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To My Mother and Father

Abstract

Even though economists have been trying to understand why there are differences in income levels between countries for a long time, the gap and many question marks still remain. There is nothing in the traditional neoclassical theory that considers the institutional framework in which different capital is accumulated, innovations are created or input is turned into output. However, the social, legal, political and economic framework has been accepted as crucial for the understanding of why some countries grow rich and others stay poor. Another shortcoming of the standard growth models is the narrow view of the level of productivity, while productivity growth is assumed to be crucial for economic growth. Even if we accept that productivity is only determined by technological development, as is often assumed, the definition of technology is also oversimplified. This thesis analyzes economic growth and the environment with a broader perspective on investment decisions and productivity, by including institutional aspects and specific innovation mechanisms. It contains an introduction and five separate studies.

Paper 1: The Effect of Democracy on Different Categories of Economic Freedom

Many empirical studies conclude that democracy increases economic freedom. However, these studies use highly aggregated indices of economic freedom, which eliminate interesting information and obstruct policy conclusions. The purpose of this paper is to empirically study how different categories of economic freedom are affected by democracy, measured either as political or civil freedom, in developing countries. Democracy seems to increase the economic freedom categories *Government Operations and Regulations* and *Restraints on International Exchange*, but not affect the categories *Money and Inflation* and *Takings and Discriminatory Taxation*. That a low level of democracy would imply larger changes in economic freedom reform does not receive any support in this study. The robustness to extreme points and the model specification is tested. The result for all variables except *Restraints on International Exchange* passes these tests without major changes.

Paper 2: Effects of Economic Freedom on Growth and the Environment: Implications for Cross-Country Analysis

The purpose of this paper is to discuss the effects of specific economic freedom categories on both economic growth and the environment, and present some important considerations for cross-country regressions. First, there is a survey of arguments for positive as well as negative effects of economic liberalization. Measurement problems are then considered followed by a number of model specification issues. Sensitivity tests and potential econometric problems are also discussed. The main conclusion is that decomposition is important since different economic freedoms can be expected to have different effects on growth and the environment, and are dependent on different interacting factors. The theoretical insights have a crucial role when it comes to selecting what empirical issues to take into account since there is a limit to the number of issues possible to consider. Due to the complexity of the links, a lot of effort should also be devoted to sensitivity tests.

Paper 3: Economic Freedom and Growth: Decomposing the Effects *(co-author Fredrik Carlsson)*

Most studies of the relation between economic freedom and growth of GDP have found a positive relation. One problem in this area is the choice of economic freedom measure. A single measure does not reflect the complex economic environment and a highly aggregated index makes it difficult to draw policy conclusions. In this paper we investigate what specific types of economic freedom measures that are important for growth. The robustness of the results is carefully analyzed since the potential problem with multicollinearity is one of the negative effects of decomposing an index. The results show that economic freedom does matter for growth. This does not mean that increasing economic freedom, defined in general terms, is good for economic growth since some of the categories in the index are insignificant and some of the significant variables have negative effects.

Paper 4: The Effects of Economic and Political Freedom on CO_2 emissions *(co-author Fredrik Carlsson)*

In this paper we investigate the effects of political and economic freedom on CO_2 emissions. As far as we know this is the first cross-country study of the relationship between economic freedom and environmental quality. Economic freedom is measured in several ways. We find that increased price stability and legal structure decrease emissions in countries with a small industry share of GDP, but increases emissions in countries with a large industry share of GDP. The decreasing effect from increased use of market is significant but non-robust, and increased freedom to trade does not have any significant effect. The effect of political freedom on CO_2 emissions is insignificant, most probably since CO_2 emissions is a global environmental problem and hence subject to free-riding by the individual countries.

Paper 5: Technological Opportunities and Growth in the Natural Resource Sector

Both technological and natural resource possibilities seem to evolve in cycles. The "Resource Opportunity Model" in this paper introduces the technological opportunity thinking into natural resource modeling. The natural resource industries' choice between incremental, complementary innovations, and drastic, breakthrough innovations, will give rise to long-run cycles in the so-called familiar resource stock, which is the amount of natural resources determined by the prevailing paradigm. Incremental innovations will increase the exhaustion of the stock, and drastic innovations will create a new paradigm and, thereby, new technological opportunities and a new stock of familiar resources. Drastic innovations are endogenously affected by the knowledge level and induced either by scarcity of technological opportunities or by scarcity of resources. Generally, increased innovation ability increases the knowledge stock and cumulative income over time, but does not affect the sustainability of the resource stock even though the intensity of the resource cycles increases. However, too low innovation ability might drive the sector into technological stagnation, and resource exhaustion in the long run; and too high innovation ability might drive the sector into extraction stagnation, and resource exhaustion in the short run.

Keywords

Carbon dioxide, Cross-country regressions, Cycles, Decomposition, Democracy, Economic freedom, Economic Growth, Environmental quality, Innovations, Institutions, Natural Resources, Paradigm shifts, Political freedom, Technological opportunities.

