though education in the working population is undoubtedly one of the major factor of human capital accumulation, it may however seem limiting to consider that human capital can be reduced to the observed average number of schooling years. Indeed, other key factors are likely to play a part in the rise of individual productivity such as experience, job tenure or health and micro-economic analyses strongly suggest that, in particular, experience can be considered as a major factor in the formation of individual human capital (Becker, 1964; Mincer, 1974). Moreover, productivity associated with this factor is commonly identified through the estimation of individual income functions. From a macro-economic point of view, taking into account experience directly refers to the idea of "learning by doing" developed in recent endogenous growth theories. From the empirical side, the development process of East Asian countries seems consistent with this idea since, besides a strong increase in the average education level, these countries also experienced a rapid demographic transition and consequently a rapid change in the distribution of age and experience[5]. Taking explicitly into account experience in the accumulation or destruction of human capital thus seems important in order to evaluate the global impact of human capital in the growth process.

The third issue mentioned at the beginning of this section concerns the identification of different channels through which human capital accumulation can influence growth. By creating a more productive labour force and endowing it with knowledge and skills, human capital accumulation contributes directly to economic growth. Yet, its role is not limited to

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[5] World Bank (1993).

this direct effect and may appear through indirect channels. As mentioned above, "learning-by-doing" or "on the job training" (Lucas, 1993) is one of the channels through which human capital can affect growth and one way to address this issue is to account for experience when measuring human capital. Recent growth theory developments have also emphasised the externalities related to human capital expansion. As stressed by Lucas (1988), the average level of human capital in a population can also affect the productivity of each individual within the group through interactions and "learning by watching". Recent theoretical developments have thus emphasised the potential role of externalities related to human capital expansion. Despite the renewed theoretical interest in clarifying the channels through which human capital may influence economic growth, empirical studies based on aggregate data mainly focus on the direct relation between human capital and growth and do not explicitly take into account indirect channels mentioned above.

This short discussion makes it clear that developing the three points mentioned above implies getting access to more information than can usually be found in macro-data. In this paper we explore potential improvements which can be derived from two types of disaggregated data: micro-data and sectoral macro-data. To answer questions raised by the first two points mentioned above, we propose an alternative methodology consisting in using available information at the micro-level to build new aggregated human capital indicators. Concerning the third point, the use of disaggregated data at the sectoral level allows for direct specification and evaluation of external effect between different sectors of the economy. For most countries, an obvious drawback of this approach concerns the lack of disaggregated information on a sufficient length of time, allowing for the estimation of macro-economic production functions. This exercise however finds a privileged field of application in the case of Taiwan for which available micro-level information as well as sectoral data cover a remarkably long period and can be related to a rapid and human capital intensive growth process.

The second section presents the major evolution which occurred in Taiwan over the 1976-95 period. This experience of high growth combined with rapid education expansion and strong demographic changes makes this country a good candidate in order to evaluate biases induced by the use of usual human capital measures and specification. The third section presents the construction methodology for alternative measures of human capital stock, which we then apply to the Taiwan case over the 1976-95 period. The fourth section discusses the use of sectoral data in identifying external effects related to human capital accumulation and provides estimation results for sectoral production functions in Taiwan. Finally, section 5 proposes a growth decomposition exercise, which allows for an evaluation of the sensitivity of results concerning the role of human capital with respect to various alternative definitions and specifications.

2. Economic development in Taiwan: some stylised facts

2.1. Economic growth and industrial structure

The Taiwanese growth process is commonly referred to as a success example of economic development. Indeed, since the settlement of the Republic of China in Taiwan in 1949, growth rates have kept very high and sustained, the economic structure has experienced strong changes and the whole population largely benefited from these high growth rates[6]. Indeed, Taiwan has had among the world's highest growth rate since the beginning of the 50s

[6] Numerous studies have presented the Taiwanese "miracle" among which Fei, Ranis and Kuo (1979) and, more recently, Dessus, Shea and Shi (1995).

with an average annual growth rate of per capita GDP above 6% over the 1951-96 period. Moreover, the growth process has been remarkably sustained despite the strong shocks which hit the world's economy over this period.

This growth process has been accompanied and allowed by strong sectoral changes. As can be seen in Table 1, the share of agriculture in GDP has rapidly declined to the benefit of manufacture up to the 80s, when the tertiary sector has become the most dynamic sector[7].

(Table 1 around here)

In the vast literature developed around explanations for the "Asian miracle", a number of studies, based on the growth accounting framework (Denison, 1967) have tried to evaluate the share of economic growth which can be imputed to factor accumulation and the share due to total factor productivity growth[8]. In the case of Taiwan, this decomposition leads to a measured contribution for total factor productivity growth around 50%, the range of measures being from 1/3 to 3/4[9]. Following Young (1992) however, a controversy has risen on the magnitude of total factor productivity growth in East-Asia, which led some authors to claim that the growth process in the region was mainly of an extensive nature while other argue that it has been based on productivity improvement[10]. Beyond the controversy however, whatever computing method is used, different studies agree on one main, conclusion: rising human capital stock, measured by average educational attainment, has had a major positive impact on productivity and thus on growth.

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[7] Moreover, within manufacture, highest growth rates have been experienced by the most technology intensive sectors, such as electronics.

[8] For the Taiwanese case, see in particular Kuo (1983), Fry (1990), Pack (1992), Tallman and Wang (1994) and Bosworth and Collins (1996).

[9] See Dessus (1998) for a recent survey on this issue.

