What are the drivers of the Swedish sustainable development path? New evidence from Bayesian Dynamic Linear Models.

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Abstract

In this paper, we use Swedish Genuine Savings (GS) indicators, extended to account for a wider range of impacts on natural and human capital than previous GS indicators, to study Swedish long-term sustainability. Following Ferreira et al (2008) and Greasley et al (2014), technological progress and population effect are also included in the GS measures. We introduce a new quantitative methodology to the literature on sustainable development by applying Bayesian analysis of Dynamic Linear Models (DLMs) to GS indicators. This is the first time that parameter uncertainty has been used in examining the links between GS and long term well-being, providing new empirical evidence on the driving forces that underpin Swedish sustainable development.

Keywords: Dynamic Linear Model, Genuine savings, Sweden, Weak sustainability

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1. Introduction

In this paper, we use extended time series for changes in various Swedish capital stocks, including changes in the stocks of human and natural capital, to assess whether they can be used to predict future Swedish well-being. This paper contributes to the literature on sustainable development by assessing how well the Genuine Savings (GS) indicators developed in the environmental economics literature function in practice; this has been done in previous studies, but rarely with as long and comprehensive time series as those we use here. We also contribute by estimating the time-varying impact of the GS indicators on future well-being using DLM. We estimate the model with a Bayesian approach and found a weak predictive power with a consistent increasing dependent trends for all GS explanatory variables.

From a capability-based view, sustainable development is a path of an economy where the real value of changes in the capital stocks is non-negative. From an outcome-based view, it is a path of an economy where utility or real consumption per capita is not declining. A well known definition in Pezzey [19] states that development is sustainable if future utility is non-decreasing. While strong sustainability models focus on the preservation of ecological goods, weak sustainability - the sustainability concept favoured by most economists - deals with future well-being as a function of capital stocks. In recent years, the concept of sustainable development also implies sustainability of ecological, economic, and social systems in the long run. New definitions have invoked human responsibility in temporal scope, spatial scale and cultural reach.

In the literatures on weak sustainability, wealth accounting and national income accounting, GS is a forward-looking measure which has been considered as the leading economic indicator of changes in future well-being. The concept is also known as Adjusted Net Saving (ANS) or comprehensive investment. In that sense, GS is the real value of changes in the capital stocks. The theoretical literature on GS suggests that, properly measured, net savings should be equal to changes in well-being and that negative GS implies unsustainability in a competitive economy. Along the lines of Hanley et al. [9] and Ferreira and Vincent [3], the current savings should equal the change in the present value of future well-being along the optimal path of an economy.

Since the current state of the economy is crucially characterised by its resources, technology, current level of consumption and population, the driving forces of a general capability-based model are typically well-being, wealth and consumption.

1.1. A simple GS model

Hartwick [10] studies a Cobb-Douglas production function which is constant return to scale in production and optimality in the resource extraction plan. In a closed economy, the Hartwick rule indicates that the necessary condition of sustainability is that net savings in each period equals to zero so that total capital is maintained. Nevertheless, Mitra [15] proves that the Hartwick rule is a necessary but not sufficient condition for the optimal path.

In a simple closed economy with a single resource, Hartwick [11] discusses the GS model in an intertemporal optimization framework. Let W be the present value of utility on the optimal path. It is assumed that the utility of consumers U is a function of consumption C and environmental services B, $U = U(C, B)$. Denote r as a fixed pure rate of time preference. The social planner's problem is written as follow

$$Max \quad W = \int_t^\infty U(C, B)e^{-rs} ds \tag{1}$$

subject to

$$\begin{aligned}
\dot{K} &= F - C - a - m \\
\dot{X} &= e(F, a) - d \\
\dot{S} &= g(S) - R \\
\dot{N} &= q(m)
\end{aligned}$$

where $\dot{K}$ is investment in produced assets. The production function of the single resource is given by $F(K, R, N)$, where K is non-tradable capital, R

stands for resource use and N is human capital. a denotes pollution abatement expenditures and m is current education expenditures or investment in human capital. Pollution emissions e depend on the production function F and on abatement a, $e = e(F, a)$. Furthermore, $\dot{X}$ is the net change in the stock X of pollutants, with d as the natural dissipation of pollution. The change in the resource stock $\dot{S}$ is a function of the resource stock's natural regeneration $g(S)$ and the economy's resource use R, so that $\dot{S} = g(S) - R$.