Preface

When I started my university studies I wasn't sure of what I wanted to become. I planned to study economics for one semester, thinking that I then would know what was worth knowing in the field of economics. It didn't take one semester… Economics turned out to be the tool that I searched for in understanding the world, and I was stuck. Being a PhD student has been an exciting experience, both intellectually and personally, and it has offered me some of the best moments of my life. Many people have been important for the completion of my thesis and many more have been exposed to its negative, and sometimes exaggerated positive, external effects.

First of all I would like to thank my supervisors, Olof Johansson-Stenman and Fredrik Carlsson. I am forever grateful for their full support and encouragement even though I went my own way in the choice of research area. Olof, with his inspiring attitude towards research, will always be my "academic hero." The combination of being extremely sharp in the technical details but always returning to, and questioning, the basic meaning of the study, makes him an outstanding researcher. It is a fantastic feeling when one of the people you respect the most, believes in you. Fredrik has made crucial contributions to this thesis and to my research skills. He (among many, many other things) taught me the handicraft of research in general and that "The never-ending story" may actually end. At least for a moment…

There are several other people whose suggestions have led to improvements of my work, and I cannot thank them enough for their interest and time. Ola Olsson has been important, not only by his inspiring work and ideas, but also by our frequent discussions and of course as a friend. I would also like to express my immense gratitude to Clas Eriksson for his encouragement and all the hours spent penetrating my work. In the early stages of my thesis I had the great honor of inviting Sjak Smulders for supervision. Apart from giving me the basic intuition of growth theory (and organ playing!) he has been a continuous support. I am not only grateful for having Douglas Hibbs as my office neighbor, and all that comes with that, but also for his interest in my work and our inspiring discussions. I would also like to thank Peter Martinsson and

Arne Bigsten for their careful work as discussants at my higher seminar, and for all the improvements of the thesis that this led to. I am looking forward to future interactions with all of you!

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A special thank to Lars Drake at the Swedish University of Agricultural Sciences for introducing me to the world of research. And Thomas Sterner – thank you for believing in me as a PhD student and for your encouragement that has meant a lot to me. Thanks also to my friends at Uppsala University who made the first year, that is terrifying for many, one of the best ones for me. During my time in Gothenburg I have met people that I will never forget, for one reason or another. Mattias Erlandsson, with whom I spend most of my waking time and enjoy every second - no matter if we discuss research, go for a beer, or do nothing. Åsa Löfgren, whose sweet friendship I never intend to let out of my life. Anna Brink, whose down-to-earth view of life and the world has been an infinite source of inspiration. Jessica Andersson - my dear soul mate. Henrik Hammar, whose mere appearance makes even the worst day blissful. Johan Adler, who still hasn't stopped surprising me. And of course, my favorite Latin Swede, Francisco Alpizar. Thank you all for the many hours of discussions about major, life-supporting issues and completely unimportant details of life.

I cannot express strongly enough the love I have for my family. My grandmother Kerstin, my parents Christina and Ingmar, and my brothers Christian and Henrik - thank you for always being there for me and for staying awake while I present my theories about… everything. Finally, Anna - without you there hadn't been much left of the author of this thesis by now. You are my best friend and the invisible hand of my life.

Göteborg, December 2002

Susanna Lundström

Contents

Introduction

Even though economists have been trying to understand why there are differences in income levels between countries for a long time, the gap and many question marks still remain. The traditional neoclassical growth theory has identified several crucial variables for economic growth and predicts, basically, that countries with higher saving rates and technologies that use capital and labor more efficiently, will have higher growth rates. Assuming that technology is an international public good, this would result in income convergence among countries. Capital would be allocated to the countries with a small capital stock since, all other things being equal, the marginal product of capital would be higher in these countries. However, this pattern has mainly been noticed in OECD countries and a few countries in Asia (DeLong, 2002). For the rest of the world there seems to be a missing link in the answer to the low levels of income, which is not explained by the standard theory.

There is nothing in the traditional neoclassical growth theory that considers the institutional framework in which capital (physical, human or natural) is accumulated, innovations are created or input is turned into output. It is institutionally neutral in the sense that it takes the institutional context as given. The new institutional theory focuses on the social, legal, political and economic framework that determines the set of sanctioned human behavior and choices (Scully, 1992). That the institutional setting affects the marginal product of different capital has been largely accepted, but few empirical or theoretical studies have taken this into account. However, systematic empirical research led to the "politicization" of neoclassical growth theory (see Hibbs, 2001), where institutional mechanisms are put forward as crucial for the efficiency of factor inputs and technological development. Saving rates and other central elements in the neoclassical theory are only seen as middle stages between institutional factors and economic growth. Investments and innovations are thought to be lower in an economy with weak property rights, macroeconomic instability or a high degree of rent-seeking activities, since entrepreneurs cannot be sure of receiving the rents of their work and they need to spend money on, for the society, unproductive activities. By combining the neoclassical theory with institutional theories at the macroeconomic level, new insights about income differences and economic growth become possible (Scully, 1992).

