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ARTICLE



A semi-endogenous growth model with public factors, imported capital goods, and limited export demand for developing countries

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ABSTRACT

We build a semi-endogenous growth model for developing countries with non-rivalrous public factors, imported capital goods, and an export demand function. The model exhibits the three-way interaction between public and private investment and trade shown recently in the empirical literature. A parameter for government-investment inefficiency has transitional growth effects distorting between public investment and private capital, consumption, and exports, the latter biasing the terms of trade. Our analysis of a vector error-correction model (VECM) for Trinidad & Tobago shows that additional expenditure for public investment increases output less than taxes decrease per capita consumption and therefore is sub-optimal there. Both temporary and permanent shocks on public investment have level effects supporting semi-endogenous growth modeling and demonstrate that the VECM effects are in line with the logic of the theoretical model; terms of trade are endogenous.

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1. Introduction

Closed economy or small open economy growth models tend to underemphasize three important phenomena. First, many countries import almost all of their capital goods, which have to be paid for by exports either immediately or later if debt is incurred. Second, models with a small-country assumption, defined as given terms of trade, underestimate the sources and effects of changing terms of trade, and thereby the price mechanism. Third, public investment has non-rivalrous properties and governments have to find the optimal level of taxation and public investment. Whenever a model in the literature takes one of these problems into account, it ignores the other two. The interaction of public capital, imported capital goods, export demand (see online appendix for a panel of African countries) and the basic properties of growth models like population growth, investment, and human capital accumulation is

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 Supplementary material can be accessed [here](#).

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therefore not considered. To address this gap in the literature, the first purpose of this paper is to expand a human capital augmented Solovian growth model similar to that of Mankiw, Romer, and Weil (1992) with imported capital goods, limited export demand and endogenous terms of trade as in Bardhan and Lewis (1970)¹ and non-rivalrous² public factors as in; Ziesemer (1990). Consequently, long-run growth rates depend not only on exogenous technical progress but also on world income growth, income and price elasticities of export demand, the growth rate of the number of persons with access to education and the elasticity of production of public factors in human capital. The non-rivalrous character of public factors and endogenous terms of trade can both generate semi-endogenous growth and do so when modeled jointly. Transitional growth consists of a system of three central differential equations in private capital, human or public capital and the terms of trade. The model is intended to capture the growth forces of countries with little or no R&D so that endogenous growth through R&D production functions is ignored.

In principle, this model can be estimated in several ways. Depending on the choice of method like a linear vector error-correction model letting the data speak and lags taking care of non-linear developments or non-linear estimation of the equations and parameters as they come out of the theory, the estimation is more or less closely related to the model. We apply a vector error-correction model (VECM) to Trinidad and Tobago, which has achieved the level of a high-income country recently without a prominent role of R&D (Mohan, Strobl, & Watson, 2014), it depends strongly on exports, not only of oil, and it has invested well in public capital besides having good data availability. As a second purpose of this paper, we add to the literature using dynamic simultaneous equation models in the analysis of public investment in developing countries. It contains the early contributions of Canning and Fay (1993), and the more recent ones by Ferreira, Hamilton, and Araújo (2006), Canning and Pedroni (2008), Sahoo, Dash, and Nataraj (2010), Agénor and Neanidis (2015) and Fosu, Getachew, and Ziesemer (2016). Dynamic approaches are able to distinguish short and long-run effects of public investment and other variables (Glomm & Ravikumar, 1997) and take dynamic feedback from and to other variables into account (De Frutos & Pereira, 1993). Moreover, the VECM deals adequately with the basic econometric problems discussed in the early surveys on public capital and growth: common trends, energy prices, causality, non-stationarity, and cointegration, and simultaneity (see De Frutos & Pereira, 1993, Gramlich 1994; Glomm & Ravikumar, 1997).

Earlier literature has focussed on the effects of public investment or capital or (combinations of) physical and quality indicators on output or its growth (see

¹Khang (1968) has a similar model but associates it with imported raw materials. In Acemoglu and Ventura (2002) an endogenous growth mechanism is dampened by falling terms of trade leading to a falling value of the marginal product of capital; the demand side is neutralized through homotheticity assumptions. In the models of Khang (1968), and Bardhan and Lewis (1970) terms of trade growth enlarge (diminishes) the growth rate of the Solow model if the speed of growth of supply is lower (higher) than that of demand. Therefore, we find semi-endogenous growth in these models.

²Many other papers follow Barro (1990) where the public factor enters the production function in the same way as capital and labor, and therefore could be privatized, which is less obvious for non-rivalrous factors. Duran-Fernandez and Santos (2014) are an exception in that the public factor is regional and non-rivalrous regarding subsectors. In Chakraborty and Dabla-Norris (2011) they are non-rivalrous factors in regard to firms, taxed households are identical (avoiding tax conflicts), and the major problem discussed is one of the benevolent government auditing corrupt bureaucrats to ensure the quality of public capital.

Canning and Fay (1993), Glomm and Ravikumar (1997), Sanchez-Robles (1998), Calderón, Moral-Benito, and Servén (2015), Agénor and Neanidis (2015)) at various regional or sectoral levels (Duran-Fernandez & Santos, 2014). In contrast, we think, similar to Fosu et al. (2016), that consumption per capita rather than GDP per capita should be considered; of course, both are positively related to utility and welfare. Consumption equals output diminished by public investment (or taxes) and exports. For economies without a machinery sector, exports are used for importing private investment goods. A possible outcome, found in our application for Trinidad and Tobago, is that public investment may stimulate private investment and enhance the GDP; but consumption per capita may be decreased – unlike Sub-Saharan Africa according to Fosu et al. (2016) – if the effect on GDP per capita on disposable income is lower than that of taxation. In sum, it seems worthwhile to set up a growth model where the crucial parameters of public capital and export demand function change all formulas for the transitional and long-run growth rates and levels through their connection by relative prices of domestic and foreign goods.

In section 2, we generalize the Solow model in regard to those aspects which are essential in changing steady state growth rates as shown in the analysis of section 3 – with many simplifying assumptions when compared to multi-sector growth models. The variables emphasized in sections 2 and 3 are used in section 4 – for a country with good data availability, Trinidad and Tobago – to show that the results from a vector-error-correction model coincide with those of the theoretical model after some minor country-specific adjustments. Section 5 summarizes and concludes with some comparisons of the theoretical and empirical models with those of exogenous and (semi-) endogenous growth models.