2.2. Population structure and education

The Taiwanese development process is characterised by strong changes in the population structure and particularly in the educational and age structure. Indeed, education has always been one of the major focus of the Taiwanese government, which tried to keep the educational system in relation with the rising need for educated labour induced by growing manufacturing and services sectors. Among important measures, one can recall the implementation of *Manpower Development Plans* from 1966 onwards and the rise from 6 to 9 years of free and compulsory education in 1968. A point of importance here also concerns the distribution of investments in the educational system, which have first focused on primary schooling, then on secondary education and finally on higher education[11]. This policy resulted in a dramatic increase in enrolment rates[12], a rapid decline of male/female differential in access to higher education (Liu, 1992) and a fast rise in the average education of the labour force. Thus, high investments in education led to a rise in the average number of years of schooling of people aged 15 and above from 2.7 years in 1951 to 9.7 in 1995[13]. Moreover, investment in education has not only led to increasing education level but also to a rise in quality as shown by the strong increase in the number of teachers per student as well as in total expenditure per student (Liu, 1992; Dessus, 1998).

A second important feature about the evolution of the Taiwanese population structure concerns changes in the age structure. Indeed, Taiwan's development and rising female education have been accompanied by a rapid decline in fertility which in turn induced a rise in the average age of the population. This evolution induced an increase from 17.1 years of

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[10] Felipe (1999).

[11] See Woo (1991) for a full description of public investments in the educational system.

[12] From 1950 to 1990, gross enrolment rates have risen from 85% to 100% for primary education, from 20% to 85% for secondary education and from 1% to 19% for higher education (Dessus, 1998).

potential experience among working individuals in 1976 up to 19.6 years in 1995. Moreover, rising school enrolment and female participation together with a decrease in retirement age deeply changed the overall population structure within working individuals, especially concerning the joint distribution of education and experience. Indeed, as investment in education induced an inflow of young educated workers, with low experience, the demographic transition led to a concentration of experience among older and less educated workers.

The Taiwanese case thus appears as a natural candidate for the evaluation of potential biases induced by usual indicators and specifications in measures of human capital contribution to growth. Indeed, rapid increase in average education and experience have occurred during a phase of sustained growth and the Taiwanese remarkable growth process has led some authors to emphasise the need to identify and quantify externality phenomenon besides pure accumulation process (Lucas, 1993). Moreover, the choice of Taiwan as an illustrative example also provides a strong technical motivation since available micro and sectoral data cover a remarkably long period compared to most developing as well as developed countries, a period over which dramatic structural changes have been taking place on GDP growth as well as on education and age structure. Since data limitation is one of the major constraints when trying to further identify mechanisms underlying the relation between human capital accumulation and growth, the empirical application computed here can be taken as a benchmark to evaluate how much can be learned from the use of micro and disaggregated data.

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[13] The 1951 figure comes from Chang (1991), the 1995 figure comes from authors' calculations made on the 1995 DGBAS household survey.

3. Alternative measures for human capital stock

3.1. Construction method

General methodology

As has already been stressed above, the measurement of human capital stock raises a number of questions for estimating macro-economic production functions, which deal with implicit aggregation hypothesis inherent to specific indicators as well as with the dimensions to include into the notion of human capital.

In order to answer, at least partially, to these questions, we need to get information on the aggregation procedure of individual human capital into aggregate human capital stock as well as on the interaction between the different dimensions we wish to include in this notion. Such information does not exist at a macro-economic level but can be found through the use of micro-economic surveys.

The procedure for building alternative aggregate human capital indicators is the following. We first estimate income functions at the individual level through the usual mincerian form:

(1) $$\ln(y_i) = a.educ_i + b.exp_i + g.exp_i^2 + d.X_i + e_i$$

where *y* represents individual income, *educ* the number of schooling years, *exp* the number of years of potential experience[14] and *X* a vector of additional explanatory variables[15]. Under the hypothesis of remuneration of labour at its marginal productivity, estimation results allow for

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[14] Potential experience is defined as the difference between observed age and age at time of leaving the educational system.

a determination of the productivity ratio between two individuals with different education levels (*educ* and *educ'*) and identical with respect to all other characteristics:

(2) $$p_{(educ/educ')} = \frac{e^{a.educ}}{e^{a.educ'}}$$

This provides a weighting scheme for education at the individual level and thus allows for the computation of the following human capital stock over the whole working population:

(3) $$H_1 = \sum_i e^{(a.educ_i)}$$

This measure answers usual critics about the implicit aggregation hypothesis since it actually refers to a stock of human capital[16] where individual labour is weighted in a way consistent with observed differences in productivity induced by differences in education[17]. It should be noticed here that the mincerian formulation (with $a > 0$) implies that the indicator is more sensitive to a rise in education at the top of the educational distribution than to the same rise occurring in the bottom of the distribution. In other words, the growth rate of H_1 is all the more important that education rises in the high levels, whereas the usual indicator computed as an average level of education is only sensitive to the overall rise in total education years.

Income functions estimations also allow for an extension of human capital indicators to include experience. Indeed, the first part of equation (1) ($a.educ_i + b.exp_i + g.exp_i^2$) can be considered as an indicator of individual human capital incorporating education as well as experience[18]. Thus, under the remuneration at marginal productivity hypothesis, the productivity ratio between two identical individuals except for education (*educ* and *educ'*) and experience (*exp* and *exp'*) is given by:

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[15] Additional variables included for the empirical application to Taiwan are: a sex dummy, urbanisation dummies and relation to household head dummies. We do not need to correct for potential selection bias here since we only want our weighting scheme for human capital to cover the working population.
[16] Human capital stock is to be understood here in its broad sense including labour.
[17] The weighting scheme is based on individuals with no education, which contribution is assumed unitary.
[18] This formulation actually defines substitutability between these two factors at the individual level.

(4) $$\tilde{p}_{hk/hk'} = e^{a\,(educ-educ')+b\,(exp-exp')+g\,(exp^2-exp'^2)}$$

Equation (4) provides a new weighting scheme, which leads to a second indicator for human capital stock among the working population:

(5) $$H_2 = \sum_i e^{a\,.educ_i+b\,.exp_i+g\,.exp_i^2}$$

The human capital unit in H_2 is then an individual with no education and no experience and the aggregation scheme proposed in equation (5) allows to take into account interactions between the two dimensions of human capital at the individual level. H_2 thus incorporates available information on marginal distributions of education and experience in the working population as well as information on the joint distribution of these two factors. This last remark is of strong interest in the case of a rapid rise in education as observed in Taiwan, since increasing average education is induced by higher education of youngsters with less working experience.