This thesis tries to add some knowledge related to this relatively new area of research by approaching capital accumulation and productivity in an institutional context. It contains studies on what determines the growth-related institutions, and their effects on economic growth as well as the environment. Moreover, the productivity development from technological advances in the natural resource sector is studied in more detail than the standard models, by allowing for different kinds of innovation. This opens up for future research on the connection between institutions and technological innovations.

The theoretical framework of many cross-country growth regressions takes the traditional neoclassical Solow-Swan production function with exogenous long-run growth as their starting point (Solow, 1956; Swan, 1956). What follows is a short presentation of the main features of this theory, which will serve as a reference point for the following chapters of the thesis.[1] Production Y, is a function of physical capital, K, labor input, L, and the labor-augmenting state of technology, A: $Y_t = F(K_t, A_t L_t)$. There are constant returns to scale and decreasing returns to the inputs capital and effective labor (AL). The growth rate of the work force, n, and the growth rate of technology, g, is exogenously determined. The change in the capital stock is determined by $\dot{K} = sF(K_t, A_t L_t) - \delta K$, where s is the exogenously given saving rate and δ the constant rate of capital depreciation. Hence, a constant share of production is saved and invested. Assuming a Cobb-Douglas function, $Y = K^{\alpha}(AL)^{1-\alpha}$, we know that in the steady state (the equilibrium where the capital stock per effective worker is constant), the output per worker is

$$y^{SS} = A\left(\frac{s}{(g+n+\delta)}\right)^{\frac{\alpha}{1-\alpha}}, \qquad (1)$$

[1] See e.g. Barro and Sala-i-Martin (1995), for details of the derivations.

where *SS* indicates that we look at a steady-state value. Assuming that $A = A_0 e^{gt}$, then by taking logs of Equation 1, and indexing for the *i*th country we have,

$$\ln y_{i,t}^{SS} = \ln A_0 + gt + \frac{\alpha}{1-\alpha}\ln s_i - \frac{\alpha}{1-\alpha}\ln(n_i + g + \delta). \tag{2}$$

We now have an expression for the steady-state or "potential" production in a country. To find the growth specification we start by taking a linear approximation around the steady state. Expressed in terms of production per effective worker, $\bar{y}$, we arrive at the cumulative growth from t to $t+T$,

$$\ln \bar{y}_{i,t+T} - \ln \bar{y}_{i,t} = \lambda\left(\ln \bar{y}_i^{SS} - \ln \bar{y}_{i,t}\right), \tag{3}$$

where $\lambda = \left(1 - e^{-\beta T}\right)$ and β is the rate of convergence to a country's steady state. Equation 3 clearly shows that the growth rate is a function of the gap between the potential and the actual production, and the closer the economy is to the potential production, the lower the growth. By combining Equation 2 and 3, and express the equations in terms of production per worker, we can write the growth of the Cobb-Douglas function as

$$\ln y_{i,t+T} - \ln y_{i,t} = C - \lambda \ln y_{i,t} + \lambda\frac{\alpha}{1-\alpha}\ln s_i - \lambda\frac{\alpha}{1-\alpha}\ln(n_i + g + \delta), \tag{4}$$

where $C = \lambda(\ln A_0 + gt) + gT$ and $\beta = (1-\alpha)(n_i + g + \delta)$. This is the function underlying a large amount of cross-country growth regressions. It contains three main parts. First, there is a growth constant, assumed to be common to all countries. Second, there is the initial level of production, which gives the convergence effect. Third, there are the factors determining the steady-state level of production. Technology is assumed to be a global public good and the depreciation rate the same in all countries, which leaves the country-specific saving rate and the growth rate of the work force to explain steady-state income differences between countries.

If we assume equal saving rates and growth rates of the work force, we should observe an absolute convergence across countries towards a global steady-state income level. This hypothesis does not receive empirical support. Even though we allow for differences in the saving rates (i.e. there might be convergence to a steady state conditional on the country-specific saving rate) this explanation is not very satisfactory and we still do not find any empirical evidence. Augmenting the Solow-Swan model by including the human capital stock and assuming that parts of the savings are allocated to this kind of capital, will improve the ability of the model to explain income differences remarkably (see e.g. Mankiw, Romer and Weil, 1992).[2] However, we are still left with questions such as what determines the country-specific saving rates. Even if we assume that the saving rate is endogenous, as in the Ramsey-Cass-Koopmans exogenous growth model (Ramsey, 1928; Cass, 1965; Koopmans, 1965), the question of why saving rates differ across countries is only transformed into the question of why there are differences in the inter-temporal elasticity of substitution and the rate of time preference (Hibbs, 2001).