2. The model

It is assumed that a country produces one good under constant returns to scale described by a Cobb–Douglas function. Y denotes output, g represents the growth rate of technology or total factor productivity and K , H , and L_1 stand for private physical capital, human capital and (unskilled) labor inputs, respectively. A is a level parameter. The production function is

$$Y = A_0 e^{gt} K^\alpha H^\beta L_1^{(1-\alpha-\beta)}, \dots 0 < \alpha, \beta, \alpha + \beta < 1 \quad (1)$$

Adopting the notation of “ \wedge ” for growth rates, (1) can be reformulated as

$$\hat{Y} = g + \alpha \hat{K} + \beta \hat{H} + (1 - \alpha - \beta) \hat{L}_1 \quad (1')$$

Denoting the derivative of a variable with respect to time by a dot on the variable, net-investment in each period is denoted as \dot{K} . Ruling out international debt for the sake of simplicity, equality between investments and savings is given by

$$\dot{K} + \delta K = sp(1 - \kappa\tau)Y \quad (2)$$

where s is a percentage rate of saving out of net income, p is the relative price of exported output to the price of imported capital inputs, and τ is a flat-rate income tax. In line with Pritchett (2000), we assume that from tax revenues τY , bureaucracy and

corruption extract $(1-\kappa)\tau Y$, $\kappa \leq 1$. It is a partly illegal income of private households acting like a tax reduction if $\kappa < 1$. The sum of net factor income, $(1-\tau)Y$, and legal and illegal income from transaction costs, $(1-\kappa)\tau Y$, is the term in (2). For the sake of simplicity, we ignore the possibility of incurring debt and pay for imports later. This avoids complications, which are unnecessary for our purposes. Imported capital goods, ignoring other imports, have to be paid for by exports, where X measures exports in terms of domestic goods,

$$\dot{K} + \delta K = pX \quad (3)$$

As long as the share of imported capital goods in total imports is empirically approximately constant, this will not be a restrictive assumption. The equality of savings and exports that follows from assumptions (2) and (3) is typical of the two-gap models since Chenery and Bruno (1962) to Feder (1981), where the equations were called the savings gap and the export gap.

Income and price elasticities of export demand are denoted by ρ and η respectively and D is a level parameter. They all may differ by country, whereas in the multi-country model of Acemoglu and Ventura (2002), tractability requires that income and price elasticities are identical and therefore unity for income. World income (or the income of the country's customers) is denoted by Z . The export demand function is

$$X = DZ^\rho p^\eta, \dots \cdot \eta < 0 \quad (4)$$

We assume that policy does not interfere trying to impose an optimal tariff because of the standard retaliation argument and trade agreements excluding this. To produce human capital, each individual with upper index $[i = 1, \dots, N]$ can distribute her total labor endowment between selling unskilled labor, L_1^i , in the labor market or using labor inputs, L_2^i , for human capital (skilled labor) formation, so that an individual's labor constraint is given by

$$L^i = L_1^i + L_2^i \quad (5)$$

The L^i terms are individual labor endowments, which cannot be observed by the government. To keep things as simple as possible the labor force, N , is identified as the total population. Assuming constant population growth at rate ε with e as the exponential function gives

$$N = N(0)e^{\varepsilon t} \quad (6)$$

Equilibrium in the market for unskilled labor equates firms' demand with the sum of individuals' supply

$$L_1 = \sum_1^N L_1^i \quad (7)$$

Human capital is formed by each individual using labor inputs L_2^i , exogenous individually different labor-augmenting (learning) abilities e^i , and a public factor B . The latter can be understood either as basic research results financed by the government, a domestic knowledge stock or other public physical and institutional capital for provision of water, transport services, electricity, and communication,

which interact with health and education (see Calderón & Servén, 2014a; Leipziger, Fay, Wodon, & Yepes, 2003; Stone, Bania, & Gray, 2010). As with the individual labor endowments, the government cannot observe individual learning abilities. Human capital is assumed to depreciate completely after each period, since it cannot be transmitted between generations. Total depreciation simplifies the model considerably. The human capital production function with constant level parameter F is assumed to be

$$H^i = F(e^i L_2^i)^\varphi B^{(1-\varphi)}, \dots \dots 0 < \varphi < 1 \quad (8)$$

Alternatively, one could interpret H^i as transport or telecommunication service and B as transport or communication infrastructure, both with heterogeneous productivities e^i . The change in the stock of public factors is financed by the government through a flat-rate tax τ , diminished by a factor $\kappa < 1$ capturing bureaucracy and corruption costs as suggested and modelled by Pritchett (2000), Agénor (2010), Dabla-Norris, Brumby, Kyobe, Mills, and Papageorgiou (2012) and Gupta, Kangur, Papageorgiou, and Wane (2014). The public capital stock is assumed to depreciate at a rate θ .

$$\dot{B} = \kappa\tau Y - \theta B \quad (9)$$

By implication, B is efficiency-adjusted capital and $\kappa\tau Y$ is the efficiency adjusted gross investment. Bureaucracy and corruption are treated here and in (3) as a reduction of tax revenue and payments, because it is not lost but rather goes from public into private budgets, whereas in other literature it is treated as a pure waste, or remains in the firms' budgets (Berg, Portillo, Yang, & Zanna, 2013). Equilibrium in the market for human capital equates firms' demand with the sum of individuals' supply,

$$H = \sum_1^N H^i \quad (10)$$

Profit maximization by firms results in the following marginal productivity conditions (with r denoting interest on capital, δ the rate of capital depreciation, q the market price of human capital, and w the wage rate for unskilled labor).

$$r + \delta = \alpha \frac{pY}{K} \quad (11.1)$$

$$q = \beta \frac{Y}{H} \quad (11.2)$$

$$w = (1 - \alpha - \beta) \frac{Y}{L_1} \quad (11.3)$$

The Bardhan and Lewis (1970) model and that of Acemoglu and Ventura (2002) have in common that the terms of trade appear in the formula for the marginal product of capital as they do in equation (11.1).

Households decide how to distribute individual labor endowments by maximizing.

$$\max(1 - \tau)[qH^i + wL_1^i] \text{ s.t. (5) and (8)}$$

Insertion of (5) and (8) yields.

$$(1 - \tau) \left[qF(e^i L_2^i)^\varphi B^{(1-\varphi)} + w(L^i - L_2^i) \right]$$

Maximization with respect to L_2^i gives (12). Individuals maximize their income by deciding on the optimal allocation of their individual labor endowments over unskilled labor L_1^i and labor spend in human capital formation L_2^i , which requires that the value of the marginal product of labor in human capital formation equals the real wage rate in terms of human capital prices,

$$\frac{w}{q} = \varphi \frac{H^i}{L_2^i}. \quad (12)$$

Since all individuals face the same real wage rate, w , and rental price for human capital, q , and abilities are labor-augmenting by assumption, it follows from (12) that the human capital–labor ratio is identical for all individuals and therefore equal to the aggregate relation,

$$\frac{H}{L_2} = \frac{H^i}{L_2^i}. \quad (13)$$

This property of the model avoids having complicated aggregation problems in our case of heterogeneous households. The conflict about public factors and taxes arising from the heterogeneity is shown in the online appendix. The vested interests of people using public capital intensively are different from those owning capital and labor above average, all measured relative to their human capital. Agreement is hard to achieve and resistance against taxation or public investment has been strong in many countries.³ The macroeconomic data for investment and savings as a share of GDP of the least developed countries are higher than those of the USA since 2002 and were close to them since many decennia. This is not the case concerning public goods and networks related to water, wastewater, transport (roads, railroads, harbors, airports), electricity, education, health, and internet, all of which affect human capital.⁴ Although the literature has achieved consensus to keep distortions low, the redistributive character of other than Lindahl taxes and for public investment has remained controversial. Similarly, in the examples for transport and telecommunication, productivity differences of transport and ICT firms replace abilities or different productivities of human capital producing households. This type of tax conflicts can only be solved by policy, and in order not to narrow down the model to certain policy constellations, we leave the tax exogenous.

