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ANALYSIS

Economic openness and green GDP

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Abstract

Since the early 1990s there have been several attempts to develop national income accounting systems which recognize the negative impacts of environmental degradation and income inequalities on economic welfare. Collectively, these "green" gross domestic product (GDP) studies have generated a wealth of new time series data sets which can be used to reexamine the links between GDP and a host of factors commonly included in traditional economic growth models. In this paper, we develop models of green GDP growth and the gap between traditional and green GDP by using a panel data set from eight countries spanning 30–50 years. In both the growth and gap models, the effects of economic openness are tested. We find strong and robust results suggesting a negative nonlinear correlation between openness and green GDP growth and a positive nonlinear correlation between openness and growth of the gap between traditional and green GDP. While green GDP accounting systems are still in their infancy, our paper nonetheless implies that once these more comprehensive measures are fully developed, empirical models which explore factors contributing to the growth of economic welfare over time should be reexamined.

Keywords: Green GDP; ISEW; GPI; Openness; Growth models

1. Introduction

Theoretically, it has been well established that gross domestic product (GDP) fails as a true measure of economic welfare (Stockhammer et al., 1997). Among other shortcomings, GDP has been criticized for its failure to appropriately address the degradation and depletion of natural capital, gross income inequalities, and economic activity that is purely defensive in nature such as expenditures needed to clean up toxic waste (Castaneda, 1999; Torras, 2003). Moreover, by only counting those goods and services that are priced in the market, GDP ignores a large number of economically valuable inputs and outputs that are not bought and sold in the marketplace such as the wide range of ecosystem service values associated with protected natural areas (NRC, 1999).

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Beginning with the seminal work of Daly et al. (1989) there have been several attempts to develop alternative national income accounting systems that address these deficiencies. Collectively, these systems measure what is commonly referred to as "green" GDP. Major objectives of these green GDP accounting systems are to provide a more accurate measure of welfare and to gauge whether or not an economy is on a sustainable time path (Hanley, 2000). Two of the most popular green GDP systems are the Index of Sustainable Economic Welfare (ISEW) and the Genuine Progress Indicator (GPI). Examples of countries with ISEW data include Austria, Chile, Germany, Italy, the Netherlands, Scotland, Sweden, and the United Kingdom, while the United States and Australia offer examples of nations addressed by proponents of the GPI (Neumayer, 2000). A more standardized alternative is being developed for use as an annex to the United Nations System of National Accounts (UN, 2003). Applications of these new accounting systems provide compelling evidence of a widening gap between traditional and green GDP, indicating that over time, more and more economic activity may be self canceling from a welfare perspective (Max-Neef, 1995).

While methodologies differ somewhat, the ISEW, GPI, and other green GDP accounting systems all involve three basic steps (Stockhammer et al., 1997; Neumayer, 2000). Computation usually begins with estimates of personal consumption expenditures, which include both market and non-market goods and services. Deductions are then made to account for purely defensive expenditures such as pollution related costs or certain avoidable health care costs such as those related to automobile accidents. Deductions for costs associated with degradation and depletion of natural capital incurred by existing and future generations are also made at this stage. The final step is to weight the result from the second step by an index of the inequality in the distribution of income and labor to arrive at the final green GDP measure.

While theoretical and computational issues hinder universal acceptance of any of the green GDP accounting systems, they nonetheless provide a source of time series data which can be used to reexamine the links between GDP and a host of factors commonly included in traditional economic growth models. One factor subject to intense scrutiny in recent years is economic openness.

A number of studies have reported on the beneficial aspects of more open trade regimes, noting, for instance, that export expansion raises the rate of economic growth by way of its impact on total factor productivity (Dar and Amirkhalkhali, 2003). Other studies link greater openness to deteriorating social and environmental conditions, such as increased income inequality or greater emissions of greenhouse gases (Baten and Fraunholz, 2004; Managi, 2004). An econometric study of the effects of openness on green GDP can shed light on this debate.

In this paper, we develop models of green GDP growth and the gap between traditional and green GDP by using a panel data set from eight countries spanning 30–50 years. In both the growth and gap models, the effects of economic openness are tested. In the growth model, openness is considered along with measures of human and physical capital typically included in models of aggregate production functions. In the gap model, openness is considered along with environmental variables commonly associated with the gap between GDP and green GDP. Beginning with level models of green GDP and this gap, we examine the presence of unit roots to implement a proper data transformation.

The paper proceeds as follows. In Section 2, we make note of the ongoing debate over economic openness and economic welfare and the contribution this paper makes to that debate. Section 3 describes the green GDP and gap models as well as our data set. Modeling results and tests of robustness are reviewed in Section 4. In Section 5, we discuss the results and offer some concluding thoughts.

2. The openness debate

Although conspicuously absent from the dominant growth models of the past 50 years, the connection between greater openness to trade and growth of gross domestic product (GDP) now has considerable theoretical support. For example, simple modifications to the venerable Harrod–Domar (1957) model demonstrate how greater trade openness leads to both a positive level effect and positive growth effect on the value of GDP by increasing the relative prices of consumption goods in which a given economy has a comparative advantage (Bhagwati et al., 1998). Likewise, open-economy modifications to the standard neoclassical model show how knowledge spillovers from abroad can positively influence both the level and growth rate of output (Ben-David and Loewy, 2003).

Stronger support can be found within the framework of modern endogenous growth models which provide direct links between growth and endogenously chosen policy options such as freer trade regimes. Dowrick (1994) groups such models into two distinct categories: (1) models which follow Adam Smith in emphasizing the role of trade in enabling specialization which increases productivity through learning by doing or through specialization of research, and (2) Ricardian models where comparative advantage leads to specialization in particular activities that may be characterized by higher rates of productivity growth.

Against this theoretical backdrop, there has been a profusion of empirical work over the past two decades generally confirming the positive relationship between openness and growth. Surveying the literature to date, Dowrick (1994, 21) found that "[a] wide range of studies conducted over the past decade or so have indicated a fairly consistent pattern of positive correlations between trade openness and growth." Since that time, empirical verifications which rely on ever larger data sets have been published with regularity. For example, using data from 93 countries, Edwards (1997) found that more open countries experienced faster productivity growth. More recently, Karras (2003, 1) concluded that "the effect of trade openness on economic growth is positive, permanent, statistically significant, and economically sizable" after analyzing a panel data set representing as many as 105 nations.