Even though the endogenous growth theory has contributed greatly to the understanding of economic growth by allowing for endogenous productivity growth, we are still left with some question marks when it comes to global income differences.[3] The process of capital (physical, human or natural) formation in endogenous growth models is typically affected by research and development or other policy variables, and is assumed to give permanent effects on the growth rate. Again, the empirical evidences are disappointing (see e.g. Jones, 1995). Summing up, high growth is not the characteristic of low-income countries, as implied by the neoclassical growth models, or of high–income countries with a well-developed research and development sector, as implied by many endogenous growth models.

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[2] The production function is in the human capital augmented model is $Y = K^{\alpha^K} H^{\alpha^H} (AL)^{1-\alpha^K-\alpha^H}$, and the growth function, with the convergence rate $\beta = (n_i + g + \delta)(1 - \alpha^K - \alpha^H)$, is

$$\ln y_{i,t+T} - \ln y_{i,t} = C - \lambda \ln y_{i,t} + \lambda \frac{\alpha^K}{1-\alpha^K-\alpha^H} \ln s_i^K + \lambda \frac{\alpha^H}{1-\alpha^K-\alpha^H} \ln s_i^H - \lambda \frac{\alpha}{1-\alpha^K-\alpha^H} \ln(n_i + g + \delta).$$

[3] See Aghion and Howitt (1998) for an overview.

The idea behind growth theory conditional on institutions is that economies that function in the same institutional context may converge toward the same steady state.[4] With improved institutions, the potential production level increases and therefore also the growth rate. Institutions may affect growth both by increasing investments (i.e. the saving rate), and hence the stock of capital, or by increasing the productivity of the stock's transformation into output. Hence, institutions may enforce the convergence effect, but also affect the steady state growth as is possible in the endogenous growth models (i.e. the potential for productivity increases is improved by better institutions, either directly or by affecting the incentives for technological development).

Hence, the country-specific steady state is determined by environmental variables and the private sector's choices that include fertility and saving rates, but also by the government's choices that include government expenditures, enforcement of property rights, tax structure, regulations, etc. (Barro, 1996). This would explain why traditional growth theory may contribute much to the understanding of income differences among OECD countries, but when including for example African countries with a very different institutional set-up, the theory becomes less useful. Moreover, there seems to be a subset of low-income countries that converge toward the richer countries, which raises the question of whether this subset of countries might have adopted an institutional framework similar to the rich countries.

The methodological approach to growth conditional on institutions is mainly based on the work of Barro (1991). He estimated a cross-country regression where $\ln y_i^{SS} = a + X_{i,t}b$. Hence, the potential production is determined by several country-specific factors included in the vector $X_{i,t}$. This vector most often includes the Solow-Swan variables, such as investment as a share of GDP and human capital measures, but it may also include institutional variables that are assumed to affect the steady-state level of capital and production. b is the coefficient vector associated with $X_{i,t}$. We hence have the following growth equation:

$$\ln y_{i,t+T} - \ln y_{i,t} = c - \lambda \ln y_{i,t} + \lambda \ln X_{i,t} b, \qquad (5)$$

[4] See e.g. North (1990) for the basic ideas of institutional economics.

where $c = C + \lambda a$.[5] Income growth in country *i* thus depends on a growth constant common to all countries, country *i*'s initial income, and country *i*'s specific determinants of steady state, such as the capital-specific saving rates and institutional variables. However, as noted by, for example, Temple (1999), it is not obvious if the variables in vector X temporarily affect the growth rate by affecting the steady-state *level* of income, as assumed by the exogenous growth literature (i.e. the increased growth rate is temporary until the new steady-state level is reached), or if they permanently affect the steady-state *growth rate* of income, as assumed by the endogenous growth literature (i.e. an improved ability to increase the steady-state level of income continuously).

The assumption that institutions affect growth has put them in the focus of policy makers. Given that they are central to the policy process, there are several other research questions that arise such as how they are developed and if they have effects on welfare other than increasing income. The focus in this thesis is on the market-based institutions, closely related to the concept of economic freedom, which according to previous empirical studies seems to be crucial for growth. The first question analyzed is what determines the levels of the growth-related institutions that should enter in Equation 5. Paper 1 "The Effect of Democracy on Different Economic Freedom Categories" studies the link between democracy (civil or political freedom) and a decomposed economic freedom index in less developed countries. There are several hypotheses regarding the impact of democracy on the development of economic freedom. Some argue that democratic institutions are a precondition for the development of the market-oriented institutions, while others believe in an autocratic "firm hand" policy for a successful market reform. A third view argues that there are other determinants of economic liberalization, independent of the political regime. Previous studies have examined the correlation between democracy (including both civil and political freedom) and an economic freedom index, while this paper examines the correlations between political and civil freedom separately, and four different

[5] Equation 5 corresponds to Equation 4 with the exception of an extended specification of the steady-state determinants, and λ is now a free-form coefficient.

categories of economic freedom. By this approach it is possible to test for the coexistence of different views since they might be connected to different kinds of freedom relations. The results show that the level of democracy positively affects some categories, while others are not related to democracy at all. That a low level of democracy would imply larger changes in economic freedom reform does not receive any support in this study. The paper also emphasizes the stability issues giving particular consideration to the effects of the model specification and extreme points.