Alternative specifications

Income functions specification used to derive weighting schemes for human capital measures can be extended in different ways in order to take account of a variety of weighting schemes as wide as possible. A more flexible specification can thus be written as follows:

(6) $$\ln(y_i) = a_1.educ_i + a_2.educ_i^2 + b_1.exp_i + b_2.exp_i^2 + b_3.exp_i^3 + d'.X_i + e_i^{'}$$

in which polynomials of order two are introduced for education and of order three for potential experience. This specification leads to two alternative human capital stock indicators defined as follows:

(7) $$H_3 = \sum_i e^{a_1.educ_i+a_2.educ_i^2}$$

(8) $$H_4 = \sum_i e^{a_1.educ_i + a_2.educ_i^2 + b_1.exp_i + b_2.exp_i^2 + b_3.exp_i^3}$$

Another specification can be estimated using education level dummies instead of schooling years. The information available in the Taiwanese household surveys distinguish 7 different educational levels (no education, primary school, junior high school, senior high school, junior college, university and graduate school), which leads to estimating the following specification, where ed^k is a dummy variable for education level k:

(9) $$\ln(y_i) = \sum_i a_k.ed_i^k + b_1^{'}.exp_i + b_2^{'}.exp_i^2 + b_3^{'}.exp_i^3 + d^{''}.X_i + e_i^{''}$$

This specification gives two new measures for human capital stock:

(10) $$H_5 = \sum_i e^{\sum_k a_k.ed_i^k}$$

(11) $$H_6 = \sum_i e^{\sum_k a_k.ed_i^k + b_1^{'}.exp_i + b_2^{'}.exp_i^2 + b_3^{'}.exp_i^3}$$

The last specification tried here allows for direct interaction between education and experience at the individual level as follows:

(12) $$\begin{aligned} \ln(y_i) &= a_1^{'}.educ_i + a_2^{'}.educ_i^2 + b_1^{''}.exp_i + b_2^{''}.exp_i^2 \\ &\quad + g^{'}.(educ_i.exp_i) + d^{'''}.X_i + e_i^{'''} \end{aligned}$$

which in turns provides a last human capital stock indicator:

(13) $$H_7 = \sum_i e^{a_1^{'}.educ_i + a_2^{'}.educ_i^2 + b_1^{''}.exp_i + b_2^{''}.exp_i^2 + g^{'}.(educ_i.exp_i)}$$

Finally, as our objective is to identify potential differences between various indicators in measuring the role of human capital accumulation in growth, we take as a reference the usual indicator provided by the average number of schooling years H_0 computed from household surveys:

(14) $$H_0 = \sum_i educ_i \Big/ N$$

where N refers to the total number of working individuals.

3.2. Human capital stock indicators for Taiwan: 1976-95

Available micro-data in Taiwan cover the period from 1976 to 1995. Data, which come from annual household surveys, cover 30,000 to 50,000 individuals at working age and give accurate information[19] on education and age structures, and individual income. We estimated different specifications for individual income functions for 7 secondary and tertiary sectors[20] ["manufacturing" (sector 1), "electricity, gas and water" (sector 2), "construction" (sector 3), "commerce" (sector 4), "transport, storage and communication" (sector 5), "finance, insurance, real estate and business services" (sector 6) and "community, social and personal services" (sector 7)] and derived 7 different measures for human capital stocks for each sector using the methodology described in equations (1) to (13).

The 20 available micro-surveys have been used to compute annual human capital stock measures, however, income functions coefficients have been estimated on pooled data with year dummies. Indeed, the temporal evolution of coefficients[21] cannot be taken into account here since this evolution also reflects in a great part changes due to technical progress[22]. Estimated coefficients are then used to compute human capital stocks H_1 to H_7 on annual household surveys. These indicators are expressed in per capita terms and weighted by

[19] These are repeated cross-section, which representativity and high statistical accuracy have been discussed among others by Deaton and Paxson (1993).

[20] Primary sectors have been excluded from the subsequent growth analysis (sections 4 and 5) for an obvious heterogeneity reason. Moreover, we did not find any information on capital accumulation for agriculture.

[21] See Bourguignon, Fournier and Gurgand (1998) for a discussion on the evolution of estimated coefficients in income functions in Taiwan.

[22] An interesting dimension of this evolution would however be changes in the quality of education and experience but this effect cannot be distinguished from technical progress or market equilibrium evolution.

total labour in sectors (total employment times average number of hours worked) available at the macro level[23].

Income function estimations are consistent with usual results for Taiwan on the period studied[24]. However, strong differences can be noted between sectors concerning returns to education and experience as shown in Table 2 for the estimation of equation (1)[25].

(Table 2 around here)

Estimation results indeed suggest that education is more productive in services (particularly financial and social services) and less productive in manufacturing, commerce and transport. Results for experience are more homogeneous, except for commerce and financial services, which seem to provide better remuneration for this factor. Figure 1 reports the evolution of aggregate[26] human capital stock over the 1976-95 period and suggests that these indicators mostly follow the same overall evolution.

(Figure 1 around here)

Table 3 confirms this observation since correlation coefficients between the various computed measures is around 90%.

(Table 3 around here)

Some differences between indicators can however be noticed. Indeed, as can be seen in Table 4, the growth rate of average education (H_0) is higher than that of H_1, H_3 and H_5. This difference can easily be explained by the fact that the observed rise in the average education level in Taiwan can mainly be attributed to increasing education of the less educated[27]. As mentioned above, alternative measures defined in section 3.1 give more weight

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[23] Taiwanese household surveys do not give any information on the number of hours worked.