Despite these rather upbeat assessments, the chorus of voices opposed to rapid economic integration on the global level remains loud and clear as demonstrated over and over again in places like Seattle, Miami, Rome, and Cancun and wherever global institutions such as the World Trade Organization or World Bank hold their regular meetings. Income inequality, deteriorating environmental conditions, poor working conditions and loss of indigenous cultures top the list of concerns expressed by broad alliances of labor unions, environmentalists, and social justice organizations present at these mass protests (IFG, 2002). Such concerns are bolstered by a significant amount of theoretical and empirical work in the published literature.

As noted by Borghesi and Vercelli (2003), the available empirical evidence suggests that the recent process of globalization of international markets has been accompanied by a worldwide increase in environmental degradation and economic inequality. Tropical deforestation and increased emissions of carbon dioxide are examples of alarming environmental trends associated with greater openness by way of increased export prices of agricultural and forest products as well as an increase in the scale of harmful economic activities (Capistrano, 1994; Managi, 2004). The evidence is mixed with respect to intracountry inequality but more consistent on the relationship between openness and greater income inequality within nations due to the downward pressure on wages for unskilled and other types of labor subject to relatively high international elasticities of demand (Ozay and Tavakoli, 2003; Baten and Fraunholz, 2004; Ghose, 2004; Marjit et al., 2004).

How can these viewpoints be reconciled? One obvious way is to insure that both sides of this debate are not talking past one another by relying on different measures of economic progress. Studies relating openness to higher economic growth rates rely almost exclusively on GDP and related measures, while studies which document the immiserating effects of openness rely on measures outside the realm of traditional growth models. Conducting growth studies using green GDP bridges this divide because green GDP is a broader measure of welfare which explicitly addresses factors of paramount concern to GDP critics.

Since no one, in fact, seriously argues that GDP was ever meant to be a true measure of welfare it seems rather obvious that the openness debate could greatly benefit by studies that use alternative GDP measures such as the ISEW or GPI despite the methodological disputes surrounding these data sets. We accomplish just this in the following sections by incorporating green GDP into a traditional model of economic growth as well as a model of the growing divide between traditional and green GDP. In both models, we test the effects of economic openness.

3. Empirical models and data

In this section we describe models of green GDP growth and the growth of the GDP–green GDP gap. After characterizing these models in general form, we present the specific forms and describe the data sets on which we rely for the analysis presented in Section 4.

3.1. A model of green GDP growth

We begin with the hypothesis that the level of green GDP at any point in time can be explained by a variant of the standard Solow growth model which suggests that real output is a function of a nation's stocks of capital and labor and influenced by other factors which may affect the productivity of these inputs such as economic openness (Solow, 1956, 1957). In general notation, we have:

$$\text{GDPgrn}_t = f(K_t, L_t, O_t), \tag{1}$$

where GDPgrn is per capita green GDP at time t as measured by the ISEW, GPI, or other alternative accounting systems, K is a measure of a nation's capital stock at time t, L is a measure of labor input at time t, and O is an index of economic openness at time t. Following Mankiw et al. (1992) this relationship can be expressed in terms of a Cobb-Douglas type aggregate production function of the form:

$$\text{GDPgrn}_t = \delta_0 K_t^{\alpha} O_t^{\beta} L_t^{l-\alpha-\beta} e^{u_t}, \tag{2}$$

which can be represented in log–linear form as:

$$\text{GDPgrn}_t = \delta + \alpha K_t + \beta O_t + (1-\alpha-\beta) L_t + u_t, \tag{3}$$

where all variables are now logged (for convenience, the log notation is dropped), α is a constant and u is the error term.

A persistent concern in the literature is to what degree these "level" models result in spurious regression due to the presence of unit roots. A time series is said to contain a unit root if it contains a long-term trend and is, thus, non-stationary. It has been widely accepted that many macroeconomic time series have a unit root since the groundbreaking work of Nelson and Plosser (1982). Using classical ordinary least squares (OLS) estimation techniques when unit roots are present can give misleading inferences and lead to spurious regression (Bhattacharya and Sivasubramanian, 2003).

To test for the presence of unit roots a panel version of the augmented Dickey-Fuller unit root test is used (Dickey and Fuller, 1979). For each series in a given model, the augmented Dickey-Fuller test involves fitting a regression of the form:

$$\Delta y_t = \alpha + \beta y_{t-1} + \pi t + \delta_1 \Delta y_{t-1} + \delta_2 \Delta y_{t-2} + \ldots + \delta_k \Delta y_{t-k} + \varepsilon_t, \tag{4}$$

and then testing the null hypothesis H_0: $\beta = 0$. If the null cannot be rejected, unit roots are present and the series in nonstationary. The panel version of this test is performed analogously, but on generalized least squares (GLS) detrended data. The specific test included in the software package used for this analysis (*Stata Intercooled Version 8.2*) is the test proposed by Elliot et al. (1996).

Once the presence of unit roots have been confirmed, converting level GDP models to growth rate form by differencing logged values in adjacent time periods or differencing of non-logged values expressed as ratios is the typical remedy for restoring stationarity. As such, we convert Eq. (3) to growth rate form so that we now have:

$$\text{GGDPgrn}_t = \delta + \alpha GK_t + \beta GO_t + (1-\alpha-\beta) GL_t + u_t, \tag{5}$$

where the "G" prefix denotes growth rate between years $t-1$ and t. This basic model has been popular in many of the recent growth models testing the effects of openness (Dar and Amirkhalkhali, 2003). It is well known, however, that such models often suffer from distortions caused by assuming fixed coefficients across countries when panel data is used, endogeneity in right hand side variables, and failure to recognize structural breaks (Dar and Amirkhalkhali, 2003; Sen, 2003). Nonetheless, the model serves our purposes here as a beginning point for investigating green GDP growth.

The specific form of our green GDP growth model relies on updated green GDP time series data published for Australia (Hamilton, 1999), Austria (Stockhammer et al., 1997), Brazil (Torras, 2003), Italy (Guenno and Tiezzi, 1998), the Netherlands (Rosenberg et al., 1995), Sweden (Jackson and Stymne, 1996), the United Kingdom (Jackson et al., 1997) and the United States (Cobb et al., 2001). For Brazil, the data consist of a modified form of the ISEW which introduces a unique weighting scheme that reflects the disproportionate impacts of environmental degradation on the poor (Torras, 2003). For Australia and the US, the GPI methodology was followed. Data for the remaining countries were computed using the ISEW methodology. For each country, there were 30–50 observations. All green GDP figures were converted to constant 2004 US dollars using exchange rates published in the Penn World Tables (Heston et al., 2002) and using consumer price indices published by the Federal Reserve Bank of Minneapolis.