Equating the right-hand side of (12) with the quotient of the marginal productivity conditions (11.2) and (11.3), both of which represent the impact of wages on the demand for labor, and making use of (13) implies

³For a recent article regarding regulation as a means to slowdown public investment and capital in Brazil, see Amann, Baer, Trebat, and Villa Lora (2016). It seems to be an open issue at this moment whether revenues from resource windfalls can be channeled more easily into a public investment than tax money in many countries as it could in Trinidad and Tobago (Berg et al., 2013; Gelb, 1988).

⁴See World Bank 1990, 1991, 1993, 1994 for early contributions, Shepherd et al. (2014), Eden and Kraay (2014).²⁷

$$\frac{L_1}{L_2} = \frac{(1 - \alpha - \beta)}{\beta\varphi}. \quad (14)$$

The allocation of total labor endowments over the formation of human capital, L_2 , and unskilled labor, L_1 , according to (14) is determined by their respective production elasticities in regards to the final output. Insertion of H from (13) and H^i from (8) into (1) yields the production function in the form that includes public capital B instead of human capital,

$$Y = A_0 e^{gt} B^{(1-\varphi)\beta} K^\alpha \left[\frac{F(e^i L_2^i)^\varphi}{L_2^i} L_2 \right]^\beta L_1^{(1-\alpha-\beta)}. \quad (15')$$

It will be shown below that the fraction in (15') is constant over time as the individual labor terms are constant. This function has increasing returns to scale because of the sum of exponents of B , K , L_1 , and L_2 . The macroeconomic labor terms and capital K have constant returns. The productivity of the constant-returns function can then be split up into a public capital term and a total factor productivity term. The intensive form as in Chakraborty and Lahiri (2007) is then

$$\frac{Y}{L_1} = A_0 e^{gt} B^{(1-\varphi)\beta} \left(\frac{K}{L_1} \right)^\alpha \left[\frac{F(e^i L_2^i)^\varphi L_2}{L_2^i L_1} \right]^\beta = (A e^{gt})^{\frac{1}{1-\alpha}} B^{\frac{(1-\varphi)\beta}{1-\alpha}} \left(\frac{\frac{K}{L_1}}{\frac{Y}{L_1}} \right)^{\frac{\alpha}{1-\alpha}} \left[\frac{F(e^i L_2^i)^\varphi L_2}{L_2^i L_1} \right]^{\frac{\beta}{1-\alpha}} \quad (15)$$

Output per worker can be attributed to TFP, public capital, the capital/output ratio and the share of education time, which corresponds to the education arguments in the growth accounting literature. As emphasized by Acemoglu and Ventura (2002), postulating a high value of $\alpha = 2/3$ or $\alpha/(1-\alpha) = 2$ leads to a strong role of capital and a weak one for total factor productivity because A has exponent three leading to a lower value of A to explain the left-hand side values than with a lower exponent. In Chakraborty and Lahiri (2007), the same mechanism is used to postulate a strong role of public capital. But the standard value of $\alpha = 1/3$ yields $\alpha/(1-\alpha) = 1/2$ and an exponent for A of $3/2$, requiring a higher value of A to explain the left-hand side values than with a higher exponent. A strong role for public capital B , in this case, requires high $(1-\varphi)\beta$, a high elasticity of production of H in (1) and of B in (8). We will use these equations below to calculate the total factor productivity growth rate g .

2.1. Equilibrium dynamics

The central differential equations and the terms of trade dynamics are as follows (see online appendix):

$$d\log(\hat{B} + \theta) = \ln A + g + \alpha \hat{K} + [\beta(1-\varphi) - 1] \hat{B} + (1-\alpha)\varepsilon \quad (9'')$$

Dividing (3) by K , taking the growth rates to solve for \hat{p} , we get

$$\hat{p} = \frac{d\log(\hat{K} + \delta) + \hat{K} - \rho \hat{Z}}{(1+\eta)} \quad (16)$$

Equations (16) and (2) indicate that there is a two-way causality between capital accumulation on the one hand and the terms of trade and exports on the other.⁵ Dividing (2) by K , and taking log differences, eliminating human capital and using (16) we get

$$d\log(\hat{K} + \delta) = -\frac{\eta(1-\alpha) - \alpha}{\eta} \hat{K} - \frac{\rho\hat{Z}}{\eta} + \frac{(1+\eta)}{\eta} [g + (1-\alpha)\varepsilon + \beta(1-\varphi)\hat{B}]. \quad (17)$$

World income growth, multiplied by the income elasticity will drive up the terms of trade in (16) in case of price elastic exports, and through that also capital accumulation goes up as in all models based on Bardhan and Lewis (1970).⁶ Falling capital goods prices, which serve as numéraire here, or increasing terms of trade, are the mirror image of the process of stimulating capital accumulation in (17) as discussed by Cai, Ravikumar, and Riezman (2015). On the other hand, (16) indicates that this effect is mitigated by the negative impact of capital accumulation on the terms of trade – emphasized by Acemoglu and Ventura (2002) – in case of a price elasticity making the denominator of (16) negative. The more negative the price elasticity, the weaker the effects of the right-hand variables on the terms of trade growth in (16) and the weaker the effects on capital accumulation in (17).

3. The level of growth: theory, policy, and empirics

3.1. Transitional dynamics of variables in levels

In terms of log levels, the central differential equations and the terms of trade equation are (see online appendix)

$$\ln\left(\frac{\dot{B}}{B} + \theta\right) = \ln A + \beta\lambda + gt + \ln(\kappa\tau) + \gamma \ln L_1 - \beta\varphi \ln L_2 \quad (9\boxtimes')$$

$$+ (1-\varphi)\beta \ln N - (1-(1-\varphi)\beta) \ln B + \alpha \ln K + \ln U$$

$$\ln p = \frac{1}{\eta} (\ln A - \ln D + \beta\lambda + gt - \rho \ln Z + \ln s + \ln(1-\kappa\tau) + \gamma \ln L_1 - \beta\varphi \ln L_2$$

$$+ (1-\varphi)\beta \ln N + (1-\varphi)\beta \ln B + \alpha \ln K + \frac{\ln U - \ln V}{\eta}) \quad (18)$$

The supply-side arguments, including capital accumulation emphasized by Acemoglu and Ventura (2002) and technical change emphasized by Kravis (1970), reduce the terms of trade, and the demand side arguments like world income growth, emphasized by Singer (1999), increase the terms of trade. These effects are stronger if the price elasticity is less negative. A higher efficiency parameter κ leads to higher public and lower private investment as well as consumption and exports, other things given; in this sense $\kappa < 1$ is a distortion through a dynamic misallocation in line with the discussion in Berg et al. (2015). The effect is transitional only because it does not show up in the

⁵See Sakyi, Villaverde, & Maza, 2015 for panel evidence.