[24] See Fields and O'Hara (1996), Fields and Leary (1997), Schultz (1997) and Bourguignon, Fournier and Gurgand (1998).

[25] Estimation results for alternative specifications are given in Appendix 1.

[26] Aggregate human capital stock is measured as the sum of sectoral stocks.

[27] Between 1975 and 1995, the share of individuals with no education in the population aged 7 and above declined from 13% to 6.5%.

to an increase in the top of the educational structure whereas average education level does not depend on who gets more education.

(Table 4 around here)

A difference can also be noticed between indicators confined to education (H_1, H_3 and H_5) and indicators including experience (H_2, H_4, H_6 and H_7), which shows that ageing within the working population led to a rise in human capital stock as the share of more experienced (older) individual rose. The observed gap between growth rates of these two types of indicators is however of a small magnitude.

As a preliminary result to what will be studied in more detail in next sections, Table 4 also shows variations across sectors in growth rates and physical capital[28], which suggests that services have been the most dynamic sectors whereas, within industrial sectors, construction has had the slowest growth rate. It can be seen from this table that the most dynamic sectors have also experienced the highest growth rates for human capital accumulation - especially commerce and finance - whereas physical capital accumulation seems to be more homogeneous across sectors. Finally, concerning the composition of human capital accumulation, the accumulation of experience noticed at the aggregate level seems to be mostly imputable to the first two sectors, which have also experienced among the slowest rates of education accumulation.

[28] Physical capital stock indicators have been estimated for each sector through the permanent inventory method using annual data on gross fixed capital formation (in 1991 NT$) and a fixed depreciation rate at the usual 4% value (Nehru and Dhareshwar, 1993). Calculations for initial capital stock made through the Harberger method led to the determination of the following "equilibrium" periods between investment and GDP: 1979-73 (*sector 1*), 1967-71 (*sector 2*), 1969-73 (*sector 3*), 1971-75 (*sector 4*), 1963-67 (*sector 5*), 1963-67 (*sector 6*) and 1964-68 (*sector 7*).

4. Estimating the impact of human capital accumulation on growth

4.1. Specification of the production function

At the individual level, human capital acquisition contributes to rising individual productivity, which, at the macro-level, leads to higher productivity since the labour force is more efficient and more able to use and adapt to new technologies. This direct effect can easily be measured within the usual Cobb-Douglas production function framework as follows:

(15) $$Ln(Y_t) = Ln(A^0) + g.t + a.Ln(K_t) + b.Ln(H_t)$$

where *Y* refers to GDP, *K* capital stock, *H* human capital stock and *t* is a time trend.

Besides this direct effect, the overall impact of human capital accumulation can also be considered through external effects. Indeed, as noted by Lucas (1993), besides the fundamental role played by human capital accumulation, Asian economies also seem to have benefited from externalities linked with education in a way which remains to be identified and quantified. One type of externality, which may be of special interest here concerns the fact that various sectors in the economy benefit from human capital accumulation occurring in other sectors through links existing between sectors and the possibility of *learning by watching*. Interrelations between sectors may indeed come from various channels (Pack and Lin, 1997): the accumulation of technology incorporated in intermediate goods, interactions between sellers and buyers of technological goods or labour mobility across sectors. It may thus be of interest to take explicitly into account the indirect impact of human capital accumulation on growth through inter-sectoral externalities.

Formally, externalities can be modelled through the specification proposed by Lucas (1988), which consists in introducing the average level of human capital in the global economy ($\bar{h}$) within the explanatory variables in the production function in addition to sectoral physical capital (K) and sectoral human capital (H):

(16) $$Y = F(K, H, \bar{h}) \quad \text{with} \quad \partial F / \partial \bar{h} > 0$$

Disaggregating data at the sectoral level allows for a panel estimation of the following Cobb-Douglas form including an externality term:

(17) $$\begin{cases} Ln(Y_{it}) = Ln(A_i^0) + g_i.t + a.Ln(K_{it}) + b.Ln(H_{it}) + g.Ln(\bar{h}_{it}) \\ \bar{h}_i = \sum_{j \neq i} H_j \Big/ \sum_{j \neq i} L_j \end{cases}$$

where L_j represents the total number of hours worked in sector j and $\bar{h}_i$ the total human capital per hour worked in the rest of the economy[29].

4.2. Estimation results

Estimations have been computed on Taiwanese data over the 1976-95 period on a panel of seven industrial and services sectors defined above. Sectoral GDP (Y_i) is expressed in 1991 NT$ using sector-specific implicit deflators, capital stocks (K_i) are estimated for each sector through the permanent inventory method (see note 16), human capital stock (H_i) refers to the eight different computation methods defined in section 3 and t represents a time trend allowing for the identification of exogenous technical progress for each sector. It should be stressed that time-length restriction does not allow for the identification of different elasticities for physical or human capital across sectors. However, as far as human capital is concerned, the construction method for H_1 to H_7 is based on the estimation of different

[29] This specification is a slightly modified form of Lucas (1988) model since disaggregating data between sectors allows to distinguish human capital accumulation *within* the sector and externalities arising from accumulation *outside* the sector.

income functions across sectors (see section 3) and thus includes differences in returns to education and experience as observed at the individual level.

Due to potential non-stationarity of variables used, we study in a first step the statistical properties of each variable in order to determine their integration order. The method used is the test developed in Levin and Lin (1993) for panel data. As shown in Appendix 2, all variables are integrated of order 1 (except for Ln(H_7) which is stationary). Estimation results for H_1 to H_7 without external effects reported in Table 5 indicate a cointegration relation between variables used since residual terms are stationary.