The production function is assumed to be constant returns to scale, continuous, strictly concave and smooth on the positive orthant. Additionally, it exhibits positive marginal returns to input factors, positive marginal cost of investment and follows the Inada growth conditions. We also assume that the utility function is concave, strictly increasing, continuous and smooth on the positive orthant. Moreover, the function of discounted utilitarianism W captures intergenerational well-being. Marginal utility of consumption tends to infinity as consumption goes to zero. Besides, the discount factor is smooth and bounded. See Sefton and Weale [21] for more details.

Following Hamilton and Clemens [8], the Hamiltonian function is given by

$$H = U(C, B) + U_C(\dot{K} - (1 - be_F)F_R(R - g) - b(e - d) + q/q'), \qquad (2)$$

where b is the marginal cost of pollution abatement. The term be_F is the effective tax rate on production. The quantity $1/q'$ is the marginal cost of creating a unit of human capital. As a result, GS is defined as a sum of investment in produced assets and human capital, less the net depletion of natural resources and net accumulation of pollutants.

$$GS \equiv \dot{K} - (1 - be_F)F_R(R - g) - b(e - d) + q/q'. \qquad (3)$$

The following sections will discuss briefly two main lines in GS literature that are measuring different GS forms and testing the predictive power of GS.

1.2. Measuring extended forms of GS

A crucial result from both theoretical and empirical research is that the future well-being of a country should conform closely with a comprehensive concept of the net investment including produced capital, natural capital and human capital. It turns out that evaluating sustainability is equivalent to assessing changes in society's aggregate capital stock, with this change in aggregate stock equivalent to an extended GS measure. An additional factor boosting GS can be technological improvement, which increases the productive capacity of the existing capital stock.

Pezzey and Burke [20] establish a hybrid indicator of the global well-being sustainability that consists the cost of population growth, CO_2 emissions and the benefit of technical progress. Their extended adjusted net savings measure is given by

$$ANS = \mathbf{P}(t)\mathbf{K}^{\star}(t) - \gamma\mathbf{P}(t)\mathbf{K}^{\star}(t) + L(t)x(t)\,, \tag{4}$$

where $\mathbf{P}(t)$ is vector of rental prices for different capital stocks (including human and natural capital), $\mathbf{K}^{\star}(t)$ is vector of net investments in those stocks, γ is a (constant) population growth rate, $L(t)$ is population and $x(t)$ is technical progress term. The first term on the right hand side measures net investment in the different capital stocks, the second term measures the reduction in the per capita capital stock caused by population growth, and $L(t)x(t)$ measures the effective addition to the capital stock from exogenous technological progress. GS measures accounting for technological progress were also discussed in Weitzman and Lofgren [23]. More recently, Greasley et al. [6] introduce empirical measures of GS augmented by changes in Total Factor Productivity (TFP). The results reveal the present value contribution of TFP growth to future income. However, Pezzey [19] argues that adding technological value may be problematic and that the existing TFP data is not adequate for green accounting.

1.3. A brief literature review on testing the predictive power of GS

In the framework of sustainable development, debates on how to test the predictive power of GS and its extended forms have recently received particular interest. The empirical literature for example, Ferreira and Vincent [3], Bank [1], Ferreira et al. [2], Gnegne [5], Mota and Domingos [16] and Greasley et al. [6], has focused on answering the question how different forms of GS affect the stream of well-being over time. However, as noted by Hanley et al. [9], there are inconsistencies in empirical results because many of these studies have used panel or time-series datasets covering only relatively short time periods; this is always problematic in time series analysis, but is of course especially problematic when the purpose is to study long-term sustainability which, by definition, extends over multiple generations.

Following WorldBank [24], we assume that the economy is competitive, that households maximize well-being, and that all externalities are internalized. The current change in total wealth per capita equals the present value of changes in consumption per capita. As a result, a change in the total real wealth per capita should be equivalent to the expression

$$G_0 = \sum_{t=1}^{T} \frac{1}{(1+r)^t} \left(\frac{C_t}{N_t} - \frac{C_{t-1}}{N_{t-1}}\right), \tag{5}$$

where t is time index, T is time period, r is discount rate, C is the change in consumption and N is total population. As seen in Ferreira et al. [2], if PVC_t is the present value of changes in future consumption per capita at time t, then PVC_t is defined as:

$$PVC_t = \sum_{v=t}^{t+T} \left(\frac{C_{v+1}/N_{v+1} - C_v/N_v}{\prod_{j=t}^{v} (1 + \rho_j - \gamma_j)} \right) \tag{6}$$

where ρ_j is the consumption discount rate at time j and γ_j is the population growth rate at time j. If the population growth rate of the country is assumed to be constant, this gives the relation

$$PVC_t = \beta_0 + \beta_1 g_t + \varepsilon_t\,, \tag{7}$$

where g is a measure of investment. Ferreira and Vincent [3] established a theoretical framework for testing the properties of GS under three hypotheses.