⁶We ignore the theoretical possibility of a negative income elasticity from the discussion, as the development literature never mentions it for the country level.

formulas for the steady-state growth rates above. The government-efficiency parameter κ is positively related to the terms of trade. Therefore, a lower efficiency leads to lower terms of trade because exports supply is enhanced when less output is used for public investment. Insertion of $\ln p$ from the left-hand side of (18) into (A2') or (A3') (see online appendix) yields (17')

$$\begin{aligned} \ln\left(\frac{\dot{K}}{K} + \delta\right) = & -\frac{1}{\eta} [\ln D + \rho \ln Z] \\ & + \frac{(1+\eta)}{\eta} (\ln A + \beta\lambda + gt + \ln s + \ln(1 - \kappa\tau) + \gamma \ln L_1 - \beta\varphi \ln L_2 \\ & + (1 - \varphi)\beta \ln N + (1 - \varphi)\beta \ln B) + \frac{\alpha(1+\eta) - \eta}{\eta} \ln K + \frac{(1+\eta)}{\eta} \ln U \\ & - \frac{1}{\eta} \ln V \end{aligned} \quad (17')$$

In our model, there is heterogeneity in abilities, capital income, and labor endowments. The implied tax conflict described above may reduce the likelihood of catching up if public investment suffers as shown by the variable $\kappa\tau$. It has a negative effect on the growth of K in (17'), but a positive one on the terms of trade in (18) because taxes reduce supply, and a positive one on the growth of B in (9''). Catching up depends upon having well-balanced public and private capital stocks because of diminishing marginal returns for both in the production functions and investment rates close to those of a golden rule.

Equations (9''), (18) and (17') form a system that we could in principle try to estimate directly or use as a guidance for a vector error-correction model, with right-hand side variables $\ln K$, $\ln B$, t , $\ln s$, $\ln \kappa\tau$, $\ln(1 - \tau)$, $\ln N$, $\ln L_1$, $\ln L_2$, $\ln Z$, the same list of arguments for $\ln p$, but s and Z not in (9'').

One crucial policy question is that of the level of the tax rate τ . Its partial effect is to increase the growth of B in (9'') and the level of p in (18) but to decrease the right-hand side of (17') for capital accumulation. In all three equations, the level of B works in the opposite direction of what the tax rate is doing. The tax and the public capital stock, therefore, have to be well balanced.

3.2. Country selection

Taking our model literally, it should be applied only to countries that have no machinery sector. Figure 1 shows that countries at all levels of GDP per capita from \$100 to \$32,500 may have no production of machinery and transport equipment expressed as a share of manufactures (MTEM) in the period 1990–2007. Similarly, using a nearest-neighbor fit, Figure 2 shows that there is a minimum of two years of schooling to have a machinery sector. However, countries with more years of schooling have a larger share of machinery. Then, countries should be chosen which really have essentially no sector for machinery and transport equipment. These are Bolivia, Burundi, Cambodia, Cameroon, Gabon, Honduras, Mongolia, Nepal, Paraguay, Qatar, St. Lucia, Swaziland, Trinidad and Tobago, and Yemen. They all have less than 1% of manufactures in machinery and

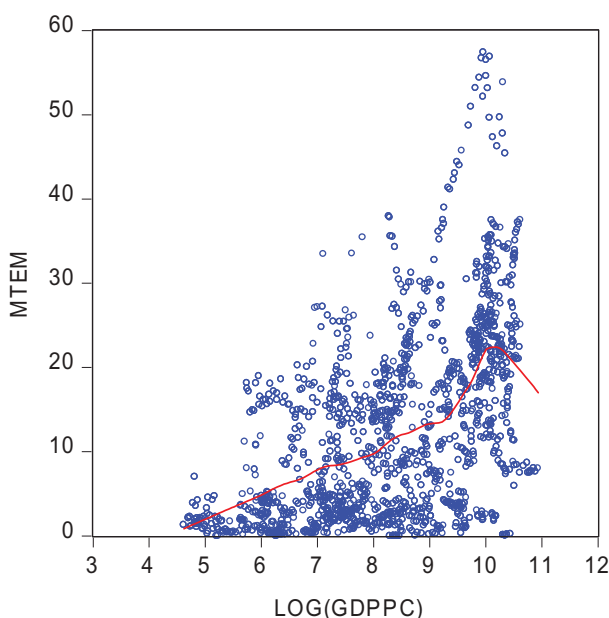


Figure 1. Absence of a machinery and transport equipment sector is possible at all levels of GDP per capita up the US \$32,500.

transport equipment. In addition, it is not always clear that “not available” is strictly distinguished from zero in the data. Countries with no data available may also be candidates. One country with no machinery sector and good availability of data is Trinidad and Tobago, which also has a good infrastructure and development success. It is for this latter reason that we focus on T&T. The sector for machinery and transport equipment was only 0.27% of value added in manufacturing in 2006 (World Bank, 2013).

3.3. Data

We construct a data set ranging from 1961 to 2007, the year in which the data of Gupta et al. (2014) end. Private and public capital series as a share of GDP come from Gupta et al. (2014), who have made the data in line with and without the efficiency adjustment reasoning of Pritchett (2000) and the PIMI index of Dabla-Norris et al. (2012).⁷ However, accepting Pritchett’s (2000) concept is one thing and using the Public Investment Management Index for efficiency adjustment is a different one. Gupta et al. (2014) use values of κ in the interval of 0.26 and 0.31 meaning only these percentages of public investment data actually are assumed to go into public capital. The consequence of this is that since 1986 the efficiency-adjusted capital stock is stagnating for Trinidad and Tobago. In contrast, the growth rates of the dis-aggregated public capital stock items in physical measures until 2007 all have positive growth rates, which are all larger than those of the non-adjusted capital stock (see Table 1).⁸ This is a clear argument against the use of

⁷ An approach using dis-aggregated rather than macro variables of public capital and investment is taken by Straub and Terada-Hagiwara (2011).

⁸ In addition, access to electricity for 2010 and 2011 is 99%. These are the physical indicator of supply. Fay et al. (2017) discuss the inefficiency of spending and use.