(Table 5 around here)

Our estimation results first need a few general comments in comparison to usual findings obtained on aggregate data. Results shown in Table 5 do not validate the hypothesis of self-sustained growth in industry and services in Taiwan, which corroborates results by Dessus (1998) on aggregate growth but opposes to Tallman and Wang (1994) who find evidence of endogenous growth in Taiwan over the 1965-89 period on aggregate data. Elasticity of production with respect to physical capital is measured around 0.23, insensitive to the choice of human capital variables. This value is somehow lower to ones commonly measured in aggregate estimations, which can be explained by our estimation method since we estimate production functions on a panel comprising four less capital-intensive services sectors and only three industrial sectors. Concerning human capital variables, as is commonly found in empirical studies on Taiwan, measured elasticity is rather high (around 0.5). Moreover, this value seems to be insensitive to the human capital measure used.

Introducing external effects in the estimation specification, Table 6 shows that our results corroborate the hypothesis of existing externality with respect to human capital across sectors even though estimated coefficients and standard errors vary very much across the various definitions chosen for human capital stock. It should also be noted here that alternative specifications proposed in section 3 seem to provide better estimations for external effects than the usual measure H_0.

(Table 6 around here)

Our estimation results thus provide three main conclusions. First, as far as elasticity of production with respect to human capital is concerned, the use of alternative human capital measures based on the estimation of income functions on micro-data does not seem to allow for the identification of a potential bias induced by the use of the usual measure (the average number of schooling years). Second, estimations run on a recent period show that the development process observed on aggregate data over a longer period has not been weakening over the last two decades. Third and most important here, our estimation results clearly identify an indirect channel through which human capital accumulation influences growth, which consists in an external effect of human capital through interactions between sectors.

5. Growth accounting: factor accumulation and externalities

5.1. Aggregate growth accounting

Estimations results obtained in section 4.2 (Table 5) with the specification defined in equation (15) can be used to compute a simple growth accounting exercise allowing for an evaluation of the respective contributions of human capital and physical capital accumulation to observed growth over the 1976-95 period.

(Table 7 around here)

Decomposition results given in Table 7 for each of the 8 different human capital indicators provide various interesting results. First, whatever measure is used, human capital accumulation explains more than 20% of total economic growth over the period studied, which is similar to the contribution of physical capital accumulation. This result corroborates the idea that human capital accumulation has played a central role in the Taiwanese development process and that its impact kept been very strong over the last two decades.

Yet, various alternative measures defined in section 3 do not lead to significant differences with the usual measure H_0. Econometric estimations as well as growth accounting results thus show that the evaluation of the impact of human capital accumulation on growth is very little sensitive to the choice of the weighting scheme used for education levels in the measure of human capital stocks. Moreover, introducing experience within human capital stock does not seem to provide different results, which tends to validate the overwhelming role of education in human capital accumulation.

These results tend to legitimate the use of the common measure of human capital stock consisting in computing the average number of schooling years within the working population despite of the theoretical drawbacks discussed in section 1. This conclusion is however surprising and needs further discussion.

It should first be noted that introducing alternative weighting schemes did not change substantially sectoral accumulation rates as has been discussed in section 3.2. Symmetrically, introducing experience within the construction of human capital stock indicators does not seem to bring enough additional information to identify a significant deviation from education based indicators. Finally, estimation results do not show significant differences in measured elasticities with respect to alternative human capital stocks. Under these conditions, the average number of schooling years appears to be a rather good proxy for more complex human capital stock measures. However, it remains to determine in what respect the goodness of fit of this first order approximation can be imputed to the very short time period upon which our analysis has been made. Indeed, even though data for Taiwan are available on a much longer time period than what can usually be found for developing as well as developed countries, the use of micro-data implies a restriction to a 20 years period, which is quite small from a time series perspective. There is good chance that this restriction may be the main reason why no difference between alternative indicators can be found even though there are strong reasons to believe that usual indicators are based upon an *ad hoc* hypothesis likely to affect measures of human capital effect on growth.

Nevertheless, if no difference can be found on the Taiwan case, there is good reason to believe that similar conclusions may arise from other case studies. Indeed, Taiwan not only has exceptionally good quality and long term micro-data but this country also experienced strong changes over the period studied in its economic, educational and demographic structure. In that respect, Taiwan seems to be a perfect candidate to try and identify potential biases induced by usual human capital indicators. In short, the basic message arising from this study is that in the absence of long term micro-data, not much can be done to elaborate better human capital indicators and taking average educational attainment as a proxy for human capital stock might be “not too bad” a first order approximation.

5.2. External effects

Concerning the identification of the channels through which human capital accumulation may influence growth, Table 8 provides a much more optimistic view. Indeed, our results suggest that a notable complementary share of observed growth can be imputed to external effects linked with human capital accumulation through inter-relations between sectors. Indeed, growth accounting exercises based on the specification defined in equation (17), which estimation results are shown in Table 6, provide an evaluation for the impact of externalities across sectors on growth between 4 and 10% of total observed growth. Even though the low precision in estimated coefficients does not allow to put strong belief in these figures, global magnitude however suggests that potentially important external effects have been taking place, which can be linked to human capital accumulation. It should be noted here that the use of a panel on industrial and services sectors allows for the evaluation of a true external effect across sectors since the explanatory variable introduced refers to average human capital stock in *other* sectors but relies on the hypothesis that all sectors have the same elasticity of production with respect to other sector human accumulation. The good results obtained with the simple specification used here call for further studies of this type of external effects.

(Table 8 around here)

Even though data limitation seems to leave little hope for a better evaluation of the direct role of human capital accumulation on growth, evidence from Taiwan thus suggests that identifying indirect channels through which human capital can influence growth may be quite rewarding and allow for a notable decline in the unexplained part of observed growth.

6. Conclusion

Usual macro-economic measures for human capital stock suffer from a number of shortcomings related to the construction procedure and the restriction to the educational dimension. Moreover, when measuring the impact of human capital accumulation on growth, empirical studies mainly focus on direct effects without allowing for indirect effects emphasised in the theoretical literature. This paper defined alternative indicators and specifications based on the use of disaggregated data and proposed an empirical evaluation on the Taiwanese experience over the 1975-96 period.