In our model, physical capital is represented by the ratio of gross fixed capital formation to GDP as, for example, used by Moudatsou (2003). The labor input is represented by the age dependency ratio (ADR) defined as the ratio of the non-working age population (<15 and >64) to the working age population. The importance of ADR in growth models has long been recognized because a larger dependent population may constrain productivity enhancing investment (Holtz-Eakin et al., 2004). Time series data for gross fixed capital formation and age dependency ratios were taken from the latest World Development Indicators report (TWBG, 2004). Our measure of openness is the ratio of the value of trade (value of imports+value of exports) to GDP, as commonly used in the literature (see, e.g. Managi, 2004). Here, however, we use green rather than traditional GDP. Trade value figures were obtained from the Penn World Tables (Heston et al., 2002). With these data, our model of green GDP growth can be represented by the following reduced form aggregate production function:

$$\mathrm{GGDPgrn}_t = \alpha_0 + \alpha_1 \mathrm{DGFCFpct}_t + \alpha_2 \mathrm{DOPEN}_t + \alpha_3 \mathrm{DADR}_t + u_t \quad (6)$$

where GGDPgrn is the growth rate of per capita green GDP as represented by the first difference of logged green per capita GDP values in subsequent time periods, DGFCFpct is the first difference in the ratio of gross fixed capital formation to GDP, DOPEN is the first difference in the ratio of trade value to green GDP, DADR is the first difference in the age dependency ratio, and u is the error term. We make no hypothesis about the direction of effect with respect to openness, but predict a positive correlation between GFCFpct and green GDP growth and a negative correlation between DADR and green GDP growth.

In this model, we are assuming a linear relationship between openness and green GDP growth. However, this may not be the case. Fig. 1 depicts how green GDP and openness relate over time for each of the countries included in our panel data set. For at least five of these countries, a non-linear relationship is strongly implied. In particular, it appears that openness is positively correlated with green GDP growth up to a point, after which its direction of effect reverses. Given this non-linear relationship, we modify our model to include a squared openness term as such:

$$\mathrm{GGDPgrn}_t = \alpha_0 + \alpha_1 \mathrm{DGFCFpct}_t + \alpha_2 \mathrm{DOPEN}_t + \alpha_3 \mathrm{DOPEN}_t^2 + \alpha_4 \mathrm{DADR}_t + u_t. \quad (7)$$

3.2. A model of the GDP–green GDP gap

As noted previously, the green GDP literature has consistently documented a growing gap between GDP and green GDP over time. Manifesting what has become known as the "threshold" effect, nearly all green GDP time series compiled to date show GDP and green GDP moving forward together up to a certain threshold point, after which green GDP growth declines or becomes negative (Max-Neef, 1995). What this implies is that when macroeconomic systems expand beyond a certain size, the additional benefits of growth are increasingly offset by the welfare costs of such growth and as a result, the gap widens (Lawn, 2003). In other words, past the threshold, more and more economic activity may be offset by the costs associated with environmental externalities and other welfare cost factors not included in traditional measures of GDP. As such, a model of the GDP–green GDP gap (hereafter "gap") is a useful way to test whether greater economic openness or other policy factors increase or reduce the proportion of economic activity that is offset or more than offset by hidden welfare costs.

To explore this issue, we construct a simple model of the gap that includes environmental factors, inequality, and openness. The inclusion of environ-

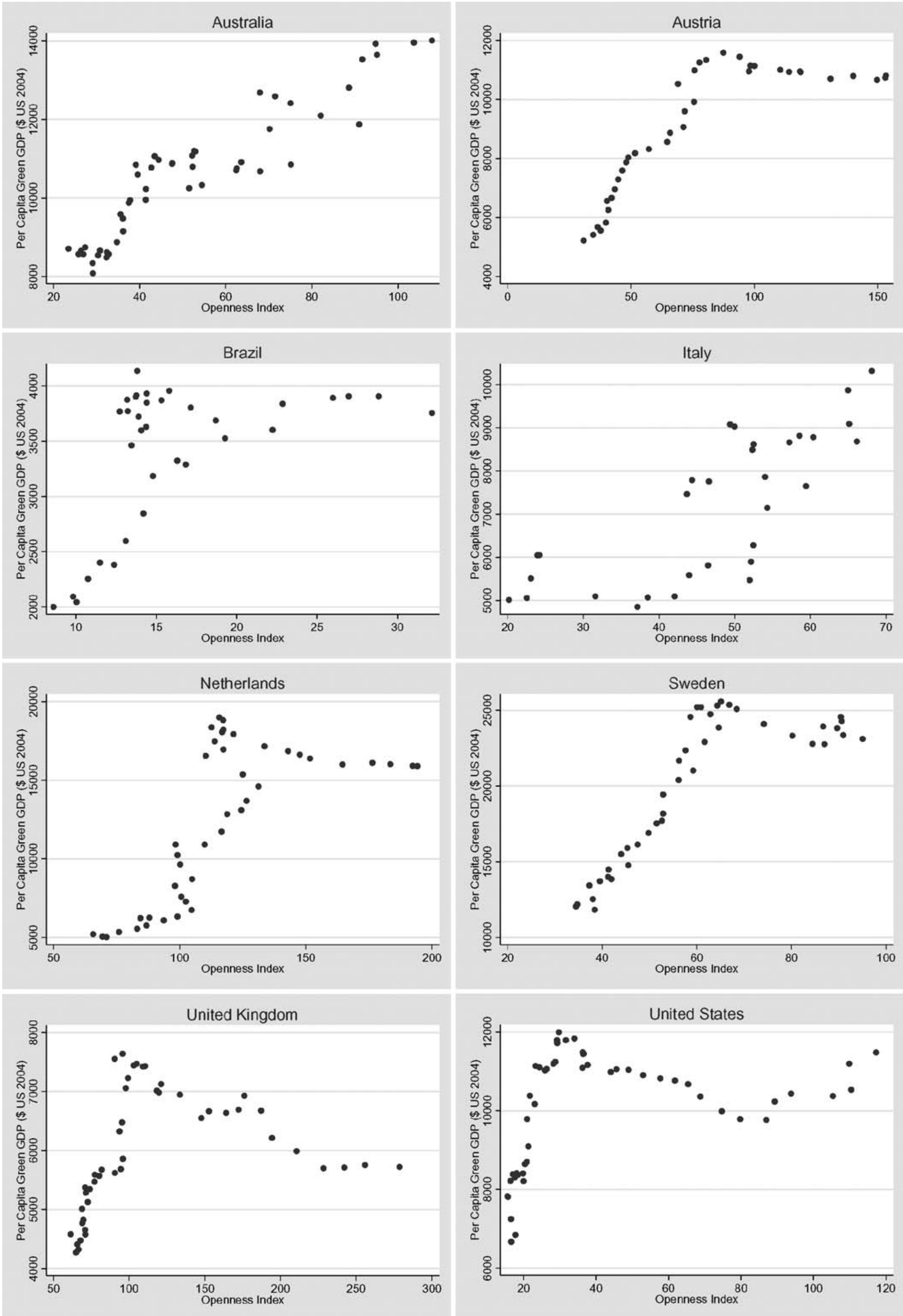

Fig. 1. Per capita green GDP and economic openness.