Hypothesis 1. $\beta_0 = 0$ and $\beta_1 = 1$

Hypothesis 2. $\beta_1 > 0$ and $\beta_1 \to 1$ as the net investment term includes more types of capital.

Hypothesis 3. $\beta_1 > 0$.

Those are listed in decreasingly rigid order. The first hypothesis states that the difference between current and average future consumption equals net investment. The second one implies that net investment becomes more consistent with the theory when it is extended. The third merely implies that net investment affects future consumption.

One of the early empirical papers studying this, Ferreira and Vincent [3], found that the first hypothesis was rejected; however, some support for hypotheses 2 and 3 were obtained. Additionally, the estimators of β_1 indicated shortcomings of education expenditure as proxy for human capital formation. Ferreira et al. [2] estimated weakly negative β_1 coefficients for gross and net investment in physical capital only, but positive β_1 coefficients when net investment was augmented by green investment and by population measures (though still without considering education expenditure or other human capital investment, and still without considering pollutant damages). Similar to the tests in Ferreira et al. [2], Bank [1] provided reasonably positive estimates of β_1 for several countries over a 20 year time horizon, but were unable to confirm the stricter versions of the hypotheses.

Using Portuguese data over the period 1990-2005, Mota and Domingos [16] show that adding TFP does not improve the explanatory power of their tests, but their production function did not account for green capital or pollution. Finally, Greasley et al. [6] tests how GS predicts future consumption per capita and real wages in the long run for Britain over 20, 50 and 100 time horizons. They conclude that British GS, and some GS-type measures augmented by TFP and population growth, might forecast changes in future well-being well over 50 or 100 years in the future. In addition to technological progress, a wealth dilution effect was also introduced and had substantial effects on some coefficients of β_1. The empirical results were sensitive to the choice of time horizon and discount rate over the period 1765-2000.

Lindmark and Acar [13] derive Swedish GS time series over the period 1850-2000, one of the longest GS time series ever developed. The estimates include physical capital, natural capital, current expenditures in education as a proxy of investment in human capital, and environmental pollutants, such as CO_2, SO_2 and NO_x. One of their findings is that Swedish GS per capita at fixed prices was negative during the 19th century, and they also note that Sweden has experienced a trade deficit during most years from the 1870s.

We draw on the work of Lindmark and Acar [13] and extend the definition of green GS further by subtracting the real value of contaminated water and food. This paper is motivated by different concerns raised in the literature on GS. First, the theory of weak sustainability highlights that a country associated with positive GS should experience non-declining future utility. Still, there is a need to understand more about several GS measures and how do they play roles in sustainable development. Second, all previous econometrics models in the empirical literature have considered parameters as constants over time. This fact leads to a lack of dynamic patterns. We break that classical assumption so that the models adapt more efficiently with the historical reality. Hence, we introduce a Bayesian approach to DLMs of GS which incorporate unknown parameter uncertainty.

The rest of the paper is organized as follows. Section 2 introduces theoretical DLMs and briefly discusses how Bayesian estimation deal with DLMs. Section 3 presents data description and the empirical results. The last section concludes anddiscusses possible future research.

2. Model specification and Bayesian analysis

2.1. Dynamic Linear Models

In this section, theoretical econometric models are formally defined through DLM. The model not only brings the flexibility in capturing the dynamic effects between the dependent and independent variables, but also treats the assumption violations of simple linear models. Petris et al. [18] consider DLMs as the generalization of linear regression model where the coefficients are allowed to vary over time,

$$y_t = \alpha_t + x_t \beta_t + \sigma \epsilon_t \tag{8}$$

$$\alpha_t = \alpha_{t-1} + \sigma_\alpha \xi_t \tag{9}$$

$$\beta_t = \beta_{t-1} + \sigma_\beta \eta_t \tag{10}$$

where the dependent variable y_t is present values of changes in future consumption per capita over T year horizon PVC_t. The independent variable x_t is one of the GS indicators listed in Section 3. In DLM, (8) is observation equations where $\epsilon_t \sim iid.N(0,1)$ and (9) - (10) are state equations where $\xi_t, \eta_t \sim iid.N(0,1)$. The parameter set of the DLMs is $\theta = \{\sigma, \sigma_\alpha, \sigma_\beta, \alpha_t, \beta_t\}$ where σ, σ_α and σ_β are the conditional standard deviations of y_t, α_t and β_t, respectively.