Our results suggest that, although micro-data can provide valuable information on productivity and population structure, data limitations leave little room for better human capital indicators than usual measures used in aggregate studies. Indeed, the application carried on Taiwan does not allow for the identification of any difference between various alternative indicators computed and average education level. Since data for Taiwan are available on a much longer period than what can usually be found even in developed countries, and given the fact that this country experienced deep structural changes over the period studied, our results suggest that there is little chance that other case studies may provide better results.

Our results are however much more promising concerning the specification of indirect channels through which human capital accumulation may affect growth. Indeed, a simple specification based on Lucas (1988) model for externality with respect to education across sectors shows significant results and allows for a notable increase in the explained share of growth. Given the simplicity of the specification used and the significance of the results, the use of disaggregated data by sectors in order to evaluate more specific external effects of human capital accumulation seems to be a promising way to further explain economic growth.

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Table 1: GDP structure (1952-94)

(% of total GDP)

Sectors	***1952***	***1960***	***1970***	***1980***	***1990***	***1994***
Agriculture	37.4	30.3	18.5	9.7	5.4	4.0
Mining & quarrying	1.6	2.8	1.5	1.1	0.5	0.6
Manufacturing	17.2	22.3	34.1	40.7	38.3	33.6
Electricity, gas & water	1.4	1.7	2.6	2.6	3.2	3.0
Construction	4.5	4.3	4.9	7.0	4.9	5.8
Commerce	15.9	18.2	17.1	14.0	15.0	16.7
Transport, storage & communication	5.0	5.2	6.9	6.6	6.9	7.1
Finance, insurance, real estate & business	12.1	11.4	11.3	13.8	19.5	21.3
Community, social & personal services	4.9	3.6	3.2	4.5	6.4	7.8

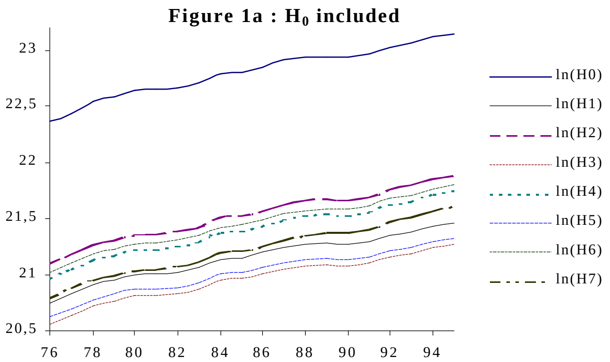
Sources: DGBAS (1995) and authors' calculations.

Table 2: Estimated returns to education and experience

	Sectors						
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
Education (years)	0.052	0.063	0.038	0.064	0.051	0.080	0.080
	140.8	*33.6*	*52.4*	*82.5*	*64.0*	*54.6*	*179.8*
Potential experience	0.036	0.035	0.033	0.044	0.033	0.046	0.032
	87.2	*14.0*	*36.9*	*53.7*	*29.4*	*32.5*	*59.4*
(Potential experience)²	-0.001	0.000	-0.001	-0.001	0.000	-0.001	0.000
	-70.1	*-8.3*	*-37.7*	*-42.9*	*-21.6*	*-19.4*	*-41.4*
Observations	140567	4207	40066	36439	23760	15145	80657
R^2	0,67	0,74	0,63	0,62	0,62	0,63	0,67

Notes: Estimations run on pooled data over the 1976-95 period. *t*-statistics in italic. Other variables included in estimations: years dummies, urbanization dummies, relation to household head dummies, sex and intercept.
(1) Manufacturing, (2) Electricity, gas & water, (3) Construction, (4) Commerce, (5) Transport, storage & communication, (6) Finance, insurance, real estate & business services, (7) Community, social & personal services.

Figure 1: Human capital stocks (1976-95)



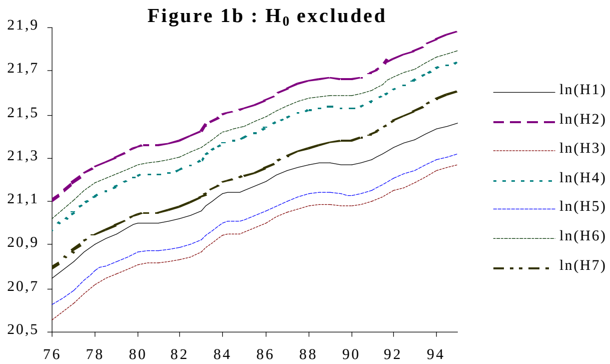


Table 3: Correlation coefficients for per capita human capital stock indicators

(1976-95)

	H_0	H_1	H_2	H_3	H_4	H_5	H_6	H_7
H_0	1							
H_1	0.916	1						
H_2	0.940	0.980	1					
H_3	0.925	0.976	0.959	1				
H_4	0.946	0.942	0.973	0.967	1			
H_5	0.953	0.970	0.980	0.988	0.987	1		
H_6	0.945	0.908	0.964	0.927	0.989	0.970	1	
H_7	0.875	0.838	0.891	0.903	0.960	0.934	0.961	1

Table 4: Sectoral growth (1976-95)

		Sectors						
Growth rate	**Aggregate**	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
GDP	*8.4*	7.3	8.5	5.7	9	8.4	10.6	10.2
Physical capital	*8.8*	8.4	8	7.9	9.7	8.6	9.4	12.6
H_0	*3.7*	2.4	2.1	3.6	5.8	2.4	8	4.9
H_1	*3.3*	1.8	1.7	2.6	5.2	1.9	8	4.8
H_2	*3.8*	2.3	2.3	2.8	5.3	2	8.1	4.7
H_3	*3.3*	1.9	1.8	2.6	5.2	1.9	8	4.8
H_4	*3.7*	2.4	2.3	2.8	5.3	2.1	8.1	4.7
H_5	*3.3*	1.8	1.8	2.6	5.2	1.8	8	4.8
H_6	*3.7*	2.3	2.3	2.8	5.3	2	8.1	4.7
H_7	*4.0*	2.3	2.3	2.7	5.3	2	8.1	4.7

Notes : (1) Manufacturing, (2) Electricity, gas & water, (3) Construction, (4) Commerce, (5) Transport, storage & communication, (6) Finance, insurance, real estate & business services, (7) Community, social & personal services.