mental quality measures and measures of inequality are obvious since these are the primary corrections to GDP offered by the green GDP models. In other words, as environmental quality deteriorates or as wealth is more concentrated in the hands of a few we would expect green GDP growth to slow or go negative and the gap to widen. The inclusion of openness is, of course, the subject of our inquiry but one that is justified given the number of studies linking greater openness to deterioration of environmental conditions as well as inequality. Moreover, as shown in Fig. 2, the gap appears to be highly correlated with openness over time in each of the countries included in our panel data set.

Due to differences in scale of economic activity among nations, we first define the gap to be the difference in logged GDP and green GDP values in a given year:

$$\mathrm{GAP}_t = \ln(\mathrm{GDP}_t) - \ln(\mathrm{GDPgrn}_t). \tag{8}$$

In general form, a model of the gap then takes the form:

$$\mathrm{GAP}_t = f(E_{1t} \ldots E_{nt}, I_{1t} \ldots I_{kt}, \mathrm{OPEN}_t) \tag{9}$$

where E is a vector of environmental quality measures affecting the gap, I is a vector of measures addressing inequality of income, wealth, opportunities, or environmental degradation, and OPEN is the openness measure discussed in the previous model.

While such a model is easy to conceptualize, presenting a specific form faces a number of hurdles including the availability of time series data and collinearity—a fatal flaw to econometric models that include variables that move together in a systematic way (Griffiths et al., 1993). An example of the former problem is the lack of a sufficient number of observations on income inequality, which, in the case of GINI coefficients, is produced once every 5 years or so in the context of standardized international data sets such as World Indicators. An example of the latter is the fact that green GDP by definition, takes into account many of the environmental or inequality factors one would like to include in a gap model. For example, almost any measure of income inequality would present a collinearity problem since green GDP is adjusted to account for this inequality. Likewise, annual figures on farmland loss would be unacceptable to include because the value of lost farmland is a cost specifically included in both the ISEW and GPI.

There are, nonetheless, environmental quality data which can be incorporated into a gap model if they are independent of the actual ISEW or GPI computational process. In our model we rely on two: a livestock production index (LPI) and per capita carbon dioxide emissions (CCO2). Both time series are published in World Indicators (TWBG, 2004). The LPI is an index based on the quantity of livestock produced in the 1989–1991 period. Inclusion of the LPI is reasonable since livestock grazing and animal feedlots are a major sources of water pollution, soil erosion, and riparian habitat loss—effects that are reflected in ISEW and GPI sub accounts such as water pollution costs and long term environmental damage (Lawn, 2003; EPA, 2004). However, since the ISEW and GPI do not directly link such costs to livestock, we can assume that the LPI is sufficiently independent for econometric modeling purposes.

Similarly, inclusion of carbon dioxide emissions is reasonable since such emissions are, of course, linked to the catastrophic impacts of global warming but also closely related to ISEW and GPI environmental costs associated with acid rain and urban air pollution. In particular, carbon dioxide emissions from automobiles and power plants are directly linked to harmful emissions of sulfur dioxide, nitrogen oxide, carbon monoxide, and ozone which are by products of the fossil fuel combustion process. And since the ISEW and GPI do not directly deduct carbon dioxide emissions costs, there should be no collinearity problem here as well.

Given all this, and assuming as before the existence of unit roots, we propose the following simple model of the GDP–green GDP gap in growth rate form:

$$\begin{aligned} \mathrm{GAPgrw}_t = {} & \alpha_1 + \alpha_2 \mathrm{LPIgrw}_t + \alpha_3 \mathrm{CCO2grw}_t \\ & + \alpha_4 \mathrm{DOPEN}_t + \alpha_5 \mathrm{DOPEN}^2 + u_t, \end{aligned} \tag{10}$$

where GAPgrw is the first difference of the gap measured in subsequent years, DLPI is the first difference of the livestock production index measured in subsequent years and CCO2grw is the difference between logged per capital carbon dioxide emissions in subsequent years. The openness indicator is as defined previously and a squared openness indicator