In the context of DLM, the strength of relationship between the dependent variable y_t and the independent variable x_t is measured through estimates of β_t. Also α_t represents for the effect of unobservable factors which are not accounted in x_t. Different from the previous econometrics analysis in the literature on GS, our proposed models provide the gains from a feature that the value of β_t changes over time. The time varying dependence structure is captured in transitional equation (10). We assume that β_t follows a random walk at each point of time index t. The effect of unobservable factors is also considered to follow a random walk. In general, we model the non-linearity relationship between y_t and x_t accounted for structural changes and omission of variables.

2.2. Bayesian Approach

We further complement classical econometrics models with insights from Bayesian approach to estimate DLM, see e.g. Petris et al. [18]. The advantages of Bayesian framework stand on the combination between the prior information and the empirical data. We make use of Bayesian DLM since it permits us to obtain the posterior distribution and predictive distributions of future values that associate with the uncertainty of characteristic of interest. Consequently, Bayesian analysis is the most natural and straight forward to deal with the updating scheme in equation (8 - 10).

According to Gelman et al. [4], we assume a inverse gamma prior distribution (IG) for $\sigma^2 \sim IG(0.001, 0.001)$, $\sigma_\alpha^2 \sim IG(0.001, 0.001)$ and $\sigma_\beta^2 \sim IG(0.001, 0.001)$. These priors are weakly informative and could cover for a wide range of parameter values of σ. The priors combined with data information will derive the posterior distribution at each time index due to Bayes's theorem. The posterior is proportional to the prior and the likelihood. For each model, we generate 20.000 iterations and eliminate 10.000 first iterations for burn-in, then we took every 10th generations to prevent autocorrelation. Finally, we obtain 1000 samples from the posterior distribution.

Rstan package is employed as a tool for Bayesian inference see Stan Development Team [22]. Rstan uses a variant of Hamiltonian Monte Carlo (HMC) algorithm to generate a sequence of random samples from a posterior distribution. Compared to Metropolis-Hastings algorithm, HMC can reduce the correlation between successive sampled states. It also converses quickly to the target distribution in high dimension, see Neal [17].

3. Data

We demonstrate the Bayesian approach of DLMs applied to the GS time series for Sweden over the period 1850-2000. In particular, our dataset is based on the data reported in Lindmark and Acar [13]. However, in order to address the research questions, we supplement these data with indicators of future well-being as given by the expression (6) using Swedish real consumption per capita series. Therefore, two different forward-looking periods corresponding to $T = 20, 50$ year horizons were developed as PVC20 and PVC50. We now turn to the list of explanatory GS variables that include, starting with the most restrictive measure:

1. $NETPINV$ is short for the net savings measure in the traditional national accounts, which contains net domestic investment in physical capital and net exports.

2. $GREENINV$ stands for $NETPINV$ plus changes in the stock of natural capital and less the value of contaminated water and food.
3. GS is $GREENINV$ plus expenditures on education and minus the value of damages from pollutants.
4. $GREENTFP$ is $GREENINV$ plus the value of changes in technological progress. At the time index t, $GREENTFP_t = GREENINV_t + \Delta TFP$, where ΔTFP is the present value over T year time horizon of the first difference of GDP_t, ΔGDP_t. In this context, $GDP_{t+T} = GDP_t(1 + \sum_{i=t}^{t+T} TFP_i)$. Furthermore, annual TFP series is constructed as follows

$$TFP = GDP/\left(L^a K^{1-a}\right), \tag{11}$$

where labour L stands for total employment, capital K is the stock of reproduced capital, a is the elasticity of output with respect to labour. Following Lindmark and Vikström [14], the elasticity of output with respect to labour or factor share is $a = 0.5$ covering the period 1850-1920 and $a = 0.65$ over the period 1920-2000.
5. $GSTFP$ is short for GS plus the value of changes in technological progress, $GSTFP_t = GS_t + \Delta TFP_t$.
6. $GSWPOP$ stands for GS less wealth dilution per capita. At time t, $GSWPOP_t = GS_t - \gamma_t\omega_t$, where the wealth dilution per capita $\gamma_t\omega_t$ is the product of population growth rate γ_t and wealth per capita ω_t. Total capital including natural capital, produced capital and human capital is computed as a proxy for total wealth in Sweden.