Table 5: Estimations of a sectoral production function, Taiwan (1976-95)

Dependent variable: Ln (Y)

	(0)	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
$Ln(K)$	0.241 (4.076)	0.225 (3.976)	0.234 (4.177)	0.226 (3.971)	0.236 (4.124)	0.232 (4.146)	0.233 (4.119)	0.234 (4.083)
$Ln(H_i)$	0.519 (12.366)	0.535 (13.324)	0.524 (13.594)	0.520 (13.066)	0.509 (13.253)	0.534 (13.685)	0.513 (13.461)	0.500 (12.786)
Observations	*140*	*140*	*140*	*140*	*140*	*140*	*140*	*140*
Residual								
t-statistics	*-3.440*	*-3.501*	*-3.327*	*-3.392*	*-3.279*	*-3.446*	*-3.322*	*-3.161*
Statut	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)

Notes : Estimations computed through Feasible Generalized Least Squares (FGLS) corrected for observed heteroskedasticity, spatial correlation and residual autocorrelation (under the hypothesis of a common AR(1) process for all sectors).
t-statistics between brackets. Each equation has been estimated including specific trends for each sector and specific constant terms have been added for sector 3, sector 5 and for sectors 4, 6 and 7.
The *i* index for *Ln* (H_i) refers to the corresponding equation number (*i*).
Residual stationarity is tested using the Levin et Lin (1993) procedure for panel data.

Table 6: Estimations of a sectoral production function with external effects, Taiwan (1976-95)

Dependent variable: Ln (Y)

	(0')	**(1')**	**(2')**	**(3')**	**(4')**	**(5')**	**(6')**	**(7')**
$Ln(K)$	0.247 (4.180)	0.279 (4.866)	0.299 (4.177)	0.281 (4.892)	0.302 (5.324)	0.287 (5.087)	0.300 (5.357)	0.299 (5.219)
$Ln(H_i)$	0.510 (12.230)	0.547 (13.604)	0.532 (13.870)	0.532 (13.324)	0.519 (13.615)	0.554 (14.101)	0.529 (14.051)	0.513 (12.910)
$Ln(\bar{h}_i)$	0.437 (1.791)	0.926 (2.297)	0.689 (2.297)	0.882 (2.077)	0.736 (2.379)	0.514 (1.558)	0.665 (2.198)	0.482 (2.378)
Observations	*140*	*140*	*140*	*140*	*140*	*140*	*140*	*140*
Residual								
t-statistics	*-3.482*	*-3.828*	*-3.755*	*-3.709*	*-3.738*	*-3.714*	*-3.776*	*-3.560*
Statut	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)

Notes : See table 5.

Table 7: Sources of Taiwanaise growth: industry and services (1976-95)

	H_0	H_1	H_2	H_3	H_4	H_5	H_6	H_7
Growth rates								
GDP	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
Physical capital	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8
Human capital	3.7	3.3	3.8	3.4	3.7	3.3	3.7	4
Solow residual	4.3	4.6	4.3	4.6	4.4	4.6	4.4	4.3
Contributions								
Physical capital	25.5	23.8	25.2	23.8	24.9	24.5	24.6	24.8
Human capital	23.1	21.3	23.6	20.8	22.7	21.1	22.8	23.7
Solow residual	51.5	54.9	51.2	55.4	52.4	54.4	52.6	51.6

Notes : Aggregate growth rates are computed using relative sector shares in GDP as weights. Contributions computed using estimations results from equations (0) to (7), table 5.

Table 8: External effect and growth accounting (1976-95)

	H_0	H_1	H_2	H_3	H_4	H_5	H_6	H_7
Growth rates								
GDP	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
Physical capital	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8
Human capital	3.7	3.3	3.8	3.4	3.7	3.3	3.7	4
External effects	1.1	0.8	1.1	0.7	1.1	0.7	1.1	1.3
Solow residual	3.8	3.4	2.9	3.5	3	3.6	3	3.1
Contributions								
Physical capital	26.1	29.5	31.5	29.6	31.9	30.3	31.6	31.6
Human capital	22.7	21.8	24	21.3	23.1	21.9	23.5	24.3
External effects	5.9	8.6	9.4	7.8	9.7	4.3	8.7	7.6
Solow residual	45.3	40.1	35.1	41.2	35.2	43.5	36.2	36.5

Notes : See table 7. Contributions computed using estimations results from equations (0') to (7'), table 6.

Appendix 1: Estimated returns to education and experience

Table A1.1 Equation 6 specification

	Sectors						
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
Education (years)	-9,4E-06	4,2E-02	-5,4E-03	2,1E-02	3,7E-03	3,1E-02	3,4E-02
	-0,01	*5,22*	*-3,02*	*7,06*	*1,15*	*4,07*	*19,98*
(Education)²	3,0E-03	1,0E-03	2,8E-03	2,1E-03	2,5E-03	2,1E-03	2,3E-03
	48,15	*2,81*	*26,39*	*14,75*	*15,59*	*6,77*	*29,31*
Potential experience	4,8E-02	4,5E-02	6,1E-02	5,6E-02	4,9E-02	5,4E-02	3,8E-02
	60,00	*7,13*	*31,12*	*35,75*	*18,38*	*19,09*	*30,98*
(Potential experience)²	-1,3E-03	-9,0E-04	-1,9E-03	-1,4E-03	-1,2E-03	-1,1E-03	-7,3E-04
	-30,60	*-3,08*	*-22,12*	*-18,37*	*-9,77*	*-7,31*	*-12,67*
(Potential experience)³	8,5E-06	6,2E-06	1,6E-05	9,2E-06	9,3E-06	5,5E-06	3,2E-06
	13,86	*1,50*	*13,61*	*8,23*	*5,33*	*2,56*	*3,89*
Observations	140567	4207	40066	36439	23760	15145	80657
R²	0,68	0,75	0,64	0,63	0,63	0,64	0,68

Notes: See Table 2.