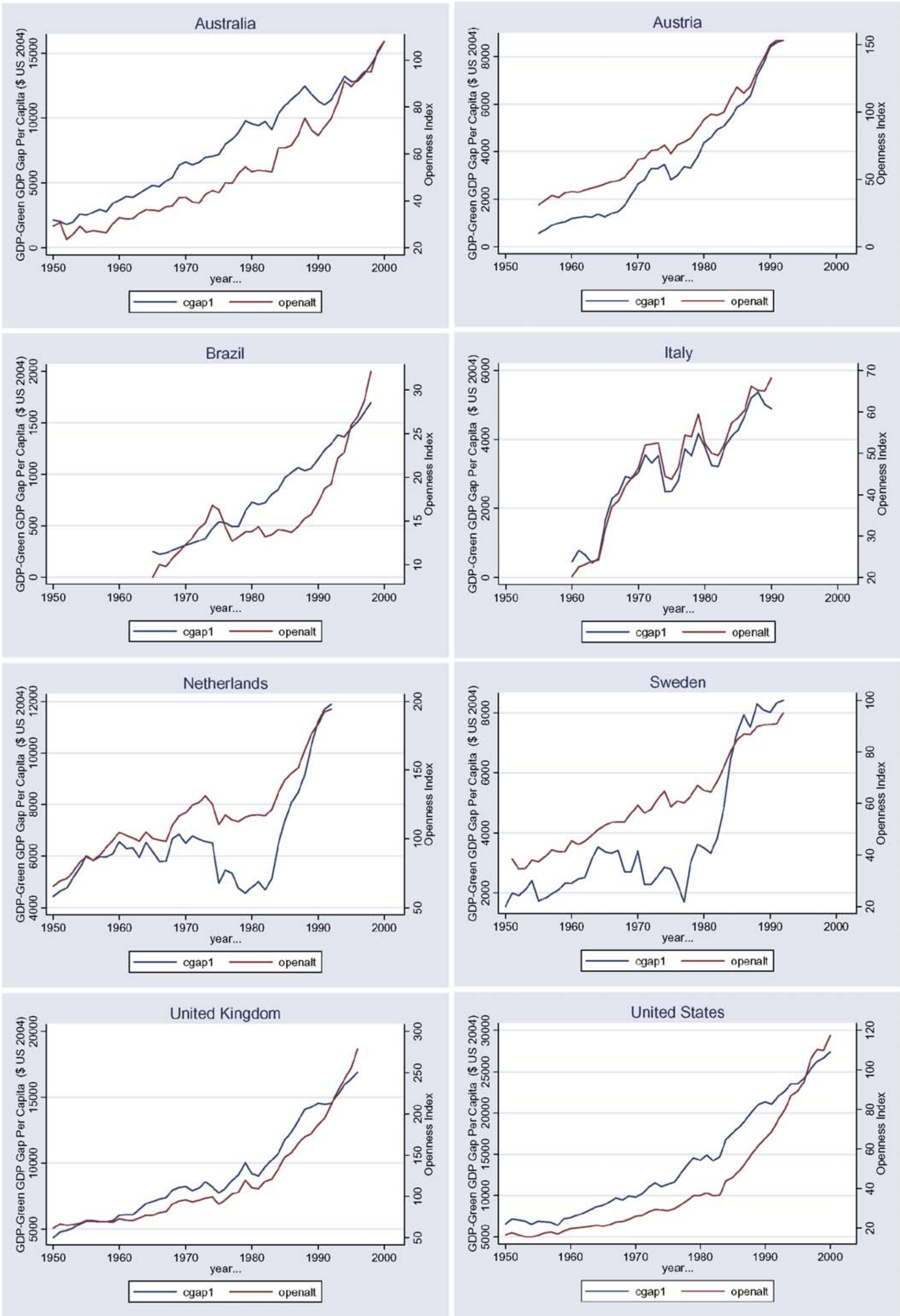

Fig. 2. GDP–green GDP gap and economic openness.

Table 1
Level model of green GDP (GDPgrn) panel estimates for 8 countries

Independent variables	Coefficients
OPEN	−61.47*** (−5.43)
OPEN^2	0.09** (2.52)
GFCFpct	65.15*** (2.73)
ADR	1720.86 (0.45)
YEAR	225.76*** (7.35)
CONSTANT	−434713*** (−7.05)
Log likelihood	−1742.072
Chi^2 signif.	79.89***
Common AR1	0.9876
Observations	237

Numbers in parentheses are z-statistics. *, **, and *** denote significance at the 0.10, 0.05, and 0.01 levels, respectively.

is included once again to address the apparent nonlinear relationship.

4. Modeling results

In this section, we present the results of the green GDP and gap models. Beginning with level models, we test for the existence of unit roots. After confirming the presence of unit roots, we transform each model into growth rate form. We then address possible cointegration by presenting error correction forms of each model. All analyses were conducted using *Stata Intercooled* statistical software version 8.2.

4.1. Green GDP modeling results

Table 1 displays panel coefficient estimates for the level model of green GDP described in Section 3.2. We test green GDP in a production function framework with gross fixed capital formation percent, age dependency ratio, openness and the square of openness as independent variables. We also add the time trend. As Table 1 shows, openness and its square are significant but with opposite direction of effect. The direction of effect for GFCFpct is as expected, and significant. The influence of ADR appears to be in the opposite direction of what we anticipated, but its insignificance precludes drawing any inferences at this stage. Lastly, the time trend coefficient is as expected with the steady growth of green GDP over the greatest segment of time in each of our series.

Table 2 reports the results of the augmented Dickey-Fuller GSL test for each series in our panel data set. For each country and for each series, Table 2 reports the Dickey-Fuller tau test statistics and their level of significance. The null hypothesis of nonstationarity of each of the series is tested against the alternative hypothesis of stationarity. As Table 2 shows, the null hypothesis of nonstationarity cannot be rejected in 7 out of 8 panels for the GDPgrn series, 8 out of 8 panels for the OPEN, OPEN 2 , and ADR series, and 4 out of 8 panels for the GFCFpct series. Given the predominately nonstationary nature of each series, conversion to a growth rate specification is justified. To verify, we conduct additional unit root tests on the growth rate of GDPgrn and the first difference of the remaining series since these are ratios. After doing this, it was apparent that a second differencing of the ADR series was needed. We then performed augmented Dickey-Fuller GLS tests on each of the converted series. Table 3 reports the

Table 2
Dickey-Fuller unit root test on level model of green GDP

Country	GDPgrn	OPEN	OPEN^2	GFCFpct	ADR
Australia	−3.449**	−0.874	−0.127	−3.580**	−2.057
Austria	−0.837	−1.371	−1.183	−2.356	−2.865
Brazil	−1.331	−0.431	0.044	−3.960***	−2.508
Italy	−2.523	−2.336	−2.730	−2.551	−2.887
Netherlands	−1.113	−1.440	−1.183	−2.119	−2.507
Sweden	−0.962	−1.585	−0.950	−3.574**	−2.386
United Kingdom	−0.786	0.228	0.366	−2.719	−2.731
United States	−1.078	0.095	0.463	−3.619**	−2.812
Remarks	Unit root in 7 out of 8 panels	Unit root in 8 out of 8 panels	Unit root in 8 out of 8 panels	Unit root in 4 out of 8 panels	Unit root in 8 out of 8 panels

Numbers are Dickey-Fuller tau test statistics. *, **, and *** denote significance at the 0.10, 0.05, and 0.01 levels, respectively.

Table 3
Dickey-Fuller unit root test on growth model of green GDP

Country	GGDPgrn	DOPEN	$DOPEN^2$	DGFCFpct	DDADR
Australia	−4.522***	−7.397***	−6.264***	−4.715***	−4.393***
Austria	−3.029*	−4.795***	−4.645***	−2.808	−4.473***
Brazil	−3.337**	−2.285	−2.212	−3.930***	−4.854***
Italy	−3.687**	−3.494**	−5.521***	−4.867***	−4.326***
Netherlands	−2.643	−3.709**	−5.162***	−2.736	−4.271***
Sweden	−2.968*	−1.680	−3.848***	−3.833***	−4.543***
United Kingdom	−2.864	−3.298**	−2.489	−4.633***	−4.331***
United States	−4.581***	−5.662***	−6.179***	−4.735***	−4.319***
Remarks	Unit root in 2 out of 8 panels	Unit root in 2 out of 8 panels	Unit root in 2 out of 8 panels	Unit root in 2 out of 8 panels	Unit root in 0 out of 8 panels

Numbers are Dickey-Fuller tau test statistics. *, **, and *** denote significance at the 0.10, 0.05, and 0.01 levels, respectively.

results. As Table 3 shows, after converting the model to growth rate form, we can reject the null hypothesis of nonstationarity for each series in the vast majority of cases.