The second step in the thesis is to look at effects of market-based institutions on economic growth and the environment, which might both be expected to affect welfare. The effects on economic growth are clear from the discussion above, but the importance of institutions in the understanding of environmental problems is evolving as a relatively new research area. Institutions affect income levels (by its effects on growth) that in turn affect the environmental quality in a country. However, there are also direct effects from institutions to environmental quality. For example, clear property rights of land may eliminate the open access problems and hence decrease land degradation, and a competitive market may increase resource efficiency as long as prices are socially optimal.

Paper 2 "Effects of Economic Freedom, Growth and the Environment: Implications for Cross-Country Analysis" discusses the effects of specific economic freedom categories on growth and the environment, and presents arguments for both positive and negative links. Accepting this rather complex approach has implications for cross-country regressions based on Equation 5. First, some measurement problems connected to the economic freedom data are discussed. Thereafter the model specification is considered, including issues such as important interaction terms and non-linearities, followed by a presentation of useful sensitivity tests. Finally some potential econometric problems are discussed. The main conclusion is that decomposition is important since different economic freedoms are expected to have different welfare effects, and are dependent on different interacting factors. Moreover, a sensitivity tests should be central to the analysis due to the complexity of the relationships. Developing clearer theoretical starting points is also important, not at least since they have a crucial role in the choice of what empirical considerations to take into account. The following two papers are examples of applications discussed in Paper 2.

In Paper 3 "Economic Freedom and Growth: Decomposing the Effects" we empirically study the link between economic freedom and economic growth based on Equation 5. As mentioned, a positive relationship has been confirmed in several studies using a general index of economic freedom. In this study the index is decomposed into seven categories and we analyze the growth effect from each category. The results confirm the importance of decomposition since the effects differ substantially when it comes to sign, amplitude and robustness. The results are carefully tested for sample and model sensitivity, as well as multicollinearity that may be a problem when using the components of an index as explanatory variables.

The effects of both economic and political freedom on the environment, in terms of carbon dioxide emissions, are analyzed in Paper 4 "The Effects of Economic and Political Freedom on CO_2 emissions". The first part presents a theoretical discussion of the direct effects of freedom on emissions (not the indirect effects via income, even though we control for income) and the second part contains a study with Box-Cox panel regressions of the links between different freedoms and CO_2 emissions. The results show that political freedom does not seem to have an effect on emissions, most probably since CO_2 emissions is a global environmental problem and hence subject to free-riding by the individual countries. Economic freedom seems to decrease CO_2 emissions by increased macroeconomic and legal stability in countries with a low industry share of GDP, but increase emissions in countries with a high industry share. The effect of trade liberalization on emissions is insignificant and the decreasing effect on emissions from increased efficiency (by increased market allocation) is not robust.

As argued, a shortcoming of the standard growth models is the narrow view of the level of productivity, A, although productivity growth is assumed to be crucial for economic growth. Even if we accept that productivity is only determined by technological development, the definition of technology is also oversimplified. In the classical Solow-Swan model A represents the technical level and evolves, because of the diminishing returns to capital, in the long run by the exogenous rate g. Endogenous growth theory has a more sophisticated approach and lets g depend on other factors such as expenditure on research and development, which may relax the diminishing returns to capital.

The so-called technological opportunity approach (see e.g. Olsson, 2001) goes one step further and lets g depend also on the type of innovation undertaken: drastic or incremental. Paper 5 "Technological Opportunities and Growth in the Natural Resource Sector" tries, through a theoretical model, to look deeper into the nature of the efficiency variable A in the natural resource sector, by applying this technological opportunity approach. Different types of innovation are induced either by scarcity of technological opportunities or natural resources, and affect the resource stocks and growth rate differently. The model presents one way of explaining the waves in resource abundance where drastic innovation creates new extraction possibilities, by extending the set of resources, and incremental innovation increases the extraction rate of a given set of resources. It also considers two stagnation scenarios of the natural resource sector. Long run stagnation may occur when the ability to innovate is too low, since no new technological opportunities or resources are created, and short run stagnation may occur if the ability to innovate is too high, since the extraction rate might be too high. The incremental phase of technological development follows the pattern of exogenous growth models with decreasing returns to scale, both in technological opportunities and natural resources. On the other hand, the sharp increase in marginal returns by the drastic innovation is characterized by endogenous technological change. This combination of both exogenous and endogenous growth periods may give us new insights about natural resource scarcity. Moreover, the decomposition of technological development may create new research possibilities in the understanding of how institutions affect the technological level in a country.