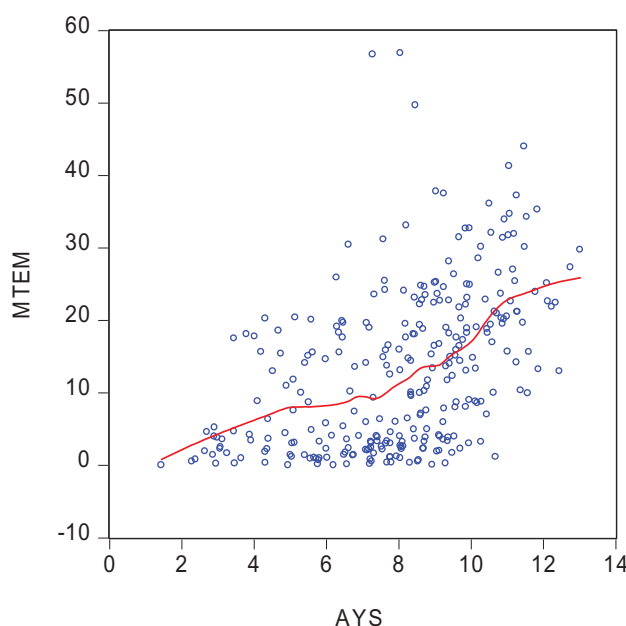


Figure 2. Absence of machinery and transport equipment sector is possible until 9.3 average years of schooling.

the PIMI type of efficiency adjustment capital for Trinidad and Tobago. A reason for this may be that Trinidad and Tobago scores high on the selected component of the PIMI index, and this may be the better indicator for public investment valuation. Any other adjustment would also lead to lower growth rates of public capital, which seems undesirable because public capital in the case of Trinidad and Tobago has already a lower growth rate than all the physical items.⁹ By implication, we have no reason to use the efficiency-adjusted data for Trinidad and Tobago, and we rather use the non-adjusted data. Oil-rich countries can compensate civil servants easily and threaten them to get fired when corruption is detected. This can avoid corruption via public investment even if managers have a negative opinion on procedures. This is in line with the resource curse literature, which would argue that resource-rich countries with weak institutions run into the curse whereas those with good institutions may have a good growth performance. Trinidad and Tobago did join the ranks of the rich countries with strong growth of public capital, both indicating that their institutions are not likely to be too bad.

Gupta et al.'s data is in percentages of real GDP. To convert the percentages to capital stock values, the series has been multiplied with GDP series taken from the PWT 6.3 (Heston, Summers, & Aten, 2009), which uses Laspeyres indices. Taking differences of the stocks yields the net investment and adding depreciation yields gross investment. Gupta et al. (2014) assume that the depreciation rate for middle-income countries increases monotonically at a constant rate from 2.5% in 1960 to 4.3% in 2010.

⁹A second point raised by Pritchett (2000) is that too high values of unadjusted public capital growth rates lead to too low values of total factor productivity growth rates. He does not include Latin America and the Caribbean into the list of problem areas. In line with that we do not find support for that argument for Trinidad and Tobago (see online appendix "Growth accounting").

Following this argument, we obtain the efficient public investment or tax rate of our model as

$$\kappa\tau_t = \frac{B_t - (1 - \delta)B_{t-1}}{Y_t}.$$

Here, $\kappa\tau$ is public investment as a share of GDP, B is public capital, δ is the depreciation rate and Y denotes GDP. The savings rate s can be calculated according to (2) as private gross investment divided by $(1 - \kappa\tau)Y$. Using the non-adjusted data implies that we use the case $\kappa = 1$.

Terms of trade are constructed as “Exports as a capacity to import” divided by “Exports of goods and services”, both in local currency units. The data is taken from the World Bank (2014).

The labor force is separated into two parts; labor in production, L_1 , and labor used in the acquisition of human capital, L_2 . For the L_1 , series we use the total labor force series from the World Bank (2005, 2013).

The second series, L_2 , is approximated by years of schooling. Barro and Lee (2013) provide average years of schooling for Trinidad and Tobago at 5-year intervals from 1950 to 2010. For the present purpose, we interpolate the series using cubic spline interpolation to obtain a complete series.

World income (in constant 2000 US\$) and the GDP growth rate are taken from the World Bank (2013). Unit root tests based on ADF (augmented Dickey-Fuller) equations with breakpoint selection suggest that only consumption per capita has a unit root for sure. For some other variables, this result is found when applying some lag length criteria applying many lags in the tests but not for others applying criteria with a low number of lags. In line with the suggestion to choose against unit roots because of the low power of the tests for a low number of observations (see Jusélius, Møller, & Tarp, 2014), the cautious interpretation is to assume only one unit root from these tests.

We have made some possibly over-simplifying assumptions, which can be avoided using a vector error-correction model. First, export and production functions may not be of the Cobb–Douglas type. Second, population growth, savings and tax rates or inefficiency parameters may not be exogenous and constant. Third, export revenues may be spent also on consumption goods and tax revenues may come from other sources and get used for other purposes than just public investment. Therefore, we drop the CD functions as well as output and export quantities from the empirical analysis in this section. Fourth, budgets need not be balanced but rather we could have foreign debt if investments exceed savings and government debt if tax revenues fall short of public expenditure. Fifth, there are country-specific factors, which theoretical models normally omit. In the case of Trinidad, it is the high share of oil in the exports. The energy sector contributes 66% of exports, 44% of GDP but only 3.1% of the employment of the country, which has a Herfindahl concentration index of exports of below 0.25 (Longmore, Jaupart, & Cazorla, 2014). An implication of this is that we use an exogenous oil price whereas prices of other exports may be endogenous as in the theoretical model.

3.4. A vector error-correction model

In addition to the eight endogenous variables listed after equation (17'), we include consumption as net income after subtracting savings ratios for public and private capital, $C/P = Y(1-s(1-\tau) - \tau)$,¹⁰ and use the factors of production instead of gross income as regressors in the VECM. Testing for lag length and stability shows that a VAR with two lags is stable, but not with more lags. The log levels rather than the growth rates of world income and oil prices are exogenous – otherwise, the VAR is not stable.^{11,12} When setting up a vector error-correction model, we treat the first nine variables as endogenous, which is confirmed by finding statistically significant adjustment coefficients in a VECM. We include a constant and a quadratic time trend into the VECM in order to avoid growing growth rates from the exogenous log levels and because they are statistically significant. VECMs have the highest log-likelihood for eight cointegrating equations.¹³ This is consistent with the fact that the number of endogenous variables $K = 9$ with the number of cointegrating equations $r = 8$ yields $K - r = 1$ unit roots which are in line with the uni-variate finding reported above that only one variable has a unit root. The statistically insignificant adjustment coefficients remain unrestricted. The long-term relations are identified as follows,¹⁴ with t -values in parentheses with those for constant and trend only at the end of the complete VECM in the online appendix.

$$CE1 : E(u_1(-1)) = \cdot LOG(CPC(-1)) \cdot - \cdot 2.9LOG(P(-1)) \cdot + \cdot 0.0457t \cdot - \cdot 11.57, \\ [-119.6] \quad (19)$$

$$CE2 : E(u_2(-1)) = \cdot LOG(K(-1)) \cdot - \cdot 0.58LOG(S(-1) * (1 - TAU(-1))) \cdot \\ - \cdot 0.044t \cdot - \cdot 24.3, [-35.68] \quad (20)$$

$$CE3 : E(u_3(-1)) = \cdot LOG(B(-1)) \cdot - \cdot 0.8LOG(TAU(-1)) \cdot - \cdot 0.042t \cdot - \cdot 24.5, \\ [-48.0] \quad (21)$$

¹⁰Note that the interest here is not included in net factor income from abroad and consumption financed by that but rather only in the consumption creating an effect of public investment or capital via GDP after paying taxes.