4. Empirical results

4.1. Descriptive Statistics

Figure 1 shows the evolution of present value of future changes in real consumption per capita using discount rate of 3%. As more than 100 year period, $PVC20$ increase exponentially from 1850 to 1990. Also $PVC20$ is always greater than $PVC50$ due to the population growth rate.

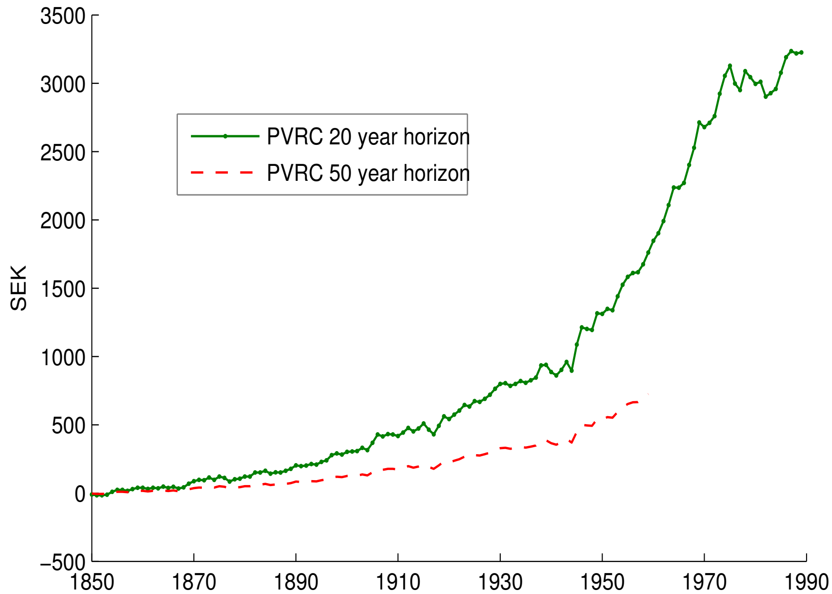

Figure 1: Present value of future changes in real consumption per capita, 3% per annum discount rate (SEK)

Table 1 describes some summary statistics for the dependent variables PVC and the list of explanatory variables. In general, $NETPINV$ has the highest mean and standard deviation. When adjusted for stock of natural capital and contaminated water and food, $GREENINV$, GS and $GSWPOP$ behave quite similarly. GS was negative until 1910. It is the stylized fact that industrialization beginning from 1910 was expected to shift Swedish GS from negative to positive values (see Figure 2) while the other GS and $GREENINV$ index adjusted for technological progress were mostly positive for all time horizons.

4.2. Estimation results

Tables 2 and 3 report posterior means of the parameters in the DLMs described in equation (8 - 10). The dependent variable y_t is the present values of changes in future consumption per capita over 20 and 50 year horizons, $PVC20$ and $PVC50$ respectively. For all columns, figures in parentheses are the stan-

Variable	Count	Mean	Standard deviation	Minimum	Maximum
PVC20	140	975.57	1032.68	-16.52	3235.05
PVC50	110	203.29	191.97	-6.81	725.41
NETPINV	151	3250.77	5186.25	-11.63	23564.52
GREENINV	151	1725.98	3069.01	-266.19	14904.64
GS	151	1870.22	3272.49	-587.76	15532.33
GSWPOP	151	1868.98	3273.14	-587.76	15532.07
GREENTFP20	131	3147.50	2937.38	16.65	10913.35
GREENTFP30	121	2888.51	2514.31	19.37	9276.11
GSTFP20	131	3154.92	2961.87	-44.25	10971.07
GSTFP30	121	2892.12	2536.18	-38.92	9330.63