Institutional effects on development and a more detailed view of productivity are issues that are in the process of being formalized. Even though these are complex research areas they are still crucial for the understanding of the development process, and should therefore be a central component of development economics. This thesis is a contribution to the field, and hopefully a source of inspiration for future research.

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The Effect of Democracy on Different Categories of Economic Freedom

By

Susanna Lundström*

***Abstract*:**
Many empirical studies conclude that democracy increases economic freedom. However, these studies use highly aggregated indices of economic freedom, which eliminate interesting information and obstruct policy conclusions. The purpose of this paper is to empirically study how different categories of economic freedom are affected by democracy, measured either as political or civil freedom, in developing countries. Democracy seems to increase the economic freedom categories *Government Operations and Regulations* and *Restraints on International Exchange*, but not affect the categories *Money and Inflation* and *Takings and Discriminatory Taxation*. That a low level of democracy would imply larger changes in economic freedom reform does not receive any support in this study. The robustness to extreme points and the model specification is tested. The result for all variables except *Restraints on International Exchange* passes these tests without major changes.

***Keywords*:** Decomposition, Democracy, Economic freedom, Institutions, Political Freedom.

***JEL classification*:** P51

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1 INTRODUCTION

Previous empirical studies have confirmed that democracy increases economic freedom (see e.g. De Melo et al., 1997; de Haan and Sturm, *forthcoming*). However, all these studies use highly aggregated indices of economic freedom, which eliminate a lot of interesting information and obstruct policy conclusions. One might ask what kind of economic freedom increases with democracy. Or, can it be that some categories of economic freedom are not related to democracy at all, or even that some categories of economic freedom decrease with democracy? Many arguments exist for positive and negative, as well as insignificant, effects of democracy on economic liberalization. On the basis of the inconclusive theoretical arguments, it is far from obvious that all categories in an economic freedom index are equally affected by democracy.

The purpose of this study is to empirically study the long run effect of democracy on different categories of economic freedom in developing countries. The sensitivity of the results is analyzed when it comes to extreme points and model specification.

The paper is organized as follows. Section 2 gives the theoretical arguments for potential effects of democracy on economic freedom. In Section 3, the data is presented. The model specification and sensitivity tests are described in Section 4. Section 5 presents and analyzes the results from the basic regressions and the sensitivity tests. Section 6 concludes the paper.

2 THEORETICAL ARGUMENTS

The theoretical arguments for the impact of democracy on economic freedom and growth are ambiguous. The arguments can be divided into three groups: the conflict view, the compatibility view and the skeptical view (Sirowy and Inkeles, 1990).

According to the *conflict view* there is a choice between either a democratic process or rapid economic transition. A first argument is that democracy makes it harder for a government to make tough but necessary decisions (World Bank, 1991). An authoritarian government is needed at least in the beginning of the liberalization process, since massive layoffs and cuts in entitlements are common in the initial stages

(Fidrmuc, 2000). Examples in favor of this view are countries such as Chile, South Korea and Taiwan, which all successfully implemented economic reforms under an autocratic regime and subsequently replaced the regime with a more democratic government (Edwards, 1991). Another example is Russia who started out with a political liberalization that ended up in institutional chaos, which retarded the economic reforms (Shleifer, 1998). A second argument for a negative effect of democracy on economic freedom is that the positive long run effects of a reform involve great uncertainty. This may lead a rational voter to oppose the changes in economic freedom even though the final effects are expected to be welfare augmenting for a majority (Fernandez and Rodrik, 1991; Conley and Maloney, 1995). An example is workers opposing privatization, even though they believe most will benefit in the end, because they do not know if their individual skills will be demanded after the reform. Since political backlashes would be unavoidable, an autocratic regime would be more likely to implement these policies, which ex-post would be popular. A third argument concerns the inefficiencies that might be created by the rent-seeking activities of interest groups under a democratic regime. Some argue that elected governments are more likely to follow the demands of some interest groups in society as a means to win votes in the short run. The redistributive role of a democratic government may therefore lead to overspendings and adverse effects on savings and productive investment (Alesina and Perotti, 1994; Block, 2002). Necessary restraints on consumption and real wages would decrease the probability of re-election. Alesina and Drazen (1991) illustrate how efficiency-enhancing reforms may be delayed because of wars over asymmetric pay-offs. The welfare-loss is not only the delayed reform but also the loss of productive activity during the conflict.

The arguments of the *compatibility view*, i.e. increased democracy foster economic freedom, are similar to the argument that democracy facilitates economic growth (see Przeworska and Limongi, 1993, and De Haan and Siermann, 1995, for surveys). First, some argue that, in contrast to the conflict view, only a government with some legitimacy would be able to stand by policies with short run costs. Democratic regimes can be assumed to have greater legitimacy because of the political and civil freedom the system allows the people to have. Second, many of the institutions needed in a democracy are also the sources of a successful economic liberalization, such as an independent legal system, a professional civil service and stable property rights. Third, democracy, and not autocracy as argued by the conflict perspective, may limit rent-seeking because of its system of checks and balances hindering self-interested leaders. Åslund et al. (1996) argue that in countries lacking such a system, the old elite, especially state enterprise directors and political leaders, continues to have advantages over the rest of the population, and a de-monopolization becomes difficult. According to North (1993), civil and political liberties are necessary to protect citizens from predatory behavior of the government. Finally, with democracy follows institutions encouraging debate, such as free elections with opposition parties and freedom of speech, which may be a fundamental base for conflict management under liberalization (Rodrik, 1999). An authoritarian regime may avoid conflicts in the short run, but has no institution for solving them.