Table 4 presents the final result of the green GDP growth rate modeling. As demonstrated by Model 1, and as before, openness is negatively correlated with green GDP growth (GGDPgrn) but the sign on its square is reversed. The coefficients on gross fixed capital formation percent (DGFCFpct) and age dependency ratio (DDADR) are significant and in the direction we anticipated in our theoretical model. We thus have a green GDP growth rate model which is consistent with the general notion of an aggregate production function and which indicates a strongly negative but non-linear relationship between economic openness and growth.

Table 4
Model of green GDP growth (GGDPgrn) panel estimates for 8 countries

Independent variables	Model 1 coefficients	Model 2 coefficients
DOPEN	−0.57*** (−9.59)	−0.57*** (−9.38)
$DOPEN^2$	0.01** (2.43)	0.01** (2.50)
DGFCFpct	0.93*** (4.58)	0.95*** (4.47)
DDADR	−280.63*** (−3.48)	−262.90*** (−3.10)
CONSTANT	2.48*** (8.66)	2.49*** (4.55)
U-hat$_{t-1}$	–	−15.42 (−0.14)
Log likelihood	466.55	448.81
Chi^2 signif.	127.55***	120.81***
Common AR1	0.1850	0.1616
Pseudo R^2	0.6156	0.6123
Observations	227	219

Numbers in parentheses are z-statistics. *, **, and *** denote significance at the 0.10, 0.05, and 0.01 levels, respectively.

With time series models, complications may arise from the fact that two or more of the series may share a long run equilibrium relationship. If they do, the series are said to be cointegrated. If series are cointegrated, converting level models to growth rate form will eliminate the long run relationship from the model and significantly reduce a model's performance (Enders, 1995). To restore this relationship, an error correction form of the model is specified. An error-corrected model restores the long run relationship between cointegrated series by including a lagged residual of the linear prediction. For a detailed methodology on cointegration and error correction models, we refer the reader to Enders (1995).

In general, if individual time series within a model are integrated of different orders, cointegration will not be a concern (Enders, 1995). This appears to be the case here, as the ADR series is integrated of order 2 while the remaining series are integrated of order 1. Nonetheless, we can specify an error correction form of our green GDP growth model to verify the absence of cointegration. That model appears as Model 2. Model 2 contains a lagged residual of the linear prediction from Model 1 (U-hatt-1). If series are cointegrated, the coefficient on this lagged residual should be significant (Mills, 1998). As Table 4 shows, it is not. Moreover, its inclusion in the model does not substantially change the direction or significance of any of the other variables. Thus, we can say that Model 1 is fairly robust, and that cointegration does not appear to exist. The final model of

Table 5
Level model of the GDP–green GDP Gap (lnGDPt − lnGDPgrnt), panel estimates for 8 countries

Independent variables	Coefficients
OPEN	9.77*** (13.27)
$OPEN^2$	−0.02*** (−7.22)
LPI	0.60 (1.01)
CCO^2	0.37 (0.11)
YEAR	−6.36*** (−3.41)
CONSTANT	−12428*** (−3.41)
Log likelihood	611.92
Chi^2 signif.	349.92***
Common AR1	0.9795
Observations	274

Numbers in parentheses are z-statistics. *, **, and *** denote significance at the 0.10, 0.05, and 0.01 levels, respectively.

green GDP growth can therefore be specified as such:

$$\hat{G}\text{GDPgrn}_t = \underset{(8.6)}{2.48} + \underset{(4.58)}{0.93}\,\text{DGFCFpct}_t - \underset{(-9.59)}{0.57}\,\text{DOPEN}_t + \underset{(2.43)}{0.01}\,\text{DOPEN}^2 - \underset{(-3.48)}{280.63}\,\text{DDADR}_t. \quad (11)$$

There are two noteworthy aspects of this model. First, the results suggest that green GDP time series are suitable for use in the context of econometric investigations of economic growth. The significance and direction of effect of both our physical and human capital measures suggest that green GDP can be modeled within the broad framework of standard aggregate production function models. And because of this, the links between growth and a host of factors commonly associated with growth can be reexamined using green, rather than traditional GDP time series. Secondly, the results contradict much of the empirical literature suggesting a strong and positive correlation between economic growth and openness. Here we find the opposite. As shown by our final model, greater openness causes a pronounced slowdown of economic growth rates.

4.2. GDP–green GDP gap modeling results

As with green GDP, we first present the results of the level model of the GDP-green GDP gap (GAP). The results are shown in Table 5. Openness has a strongly positive influence on the size of the gap, while the direction of effect is reversed for its square. Neither the livestock production index (LPI) nor per capita carbon dioxide emissions (CCO2) appear to influence the gap, while the effect of the time trend is significant and negative.

Table 6 reports the results of the augmented Dickey-Fuller GLS tests on the level series. Again, the null hypothesis here is that each of our series is nonstationary, implying the presence of unit roots. Table 6 verifies the nonstationary nature of each of our series in each country. In all but one case, the null hypothesis cannot be rejected.

Table 7 reports the results of the second round of augmented Dickey-Fuller GLS testing once each of the series has been converted to growth rate form. After doing so, Table 7 indicates that stationarity is restored to each of the series in the vast majority of cases. Thus, a growth rate form of the model is

Table 6
Dickey-Fuller unit root test on level model of the GDP–Green GDP Gap

Country	GAP	OPEN	$OPEN^2$	LPI	CCO2
Australia	−3.070*	−0.874	−0.127	−2.630	−2.510
Austria	−1.493	−1.371	−1.183	−1.177	−1.488
Brazil	−1.575	−0.431	0.044	−0.489	−2.118
Italy	−2.121	−2.336	−2.730	−1.191	−1.245
Netherlands	−0.616	−1.440	−1.183	−0.438	−1.951
Sweden	−1.398	−1.585	−0.950	−2.488	−1.467
United Kingdom	−0.959	0.228	0.366	−0.341	−2.902
United States	−1.350	0.095	0.463	−1.127	−1.993
Remarks	Unit root in 7 out of 8 panels	Unit root in 8 out of 8 panels	Unit root in 8 out of 8 panels	Unit root in 8 out of 8 panels	Unit root in 8 out of 8 panels

Numbers are Dickey-Fuller tau test statistics. *, **, and *** denote significance at the 0.10, 0.05, and 0.01 levels, respectively.