¹¹Giles and Williams (2000) explain extensively why and how trends and lags have to be chosen with the utmost care and not just by mere assumption.

¹²Stability with two lags requires entering the exogenous variables world income and oil prices in the form $t^*d(\log(X))$. This formulation enables us to explain better the formulation for shocks on the growth rates of world income and oil prices below. Under the standard formulation for log levels stability happens to occur with only one lag in the VAR.

¹³Note that standard tests are not adjusted for exogenous variables with two exceptions we cannot use here: For the case with exogenous $I(1)$ variables critical values are not available because those in Harbo, Johansen, Nielsen, and Rahbek (1998) have been derived only for $T = 400$ and those in Pesaran, Shin, and Smith (2000) for $T = 500$.

¹⁴The abbreviations are as follows. *CPC* is consumption per capita, *K* private capital, *B* public capital, *P* terms of trade, *AYS* average years of schooling, *S(1-TAU)* share of investment in private capital; *TAU* share of investment in public capital, *LF* labor force, *POP* population, and time trend t .

$$CE4 : \cdot E(u_4(-1)) \cdot = \cdot LOG(P(-1)) \cdot - \cdot 5.07 LOG(LF(-1)) \cdot + \cdot 0.0757t \cdot + \cdot 64.3, \\ [-39.7] \quad (22)$$

$$CE5 : \cdot E(u_5(-1)) \cdot = \cdot LOG(AYS(-1)) \cdot - \cdot 0.085 LOG(B(-1)) \cdot - \cdot 0.0078t \cdot + \cdot 0.19, \quad (23)$$

$$CE6 : \cdot E(u_6(-1)) \cdot = \cdot LOG(S(-1) * (1 - TAU(-1)) - 2.13 LOG(CPC(-1)) \cdot \\ - \cdot 0.01t \cdot - \cdot 17.3, [22.5] \quad (24)$$

$$CE7 : \cdot E(u_7(-1)) \cdot = \cdot LOG(TAU(-1)) \cdot - \cdot 0.723 LOG(S(-1) * (1 - TAU(-1))) \cdot \\ - \cdot 0.01t \cdot + \cdot 0.978, [-47.47] \quad (25)$$

$$CE8 : \cdot E(u_8(-1)) \cdot = \cdot LOG(LF(-1)) \cdot + \cdot 0.2 LOG(POP(-1)) \cdot - \cdot 0.02t \cdot - \cdot 15.24 \\ [22.9] \quad (26)$$

As the expected value of the left-hand side is zero, for the interpretation, all variables but those with unit coefficients could be written to the other side to get the standard equation form. This would change the signs of the coefficients. The interpretation of the partial effects, as opposed to the complete solution used below, of the long-term equations, is as follows. (19) relates consumption per capita positively to the terms of trade as in basic trade theory and in our growth model. (20) indicates that the capital stock is higher if the net savings ratio is larger. (21) relates public capital to its investment ratio. According to (22), the terms of trade and the labor force grow in proportion to each other, which is plausible if both are pulled by exports. (23) relates public capital to human capital; we have a well-functioning complementarity between private capital and public investment here for Trinidad and Tobago. (24) indicates that at a higher consumption per capita, more net savings are possible. (25) indicates that public and private capital have higher investment and a complementary relation as the stocks do in equation (23). Finally, (26) indicates that the labor force is lower if the population is higher; this simply reflects the fact that labor force growth is positive and population growth is negative. The long-term relations *CE1-8* are part of the following complete system (*Z* is world GDP, *proil* is the price of oil, *t*-values in parentheses),

$$dy \cdot = \cdot A(CE) \cdot + Bdy(-1) \cdot + Cx \quad (27)$$

Here, *dy* is the (9, 1)-vector (9 rows, 1 column) of first differences of the variables appearing first in the *CEs* and the growth rate of the population. *A* is the (9, 8)-matrix of adjustment coefficients and *CE* is the (8,1)-vector of cointegrating equations (19)-(26); *B* is the (9, 9) matrix of coefficients of the (9, 1)-vector of first differenced terms. *C* is the (9, 4)-matrix of the coefficients of the vector of exogenous variables $x' = (c, t, d(\log(Z))^*t, t*d(\log(proil)))$.¹⁵

¹⁵For the matrices of coefficients, see online appendix.

The period is 1962–2006. We do not put constraints on the adjustment coefficient if they have low t-values. Adj. R-squared for the nine equations are 0.69, 0.9, 0.95, 0.35, 0.99, 0.53, 0.14, 0.62, and 0.91. The possibilities for robustness analysis are limited by the fact that we have just enough observations to run a VECM.

Some interesting aspects that merit interpretation are the following. First, oil prices have an impact on the terms of trade growth as in Watson (2003) and also on the education equation, $d(\log(ays))$, because “most of the government revenues come from oil and gas . . . ” (Artana, Auguste, Moya, Sookram, & Watson, 2007). Second, world income growth, $d(\log(Z))$, has its strongest impact on the growth of education with a positive sign. All dependent variables are related to cointegrated equations through to some statistically significant adjustment coefficients implying that no variable is weakly exogenous. Clearly, the weak point in terms of adjusted R-squared is the equation for public investment, because this is a highly political decision. However, it should also become clear from this that public investment is endogenous. In a VECM, public capital reacts to past variables rather than pushing in the possibly false expectation of a big push (Warner, 2014).

A thousand baseline runs of a dynamic stochastic solution through the Broyden algorithm, using the bootstrap method for innovation generation and calculating the confidence interval from the whole sample, shown in Figure A5 in the online appendix indicate that the data are never outside the confidence interval. Public capital reaches its maximum during the 1990s. The standard interpretation in the literature would be that once a reasonable level of public capital is reached, public investment would be limited to maintenance and repair, the depreciation, with little net investment. Here, in addition, this flattening goes together with oil prices falling from 1981 to 1998, a pattern very similar to that of the terms of trade shown in the figures below. In contrast, average years of schooling keep growing. Unlike African countries (see Yepes, Pierce, & Foster, 2008), oil revenues are reported – in line with our results in Table 1 – to be channelled into infrastructure investment and resource-based industrialization in Trinidad and Tobago (Gelb, 1988) in connection with a special fund abroad that gets 50–70% of the oil windfalls since 1974. The rest is used for current consumption and investment (Auty and Gelb, 1988). As we model growth ideas, the baseline simulation of Figure A5 (online appendix) shows some serial correlation from cycles, but this leads to a bias only if the serial correlation is very strong (Epple & McCallum, 2006). World income growth is clearly growing but oil prices show ups and downs which are not necessarily upward trending. Confidence intervals for savings ratios are getting very large at moments of oil crises, the Latin American debt crisis in the beginning of the 1980s, and the Asian debt crises in 1997/8.