Followers of the *skeptical view* argue, more or less, that the question is mis-specified and that it is other institutions, not directly connected to a specific regime, that affect economic development. According to Clague et al. (1996), there are large variations within a democratic or an autocratic regime. In autocracies it is the time horizon of the individual autocrat that determines property and contract rights, whereas in democracies it is the durability of the regime that determines these rights. Alesina and Perotti (1994) argue that instability and uncertainty discourage investments and growth, rather than the specific political system. Moreover, comparing the conflict view and the compatibility view, it is inconclusive if a dictator would be more resistant to interest groups and rent-seeking behavior, or be a better conflict manager than a democratic government.

As is clear from the survey of arguments above, there are many aspects of the effect of democracy on economic freedom. However, this is not very surprising. Economic freedom includes many, sometimes very different, aspects and the effect of democracy can be expected to depend on what kind of economic freedom one refers to. Previous empirical studies have tended to support the compatibility view, but this does not mean that this is the only relevant view, since only the effects on a summary index has yet been analyzed. For example, the conflict view may be more appropriate when looking at discriminatory regulations as a measure of economic freedom, while the compatibility view may be accurate when predicting the government size, and the skeptical view is maybe more in accordance with reality if economic freedom refers to inflation issues. The aim of the following empirical analysis is to examine the possibility of parallel views on the relation between democracy and economic freedom, depending on the specific economic freedom measure.

3 DATA

The data on economic freedom is obtained from "Economic freedom of the world; 1975-1995" by Gwartney et al. (1996) - an often used index. The main components of the economic freedom index are personal choice, protection of property and freedom of exchange. The index is divided into four categories, each measured on a scale from 0 to 10, where 10 is the highest level of freedom. The first category, *Money and Inflation* (*EFmon*), is a measure of the availability of "sound" money to the citizens. High economic freedom in this sense means slow monetary expansion, stable price levels and absence of restrictions limiting the use of alternative currencies. The category is constructed of the variables: (i) average annual growth rate of the money supply during the last five years minus the annual growth rate of potential GDP, (ii) the standard deviation of annual inflation rate during the last five years, (iii) freedom of residents to own foreign money domestically and (iv) freedom of residents to maintain bank accounts abroad.

The second category, *Government Operations and Regulations* (*EFgov*), represents the extent of reliance on market allocation rather then allocation through the political process. High economic freedom is assumed to prevail if the government mainly functions as a provider of protection and a public good producer. The category consists of the variables: (i) government general consumption expenditures as a share of GDP, (ii) government-operated enterprises as a share of the economy, (iii) price controls – the extent that businesses are free to set their own prices, (iv) freedom to enter and compete in markets, (v) equality of citizens under the law and citizen access to a nondiscriminatory judiciary and (vi) freedom from government regulations and policies that cause negative real interest rates.

The third category, *Takings and Discriminatory Taxation* (*EFtak*), measures the extent to which the government treats citizens differently by engaging in tax and transfer activities. High economic freedom is achieved if the government does not engage in actions that favor or discriminate one group of citizens. The category includes the variables: (i) transfers and subsidies as a percent of GDP, (ii) top marginal tax rate and (iii) the use of conscripts to obtain military personnel.

The last category, *Restraints on International Exchange* (*EFint*), is a measure of citizen possibilities of gaining from division of labor, economies of scale and from specialization in areas where they have a comparative advantage. High economic freedom defined in this sense means low restrictions on exchanges across the nation borders. The category is constructed of the variables: (i) taxes on international trade as a percent of exports plus imports, (ii) difference between the official exchange rate and the black market rate and (iii) actual size of the trade sector compared to the expected size.

Gwartney et al. (1996) present three alternative aggregation techniques to construct an economic freedom *Summary Index* from the different variables Ie, Is1 and Is2. The variables in Ie are weighted by the inverse of its standard deviation. In the other summary indices, each variable is assigned a weight based on expert surveys, with experts in the field of economic freedom for Is1 and country experts for Is2. Since all three indices are highly correlated and give very similar results, only the results from the regressions with Ie (*EFsum*) will be presented in this paper.[1]

The democracy variable is based on the Freedom House indices of civil and political freedom (Freedom House, 1999). The civil freedom index measures constraints on the freedom of the press, and constraints on the rights of individuals to debate, to assemble, to demonstrate and to form organizations, including political parties and pressure groups. The political freedom index measures whether a government came to power by election or by gun, whether elections, if any, are free and fair and whether an opposition exists and has the opportunity to take power at the consent of the electorate.