Table 7
Dickey-Fuller unit root test on growth model of the GDP–green GDP gap

Country	GAPgrw	DOPEN	DOPEN^2	LPIgrw	CCO2grw
Australia	−4.975***	−7.397***	−6.264***	−4.477***	−5.039***
Austria	−2.915	−4.795***	−4.645***	−3.801***	−4.875***
Brazil	−4.259***	−2.285	−2.212	−8.277***	−2.933
Italy	−3.648**	−3.494**	−5.521***	−7.398***	−3.359**
Netherlands	−2.975*	−3.709**	−5.162***	−4.509***	−4.661***
Sweden	−4.073***	−1.680	−3.848***	−4.868***	−3.999***
United Kingdom	−3.501**	−3.298**	−2.489	−5.468***	−5.229***
United States	−4.405***	−5.662***	−6.179***	−5.597***	−4.382****
Remarks	Unit root in 1 out of 8 panels	Unit root in 2 out of 8 panels	Unit root in 2 out of 8 panels	Unit root in 0 out of 8 panels	Unit root in 1 out of 8 panels

Numbers are Dickey-Fuller tau test statistics. *, **, and *** denote significance at the 0.10, 0.05, and 0.01 levels, respectively.

appropriate to consider. Table 8 presents that model, with the following specification:

$$\hat{D}GAP_t = \underset{(-2.46)}{-5.62} + \underset{(1.91)}{93.74}\, LPIgrw_t - \underset{(-1.78)}{54.00}\, CCO2grw_t + \underset{(15.34)}{7.28}\, DOPEN_t - \underset{(-4.79)}{0.18}\, DOPEN_t^2. \quad (12)$$

Defining the growth of the gap as the difference between gap values ($GAP_t - GAP_{t-1}$) in subsequent time periods, we see that the first difference of openness (DOPEN), its square (DOPEN^2), the growth of the livestock production index (LPIgrw), and per capital carbon dioxide emissions growth (CCO2grw) all have a significant influence on the growth of the gap over time. There is a significant positive correlation between openness and the growth of the gap. The direction of effect is reversed for its square, verifying the non-linear relationship anticipated by our model. The growth of the livestock production index has a significant positive influence on the gap, as expected. Unexpected, however, was the negative correlation between carbon dioxide emissions and the gap since we expected that such emissions were positively correlated with specific ISEW and GPI line items deducted from traditional GDP.

As before, we present a second specification of the model (Model 2) in error correction form. That model takes the following form:

$$\hat{D}GAP_t = \underset{(0.47)}{2.11} + \underset{(1.80)}{89.78}\, LPIgrw_t - \underset{(1.42)}{44.35}\, CCO2grw_t + \underset{(15.05)}{7.20}\, DOPEN_t - \underset{(-4.39)}{0.17}\, DOPEN_t^2 - \underset{(-1.98)}{2350.06}\, \hat{u}_{t-1}. \quad (13)$$

Unlike our model of green GDP growth, each series in our gap growth model are integrated of the same order, implying that cointegration may exist. Fig. 2, for example, indicates that the gap and openness may have some kind of long-term relationship. Indeed, the significance of the lagged residual term in Model 2 implies that the error correction model may, in fact, be the most appropriate since cointegration is implied. In Model 2, the significance and direction of effect remains the same for openness, its square, and the livestock production index. But while the direction of effect of the per capita carbon dioxide emissions variable remains the same, it loses significance in Model 2.

Table 8
Growth model of the GDP–green GDP Gap ($GAP_t - GAP_{t-1}$) panel estimates for 8 countries

Independent variables	Model 1 coefficients	Model 2 coefficients
DOPEN	7.28*** (15.34)	7.20*** (15.05)
DOPEN^2	–0.18*** (−4.79)	−0.17*** (−4.39)
LPIgrw	93.74* (1.91)	89.78* (1.80)
CCO2grw	−54.00* (−1.78)	−44.35 (−1.42)
U-hat$_{t-1}$	–	2350.06** (−1.98)
CONSTANT	−5.62** (−2.46)	2.11 (.47)
Log likelihood	603.16	583.91
Chi^2 signif.	278.40***	275.81***
Common AR1	0.1401	0.1622
Pseudo R^2	0.7161	0.7170
Observations	266	258

Numbers in parentheses are z-statistics. *, **, and *** denote significance at the 0.10, 0.05, and 0.01 levels, respectively.

Table 9
Growth model of the GDP–green GDP gap with CCO2 country dummies panel estimates for 8 countries

Independent variables	Coefficients
DOPEN	7.23*** (15.29)
$DOPEN^2$	−0.18*** (−4.84)
LPIgrw	94.75* (1.94)
CCO21grw	128.25 (.93)
CCO22grw	−107.57 (−1.45)
CCO23grw	−58.13 (−0.71)
CCO24grw	−86.62 (−1.03)
CCO25grw	−139.40** (−2.15)
CCO26grw	−50.29 (−0.86)
CCO27grw	214.85* (1.74)
CCO28grw	−9.45 (−0.07)
CONSTANT	−5.47** (−2.33)
Log likelihood	607.94
Chi^2 signif.	297.97***
Common AR1	0.1658
Observations	266

Numbers in parentheses are z-statistics. *, **, and *** denote significance at the 0.10, 0.05, and 0.01 levels, respectively.

With model two as the final model of choice, we can safely say that greater economic openness appears to contribute to a widening gap between traditional and green GDP, providing a partial explanation of the "threshold" effect documented in previous literature (e.g. Max-Neef, 1995; Lawn, 2003). In particular, greater economic openness may cause growth in the types of economic activity that generate more welfare costs than benefits. We can also say that livestock production contributes to the gap, probably through the channels of increased water pollution and loss of natural ecosystems such as forests or riparian zones. With respect to carbon dioxide emissions, however, the model is ambiguous.