3.5. Transitory and permanent shocks

An important question is whether an increase in public investment can bring the country to a higher level of welfare. Such an increase can come as a one-time increase that then goes its way through the dynamic system, a case that can be seen frequently in our data, or it can come as a permanent increase. The first version can be captured by a one-time shock to the residuals and the second by a permanent shock to the intercept of the equations. Moreover, shocks to world income growth and oil prices can give insights on the working of the empirical model using the theoretical model for the explanation.

Table 1. Growth of Public Capital items in Trinidad and Tobago until 2007.

Public capital item	Period (a)	yearly growth rate (b)
Fixed broadband Internet subscribers (per 100 people)	2002–2007	1,056
Internet users (per 100 people)	1995–2007	0,443
Mobile cellular subscriptions (per 100 people)	1991–2007	0,507
Secure Internet servers (per 1 million people)	2001–2007	0,249
Telephone lines (per 100 people)	1990–2007	0,033
Liner shipping connectivity index (maximum value in 2004 = 100)	2004–2007	0,013
Container port traffic (TEU: 20 foot equivalent units)	2000–2007	0,086
Roads, paved (% of total roads)	1990–2007	0,010
Efficiency adjusted public capital	1990–2007	–0,00012
Non-adjusted capital	1990–2007	0,012

Source: World Development Indicators; author's calculations

Notes:

(a) Starting date limited in WDI; final date chosen as data in Gupta et al. (2014) end here.

(b) Calculated as log difference of first and last observation divided by number of years.

Figure A6 (online appendix) shows the effects of a temporary shock to public investment of 0.1 for τ , which is closer to a gradual phasing in than to a big push.¹⁶ It has a slightly positive permanent effect on public investment as a share of GDP even for the lower bound and increases public capital, followed by a slightly smaller increase in private capital. The effect on years of schooling is slightly positive, and for the labor force fluctuating in the beginning and zero in the long-run average. For the population, the increase is positive but less than for public and private capital and schooling. By implication, per capita GDP and productivity increase at a lower percentage than the capital stocks. These results are qualitatively similar to those of De Frutos and Pereira (1993). We should not draw the conclusion though that this justifies carrying out this policy because per capita consumption falls. The increase in GDP per capita is less than that in taxes paid and private capital invested. For households, the rate of return here is negative because the level of public capital is already high (see also Eden & Kraay, 2014). The terms of trade are first higher for 6 years, then, lower for 21 years, and keep going up and down. Temporary shocks for years of schooling look very similar and therefore are not shown. Temporary shocks to public capital stocks have weak effects fluctuating around zero for all variables. Warner (2014) argues strongly against growth effects from public investment booms and against complementarity effects of public and private capital. The latter is clearly present here and supported by Eden and Kraay (2014) for most poor countries. Warner uses a cross-section regression with lags but no dynamics as it could come at least from lagged dependent variables, if not from true dynamics as modeled in our paper. In addition, he does not use a tax or revenue variable which might absorb some of the negative effects (Blankenau, Simpson, & Tomljanovic, 2007), (Straub and Terada-Hagirawa (2011)) without or with non-linearity as in Fosu et al. (2016). As Warner addresses mainly big push models, he should also use econometric threshold models and take into account the network related critical mass literature (Agénor and Neanidis 2015; Daido & Tabata, 2013). In particular, Daido and Tabata (2013) show that development may be successful if firms decide upon their investments before governments do, although this creates additional problems of forming expectations regarding public

¹⁶As we deal with transitory shocks one-by-one and not several jointly, there is no issue of Cholesky ordering.

investment. The major problem, therefore, may be not whether we have a big push or a leading government, but rather that the government may not follow the needs of firms or very sluggishly so. In contrast, Presbitero (2016) reports cases of too quick increases of public investment leading to weak effects in connection with a lack of absorptive capacity. In our theoretical model, this would be captured by a low elasticity of production of public capital in human capital formation. However, we do not find this in the evidence for Trinidad and Tobago where years of schooling and private capital grow nicely in proportion with public capital after a shock. Results may differ by country, of course, also after taking into account all of these aspects. We fully agree with the practical value of Warner's five major problems discussed on page 65 of his paper. On the other hand, the damages from lack of infrastructure, the problems from poor management, and the necessity to improve both in a well-timed manner are nicely described by Nielsen and Lofgren (2011). This can better be captured by modeling a permanent change as is done here next. From the long-run level effects of the temporary shock in Figure A6 (online appendix) we can conclude that the data reject the idea that we might have a merely exogenous growth process for Trinidad and Tobago, as exogenous growth models have no permanent effects of temporary shocks (Kocherlakota & Yi, 1996).

Figure A7 (online appendix) shows the effects of a permanent increase of the tax or public investment rate by 0.01, called scenario 1, which is even more gradual than the temporary shock of Figure A6. The tax is higher throughout in scenario 1 compared to the baseline and so are human, public and private capital stocks.¹⁷ As in the case of a temporary shock, labor variables react only weakly. Consequently, GDP per capita must be larger, but consumption per capita is lower because the increase in per capita GDP does not outweigh the increase in taxes. Again, less strongly increasing terms of trade indicate more strongly growing quantities of exports and increasing private capital stocks indicate that the value of exports used for capital imports is increased and points to a low price elasticity of export demand. The higher GDP then allows for more tax revenues and public investment. Figure A7 suggests differences in levels growing at a constant rate, implying no growth rate effects.¹⁸ Trinidad and Tobago have a reasonably high public investment rate between 4% and 20% with a mean of 10% and a median of 9%. This is in the order of magnitude of what poor countries should have (see Fosu et al. (2016) for Sub-Saharan Africa and Estache (2010, Table 2) for what is required according to international institutions' estimates). Countries with very good infrastructure, high population densities or high degrees of urbanization may have lower optimal rates (Estache, 2010; Esfahani and Ramirez 2003).

Enhancement of human capital through permanent shocks (not shown) do increase years of schooling, public and private capital and therefore, with slightly falling labor, GDP per capita, but not consumption per capita. This could only happen if human and

¹⁷Similarly, Bahal, Raissi, and Tulin (2015) show the complementarity between public and private investment using a VECM for India in the post-reform period 1980–2012 but crowding out before. Their result is in line with Cavallo and Daudé (2011), who attribute crowding out to weak institutions.

¹⁸In contrast, Agénor (2010) uses functions similar to (1) and (8) but with constant returns to all non-labor factors, public capital being productive in both, and H having a negative impact on the discount rate. A permanent shock to public investment, financed through foreign aid or a reduction of unproductive and not utility enhancing government expenditure, then leads to a higher steady-state growth rate. The model deserves merit as an interesting set of conditions for a big push. However, the set of assumptions emphasized in this footnote also may be a bit optimistic.

public capital get more efficient or more productive. Whether and how these effects can be obtained seems to be unclear so far. The implicit message in Gupta et al. (2014) would be that bureaucracy costs of public capital could be decreased without net disadvantage requiring less of an increase in public investment. For human capital, the question regarding TTO would be whether its use can be improved on the supply side and on the absorbing demand side (Longmore et al., 2014). As human capital is moving out (brain drain is more than 70% of people with tertiary education abroad) the problem seems to be more on the demand side; Artana et al. (2007) point to a lack of business opportunities and to a lack of a “... culture of innovation to drive productivity”. Finally, diversification is most likely to happen in the non-traded sector, because it seems inevitable that the exchange rate fluctuates wildly with the oil price to an extent that newly exporting sectors are hardly able to digest. This intuition is also supported by the increasing rates of return for capital in the service sector and the history of a falling share in GDP of the non-petroleum tradable sector.