Table A1.2 Equation 9 specification

	Sectors						
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
Primary school	0,18	0,39	0,11	0,29	0,23	0,36	0,28
	30,04	*6,07*	*13,28*	*14,48*	*11,75*	*3,91*	*23,76*
Junior high	0,27	0,49	0,17	0,43	0,33	0,51	0,47
	43,43	*7,64*	*17,22*	*21,47*	*16,40*	*5,56*	*38,99*
Senior high	0,44	0,72	0,30	0,61	0,46	0,75	0,70
	68,84	*11,38*	*29,21*	*30,42*	*22,83*	*8,23*	*60,81*
Junior College	0,64	0,87	0,52	0,78	0,66	0,93	0,98
	87,70	*13,62*	*39,03*	*38,01*	*30,91*	*10,16*	*83,61*
University	0,87	0,99	0,73	0,95	0,82	1,10	1,09
	104,50	*15,20*	*47,65*	*45,38*	*37,49*	*12,05*	*92,77*
Graduate school	1,10	1,19	0,83	1,19	1,06	1,36	1,31
	45,76	*15,11*	*19,90*	*30,79*	*26,20*	*14,18*	*89,59*
Potential experience	0,049	0,046	0,061	0,057	0,050	0,056	0,039
	60,96	*7,24*	*30,70*	*35,90*	*18,69*	*19,72*	*31,55*
(Potential experience)²	-1,3E-03	-9,6E-04	-2,0E-03	-1,5E-03	-1,3E-03	-1,1E-03	-7,8E-04
	-32,49	*-3,26*	*-22,55*	*-18,87*	*-10,32*	*-7,88*	*-13,44*
(Potential experience)³	9,8E-06	7,1E-06	1,7E-05	1,0E-05	1,1E-05	6,4E-06	3,8E-06
	15,93	*1,69*	*14,39*	*8,86*	*5,98*	*3,01*	*4,67*
Observations	140567	4207	40066	36439	23760	15145	80657
R²	0,68	0,75	0,64	0,63	0,63	0,64	0,68

Notes: See Table 2. Reference for education is *No education.*

Table A1.3 Equation 12 specification

	Sectors						
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
Education (years)	-3,5E-02	8,0E-02	-2,8E-02	2,1E-02	-2,3E-02	5,0E-02	3,9E-02
	-19,27	*17,55*	*-8,20*	*4,54*	*-4,96*	*4,24*	*14,74*
(Education)²	4,0E-03	-	3,4E-03	2,1E-03	3,1E-03	1,6E-03	2,2E-03
	53,56	*-*	*25,24*	*12,10*	*17,51*	*3,97*	*24,02*
Potential experience	2,6E-02	4,7E-02	2,8E-02	4,4E-02	2,5E-02	5,2E-02	3,5E-02
	40,21	*12,21*	*19,94*	*30,05*	*14,93*	*16,75*	*36,69*
(Potential experience)²	-5,7E-04	-5,2E-04	-6,6E-04	-7,8E-04	-4,5E-04	-6,9E-04	-5,1E-04
	-57,39	*-9,27*	*-31,67*	*-38,88*	*-18,46*	*-18,27*	*-39,57*
*Experience*Education*	9,0E-04	-7,2E-04	6,2E-04	2,1E-05	6,1E-04	-3,4E-04	-1,0E-04
	24,49	*-4,06*	*7,87*	*0,27*	*7,59*	*-2,04*	*-2,35*
Observations	140567	4207	40066	36439	23760	15145	80657
R²	0,69	0,75	0,64	0,63	0,63	0,64	0,68

Notes: See Table 2.

Appendix 2: Unit root test on panel data

	Level		**First difference**	
Variable	***t-statistics***	**Status**	***t-statistics***	**Status**
$Ln(Y)$	0.079	I(1)	-5.118	I(0)
$Ln(K)$	-0.914	I(1)	-6.044	I(0)
$Ln(H_0)$	2.024	I(1)	-6.198	I(0)
$Ln(H_1)$	2.420	I(1)	-5.921	I(0)
$Ln(H_2)$	2.464	I(1)	-7.032	I(0)
$Ln(H_3)$	2.383	I(1)	-5.755	I(0)
$Ln(H_4)$	2.334	I(1)	-7.095	I(0)
$Ln(H_5)$	2.267	I(1)	-5.909	I(0)
$Ln(H_6)$	2.081	I(1)	-7.071	I(0)
$Ln(H_7)$	3.282	I(0)		
$Ln(\bar{h}_0)$	-2.338	I(1)	-11.368	I(0)
$Ln(\bar{h}_1)$	-0.094	I(1)	-7.697	I(0)
$Ln(\bar{h}_2)$	-2.299	I(1)	-6.708	I(0)
$Ln(\bar{h}_3)$	-0.095	I(1)	-7.728	I(0)
$Ln(\bar{h}_4)$	-2.502	I(1)	-6.251	I(0)
$Ln(\bar{h}_5)$	-0.391	I(1)	-7.711	I(0)
$Ln(\bar{h}_6)$	-2.245	I(1)	-5.991	I(0)
$Ln(\bar{h}_7)$	-1.690	I(1)	-6.060	I(0)

Notes : Stationarity tests are based on Levin et Lin (1993) at the 1% level.