Table 1: Descriptive statistics for key variables from 1850 - 2000

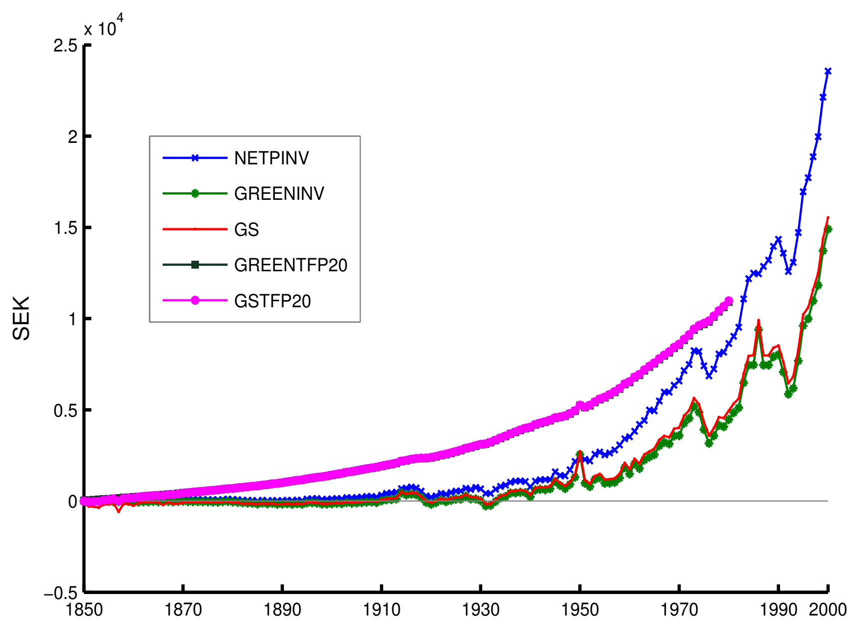

Figure 2: Net investment and GS adjust series per capita (Fixed 1912/13 prices)

dard deviations. The posterior means of $\{\sigma, \sigma_\alpha, \sigma_\beta\}$ are quite similar among the DLMs. For example,

$$PVC20_t = \alpha_t + GS_t\beta_t + 1.902\epsilon_t \tag{12}$$

$$\alpha_t = \alpha_{t-1} + 29.429\xi_t \tag{13}$$

$$\beta_t = \beta_{t-1} + 0.038\eta_t \tag{14}$$

The posterior mean of σ_β shows that the relationship of GS and PVC20 in each period will fluctuate from its past value with a standard deviation 0.038. While the posterior mean of σ_α describes the noise contribution of other unobservable factors to the trend of PVC20, standing at 29.429. The realized value of $PVC20_t$ will deviate from its predicted mean by $\sigma = 1.902$, suggesting that we obtain a slight error from the filter curve. In comparison between the dependent variables $PVC20$ and $PVC50$, the estimates over 50 year horizon are proportional to the ones over 20 year horizon. The posterior mean of σ is higher in all models explained for $PVC20$ which implies a higher level of uncertainty in term of prediction.

y_t	PVC20	PVC50	PVC20	PVC50	PVC20	PVC50	PVC20	PVC50
x_t	NETPINV		GREENINV		GS		GSWPOP	
σ	0.92	0.577	2.109	1.272	1.902	0.831	1.855	0.614
	(1.305)	(0.517)	(1.757)	(0.598)	(1.746)	(0.746)	(1.545)	(0.622)
σ_α	23.365	8.065	29.889	9.178	29.429	9.586	29.482	9.6
	(2.645)	(0.802)	(4.294)	(0.941)	(3.784)	(0.922)	(3.77)	(0.935)
σ_β	0.024	0.019	0.045	0.036	0.038	0.028	0.039	0.028
	(0.004)	(0.003)	(0.011)	(0.006)	(0.008)	(0.004)	(0.008)	(0.004)

Table 2: Posterior mean of the parameters in the Swedish DLMs for the periods $1850 - 2000$

y_t	PVC20	PVC50	PVC20	PVC50	PVC20	PVC50	PVC20	PVC50
x_t	GREENTFP20		GREENTFP30		GSTFP20		GSTFP30	
σ	4.753	1.563	4.299	1.467	4.891	1.696	5.629	1.755
	(2.166)	(0.836)	(2.422)	(0.865)	(2.469)	(0.815)	(1.957)	(0.848)
σ_α	7.978	2.798	7.58	2.739	7.862	2.69	6.752	2.384
	(2.563)	(1.022)	(2.853)	(1.049)	(2.745)	(1.02)	(2.587)	(1.04)
σ_β	0.013	0.008	0.012	0.007	0.013	0.008	0.012	0.007
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)