The ambiguous relationship between growth of the gap and carbon dioxide emissions warrants a closer inspection. In reviewing the data sets, we found two complicating factors. The first is that the effects differed across countries. In two cases, we found the expected positive correlation (Australia and the United Kingdom). In the other six, we found a negative relationship. This can be seen by looking at a variant of Model 1 which includes dummy variables representing per capita carbon dioxide emissions growth on a country by country basis (CCO2grw*Country dummy). The results are presented in Table 9. Country dummies are arranged alphabetically so that CCO21grw represents per capital carbon dioxide emissions growth in Australia and CCO28grw is the United States equivalent. The only significant coefficients were those for the Netherlands (−139.40) and for the United Kingdom (214.85), with the former having a greater level of significance (0.05 vs. 0.10). Clearly, then, some of the ambiguity is explained by the different direction of effect across countries.

A more significant explanation lies in the fact that carbon dioxide emissions may be highly correlated with economic growth since they are by-products of industrial processes, electricity consumption, and automobile use. Managi (2004) for example, included economic growth in a model of emissions and found highly significant positive correlation. If emissions are more closely tied to growth than they are tied to growth of the gap, it may explain why overall, we found a negative correlation when testing for the influence of emissions on the gap.

As evidence of this effect, we can consider an alternative green GDP growth model which includes per capita carbon dioxide emissions as an independent variable. While there may be some theoretical validity for including emissions in such a model (i.e. as a proxy for greater production of primary goods such as steel used for fixed capital assets), we do not assume this and are simply presenting this model for illustrative purposes alone. The augmented green GDP growth model is presented in Table 10. Clearly, in this model, the inclusion of per capita carbon dioxide emissions has significant

Table 10
Model of green GDP growth (GGDPgrn) with CCO2 panel estimates for 8 countries

Independent variables	Coefficients
DOPEN	−0.64*** (−11.24)
$DOPEN^2$	0.02*** (3.53)
DGFCFpct	0.86*** (4.48)
DDADR	−218.06*** (−2.81)
CCO2grw	21.64*** (5.48)
CONSTANT	2.36*** (9.69)
Log likelihood	476.57
Chi^2 signif.	184.24***
Common AR1	0.0734
Pseudo R^2	0.6807
Observations	225

Numbers in parentheses are z-statistics. *, **, and *** denote significance at the 0.10, 0.05, and 0.01 levels, respectively.

explanatory power in a positive direction. Moreover, including emissions in the model tends to improve its overall performance. Thus, the positive correlation between green GDP growth and growth of carbon dioxide emissions certainly helps explain why our hypothesized negative relationship between such emissions and the gap was not borne out by our model.

5. Discussion and concluding thoughts

The foregoing analysis suggests that green GDP time series may be useful as a tool for re-examining factors which influence the rate of growth in economic welfare. Here, we modeled the effects of economic openness. In the context of an aggregate production function model of green GDP growth and a model of the gap between traditional and green GDP we found strong and robust results contradicting the previous empirical work correlating increased openness with higher rates of economic growth. We find that economic openness is significantly associated with a reduction in green GDP growth rates and an increase in the gap, but in a non-linear fashion. These results provide some empirical support for the burgeoning literature associating greater openness with environmental degradation, income inequality, and an increase in economic activity that may be self canceling from a welfare perspective. In addition, the results imply that other factors commonly associated with GDP growth can be addressed in models that rely on green GDP time series. That being said, there are several caveats to consider.

First, there remains no global consensus on alternatives to traditional GDP measures. The methodologies associated with computation of the ISEW, GPI, and its variants remain a serious bone of contention among economists. For example, Neumayer (1999), Crafts (2002) and others argue that allowances made for environmental damage and depletion of natural capital lack a sound theoretical foundation, that costs of climate change are double counted, that costs associated with reduction in energy reserves are exaggerated, and that adjustments made to account for income inequality are unjustified. They also find that the growing gap between traditional and green GDP and the resulting threshold effect may be an "artifact of highly contestable methodological assumptions" (Neumayer 1999, 348). On the other hand, Lawn (2003, 112) finds that while green GDP methodologies may be far from perfect and can certainly benefit from more robust valuation methods, they are, nonetheless, theoretically sound and a serve as "very good indicators of both income and sustainable economic welfare." Thus, given the serious ongoing debate over both the theoretical foundations and computational accuracy of green GDP time series, modeling results which rely on such time series must be taken with a rather large grain of salt.

Secondly, it is not clear that the ISEW, GPI, and its variants are sufficiently similar to combine in a single multi-country panel model. For example, with respect to non-market benefits and costs, Lawn (2003) notes that there is a need for a standardized set of line items and valuation techniques for those items to allow for a more meaningful welfare comparisons across different nations. If the degree of dissimilarity is enough, models that group different green GDP measures together in a single panel data set may be erroneously combining different dependent variables.

Third, we estimate our models in reduced form. Endogeneity, causality, and omitted exogenous variable bias are important econometric issues which often arise in the context of such models (Cohen, 1990; Modigliani and Ando, 1990). For example, with respect to openness, there is a substantial amount of research supporting the notion that openness is endogenously determined and therefore should be modeled simultaneously with growth (Jin, 2003). Other studies note that the direction of causation is ambiguous. Some openness studies have attempted to deal with endogeneity as well the missing exogenous variable problem by relying on random coefficient forms of the growth models (Dar and Amirkhalkhali, 2003). Some researchers have even argued that it is impossible to use traditional measures of openness in growth models due to endogeneity issues. Instead, they propose an alternative openness index derived from "gravity" models which rely on geographic variables that are far more likely to be truly independent of GDP (Frankel and Rose, 2002). In our model of green GDP growth, we assumed that our openness index was exogenous to avoid these somewhat complicated issues.[3]

Despite these caveats, we believe that use of green GDP time series in econometric modeling is useful, if nothing else, to set the stage for future studies that will inevitably proliferate once standardized green GDP systems such as the United Nations System of Environmental and Economic Accounting (SEEA) are more widely implemented.

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[3] Nonetheless, to gauge the potential seriousness of the endogeneity problem, we performed panel versions of two stage least squares (2SLS) regressions on the models presented in Tables 4, 8 and 10). Under the 2SLS approach, a suspected endogenous variable is instrumentalized by regressing it against additional exogenous variables excluded from the structural model of interest. The structural model is then estimated using the least squares predictions from the first regression. In the model presented in Table 4, we instrumentalized DOPEN with population growth, growth in agricultural raw material export percentage, and net foreign direct investment. In the models presented in Tables 8 and 10, we instrumentalized CCO2grw with growth in electric power production and labor force growth. The 2SLS regressions did not substantially alter the results. Thus, our models appear to be fairly robust in the face of endogeneity concerns.

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