A common question of balance-of-payments-constrained growth models, including Keynesian and neo-classical two-gap and Prebisch–Singer models, is what a shock of world income growth does to the economy. We add a permanent shock to all equations of (27). The size of the permanent shock is 0.01 multiplied by the coefficients $c(k,3)*t$ of $dlogZ$ in these equations, which is equivalent to adding 0.01 to the growth rate of world income. The result compared to baseline is shown in Figure A8 (online appendix). The terms of trade are increasingly higher. Capital stocks are also increasingly higher, indicating that higher terms of trade are not turned into lower export quantities by high price elasticities in a way that might outweigh the effect of world income on exports. In particular, public capital, which partly goes into education, goes up as in some historical periods of Brazil (Musacchio, Fritscher, & Viarengo, 2014). Also, it indicates that exports are not predominantly used for other imports like consumption or intermediates. Savings ratios hardly react except for some strong ups and downs in the middle phase – as in the previously shown shocks – indicating that the investment stems from an increase of output and its effects on savings. Public investment does react and therefore public capital follows the private stock. Population increases strongly, probably through immigration (as in Figures A8 and A9), which is plausible if Trinidad and Tobago are making better use of world economic conditions through higher income elasticities of export demand. Consequently, the labor force also grows beyond the baseline, although average years of schooling follow the better prospects of the economy and should therefore partially reduce labor supply. In total, consumption per capita is then larger than before for about 30 years. As public and private capital stocks increasingly grow apart, we have the growth rate effect that appears in our growth rate formulas for the long run. The data show that private capital grows more quickly than public capital and under the world income shock this is reinforced because more quickly growing exports buy more quickly growing capital whereas public capitals draw on consumption via taxes. The extreme uncertainty in the gross savings rate happens to occur in 1979, the year when the restrictive monetary policy starts in the USA.

Finally, an oil price shock is in principle positive for sellers but negative for consumers. We implement it as a permanent shock of a 1% increase in the oil price growth rate by way of adding the coefficient $c(k,4)*t$ of the oil price growth variable

multiplied by 0.01 to all equations in (27). The result is presented in Figure A9 (online appendix). Terms of trade increased more than before, with ups and downs similar to those of the oil price. A slightly weaker increase in the capital stock indicates that exports increase less strongly and/or other goods are imported; differences in capital growth do not have the same shape as that of the terms of the trade difference. Public capital follows private capital again and so do public investments and average years of schooling, but all downwards now. Labor force growth and population growth go up though in the long run, perhaps through migration, and stimulation of the non-traded goods sector. Consumption per capita is going up through this and imported consumption goods. Oil price increases seemingly stimulate consumption and labor but not human, public and private capital. This suggests that producing oil is more important than buying oil.

In Figures A6–A9 terms of trade are clearly endogenous, reacting to supply, demand, and the oil component, and the assumption of exogenous terms of trade is clearly oversimplifying as admitted by Worrell, Lowe, and Naitram (2013).

All interpretations of shock scenarios are in line with the theoretical model, although the model is extended to include oil prices because of its relevance for Trinidad and Tobago. Moreover, a permanent shock to public investment, unlike to that from world income growth, seems to have level effects rather than growth rate effects, which suggests that we do not have an endogenous growth model (see Kocherlakota & Yi, 1997) behind the data of Trinidad and Tobago.

As the permanent level effects of temporary shocks exclude the possibility of an exogenous growth model and the permanent effect on the level rather than growth rate of permanent shocks exclude the possibility of an endogenous growth model, the data of Trinidad and Tobago must be driven by a semi-endogenous growth process.

4. Summary and conclusion

We have merged two growth models with a semi-endogenous growth mechanism; a human capital augmented model with non-rivalrous, possibly efficiency-adjusted public capital and a model with imported capital goods, limited export demand and endogenous terms of trade. The non-rivalry in the use of public factors in connection with the different abilities of the household to form human capital leads to different preferred rates of public investment and a strong role for policy to decide on public investment. By implication, public investment may be threatened by tax resistance. The model is relevant for countries without machinery sector and without much R&D. It shows how investment in public capital enhances exports and how export demand helps to finance public capital. Therefore, it is the first to integrate two theoretical and empirical strands of literature into growth theory. The model has three major driving forces: exogenous technical change, the growth of the number of households with access to public capital and the world income growth. Depending on whether the supply side forces or the demand side is growing more quickly, terms of trade may rise or fall in the long run. In the transition to the steady state public investment inefficiency possibly distorts the allocation against public investment leading to more private investment, consumption, and exports and lower terms of trade.

We have used the major variables of the model in a panel VAR for Sub-Saharan Africa for the motivation (see online appendix) and in a vector-error correction model

with data for Trinidad and Tobago. It has hardly any machinery sector or R&D, but has reached the ranks of the high-income OECD countries recently, and therefore must have spent the oil money well. Moreover, the growth rates for public capital without efficiency adjustment are lower than for all physical real capital data for ports, roads, internet, and telephones. Therefore, we do not use the efficiency-adjusted data of Gupta et al. (2014) based on the PIMI index, which makes the growth rates of public capital even lower. The vector error-correction model is enhanced by oil prices because Trinidad and Tobago have a strong oil sector. Thus, we contribute to the empirical dynamic simultaneous equation literature adding a prominent role of world income growth, oil prices and the terms of trade.

Transitory and permanent shocks to public investment increase public and private capital as well as education permanently and therefore the GDP per capita, but the effect is too weak to outweigh the negative effect of taxation on consumption per capita. The reason is that public investment shares are already high in Trinidad and Tobago and therefore should not be increased. In addition, higher public investment reduces export quantities and increases the terms of trade sufficiently much to allow for buying more capital goods. The latter effect points to price inelastic exports.

Permanent shocks to the growth rates of oil prices and world income show that higher trade volumes lead to more imported capital goods, higher GDP, more tax revenues, higher public investment, more public and private capital and consumption per capita. However, oil price growth increases lead to more consumption and less human, public and physical capital.

As transitory shocks on public investment have level effects, the VECM with data for Trinidad and Tobago does not follow the logic of an exogenous growth model, and because permanent shocks have level effects but no growth rate effects, we do not find reactions that are typical of endogenous growth models. By implication, the data support a semi-endogenous growth model for Trinidad and Tobago with all the mechanisms of our theoretical model.

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No potential conflict of interest was reported by the authors.

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