Table 3: Posterior mean of the parameters in the Swedish DLMs for the period $1850 - 2000$

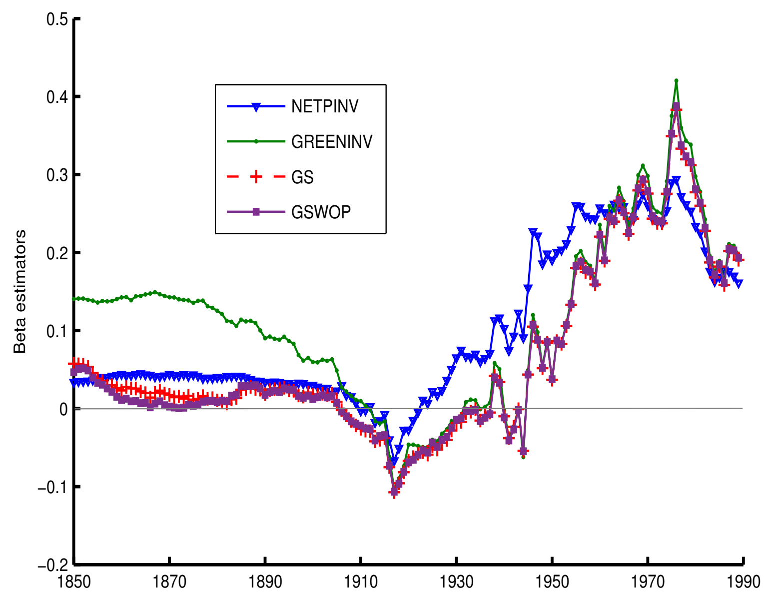

Figure 3: Posterior mean of β in DLMs for the period 1850-2000 corresponding to the dependent variable $PVC20$.

In each period, β_t follows a random walk in Figure (3 - 6). With the common measurement of GS, the behavior of β_t are similar among $NETPINV$, $GREENINV$, GS, $GSWOP$, see Figure 3. Although there is a fluctuation of

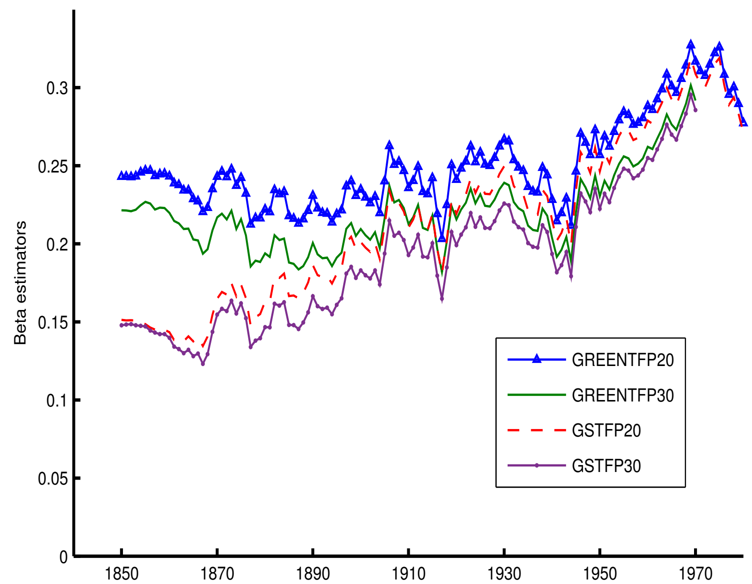

Figure 4: Posterior mean of β in DLMs for the period 1850-2000 corresponding to the dependent variable $PVC20$.

β_t before 1950 from positive to negative, it is not statistically significant. The standard deviation of β_t after 1950 becomes smaller and reach upward to one which guarantees the prediction power of GS to Swedish well-being. This is also coincident with the industrialisation revolution of Swedish after the second war war. However, if we account for the technological progress in GS, Figure 4 shows a clear upward trends of β_t through out the periods. In general, the relationship of GS and Swedish well-being is strengthen when account for more factors as the second hypothesis suggests.

The dynamics of the effects of different GS forms to $PVC50$ are illustrated in Figure 5-6. Notice that in each period, the realized value of β_t will deviate from its mean with a standard deviation σ_β that are estimated in Table 2 - 3. We observe a similar pattern like $PVC20$ despite of less significant. Accounting for the technological progress also improves the prediction power of GS. It is a sign that the measurement error of GS had reduced and β_1 is decreasingly biased toward zero.

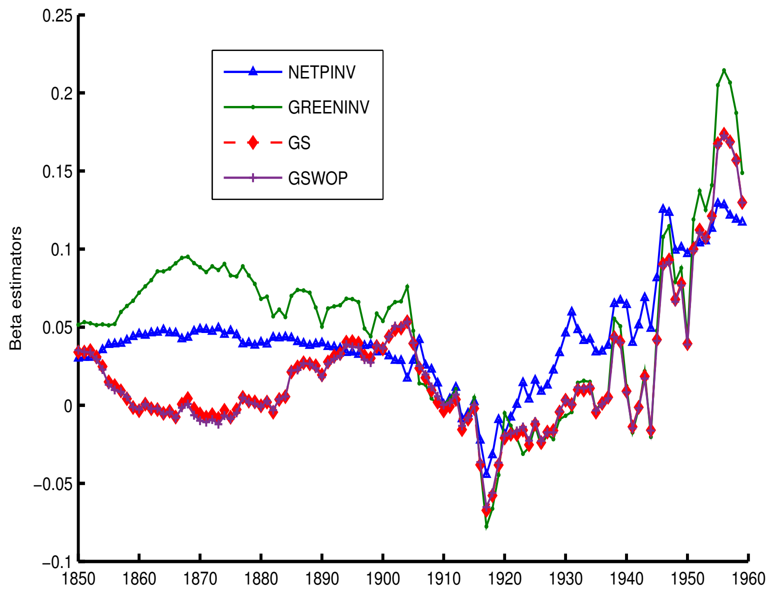

Figure 5: Posterior mean of β in DLMs for the period 1850-2000 corresponding to the dependent variable $PVC50$.

5. Conclusions

In this paper, we have extended the measure of GS to account for wider range of impacts on natural resource, human capital and technological progress. We found that accounting for the technological progress helps to improve the prediction power of GS in long run. We also use the DLM and apply Bayesian approach to analyse the dynamic effect of GS to Swedish well-being. The estimated results show that there are increasing dependent trends with all explanatory GS variables. It is suggested that the measurement error of GS reduced and β_1 is decreasingly biased toward zero.

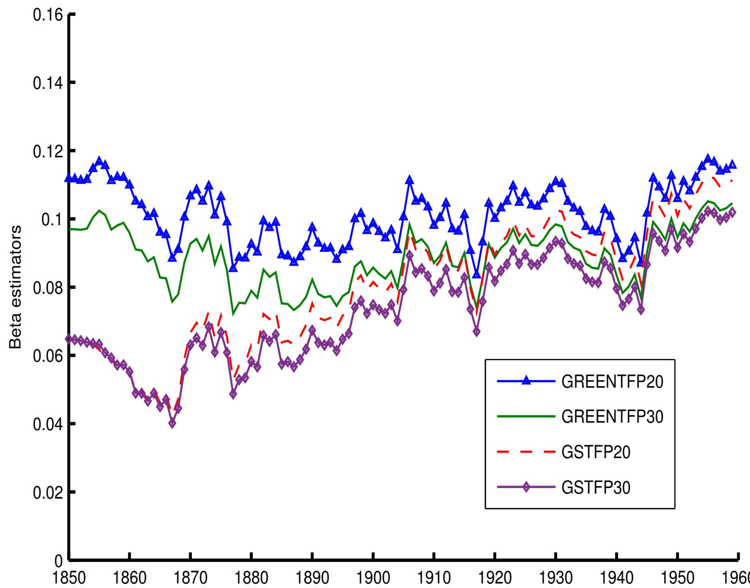

Figure 6: Posterior mean of β in DLMs for the period 1850-2000 corresponding to the dependent variable $PVC50$.

In the lines of future research, GS could incorporate with new dimensions accounting for long run net national income such as endogenous measure of technology, R & D expenditure, energy intensity, indirect trade. Social capital might be included as a measure of quality of institutions and social network. Additionally, degree of openness is expected to shift the development. Also, the sustainable path is a projection of structure of economy and prices system which is influenced by openness and globalization.

Acknowledgments

Two of the authors, Nguyen Thu and Nguyen, have financially benefited from the research fund of the Foreign Trade University, Vietnam.

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