[1] The correlation between Ie and Is1 is 0.97, and between Ie and Is2 0.95.

Both freedom measures are measured on a scale from 1 to 7, where 7 is the highest level of freedom.[2] We will use either civil or political freedom as a proxy for democracy.

The control variables and the variables used in the model sensitivity analysis are all from the *2000 World Development Indicators CD-Rom* (World Bank, 2000), with the exception of the dummy variables for regions, legal origin and developing country which come from the *Global Development Network Data Base* (World Bank, 1999). The resulting samples include 58 developing countries, presented in Table A.1 in the Appendix, for the period 1975-1995.[3] Table 1 presents descriptive statistics for the variables included in the basic regressions and in the model specification test. Note that income is presented in dollars per capita and that *gEFj* is the change in *EFj* from 1975 to 1995, where *j = sum, mon, gov, tak* or *int*.

Table 1: Descriptive statistics (58 developing countries).

Variable	Mean	Std.Dev.	Minimum	Maximum	Variable	Mean	Std.Dev.	Minimum	Maximum
CIVIL	3.53	1.53	1	7	Y75	1363.29	1022.78	231.78	4593.24
POLIT	3.21	1.80	1	7	Aid	4.62	5.78	-0.01	30.20
gEFsum	0.78	1.48	-3.30	3.58	Open	50.13	23.27	9.20	111.01
gEFmon	1.43	2.55	-5.54	6.73	Growth	5.39	3.58	-1.25	18.05
gEFgov	-0.36	1.81	-5.52	3.30	SSA	0.35	0.48	0	1
gEFtak	-0.34	3.83	-10	6.04	MENA	0.12	0.33	0	1
gEFint	0.98	1.85	-5.74	6.37	LAC	0.34	0.48	0	1
EFsum75	3.96	1.15	1.21	7.27	SA	0.09	1.28	0	1
EFmon75	2.60	1.78	0	7.92	EAP	0.10	0.31	0	1
EFgov75	5.12	1.75	1.17	8.86	French	0.64	0.48	0	1
EFtak75	6.22	2.90	0	10	British	0.34	0.48	0	1
EFint75	3.65	1.84	0	8.48					

CIVIL is civil freedom and *POLIT* is political freedom both measured as the 1973 to 1975 average; *gEFj* is the change in *EFj* from 1975 to 1995, where *j = sum, mon, gov, tak* or *int*; *EFj75* is the level of economic freedom *j* in 1975; *Y75* is the level of income in 1975; *Aid* is aid received as a share of GDP from 1970 to 1975; *Open* is imports and exports as a share of GDP from 1970 to 1975; *Growth* is growth of GDP from 1970 to 1975; the regional dummies are Sub-Saharan Africa (*SSA*), Middle East and North Africa (*MENA*), Latin America and the Caribbean (*LAC*) , South Asia (*SA*) and East Asia and the Pacific (*EAP*); *French* and *British* are dummies for legal origins.

[2] The variable has been rescaled since 1 is the highest level of political and civil freedom, and 7 the lowest level, in the original data set.

[3] Hungary was excluded since this was the only country from Eastern Europe, which is a region with a very special liberalization pattern during the studied period.

4 THE MODEL AND SENSITIVITY ANALYSIS

4.1 Basic regressions

We have chosen the fairly long run perspective of 20 years since we believe the political process of democratization and the implementations of economic reforms take time to stabilize especially when starting out with low initial values, which is the case for many developing countries. The underlying assumption of the model presented in this section is a general pressure of reform (from for example the citizens, trade partners or the World Bank/IMF) during the studied period, and the response to this pressure depends on the initial level of democracy, among other things.[4] We therefore stress that the relevance of this paper refers to this specific period, since this reform pressure may be absent during other periods. Moreover, as discussed by Jones (1995), regressing a stationary variable (democracy) on a non-stationary variable (change in economic freedom) may result in unrealistic assumptions about the potential changes in the non-stationery variable.[5] Most developing countries start out at a relatively low level of both democracy and economic freedom during the studied period (see Table 1). The result thus only refers to this sample, and may not hold for countries that are close to the upper bounds of the variables.

The model specification follows the methodology of Levine and Renelt (1992)[6] and the control variables are similar to the ones used by de Haan and Sturm (forthcoming), with the exception that all regional dummies are included, and some of the variables have different time lags. The underlying regressions is

$$gEFj_i = \alpha M_i + \beta F_i + \gamma Z_i + u_i$$

[4] An alternative specification would be to analyze how changes in democracy 1975-80, 1980-85, 1985-90 and 1990-95, affect changes in economic freedom 1975 to 1995. This would however cause severe causality problems leaving no room for credible conclusions.

[5] For example, an unlimited increase in human capital will not result in an unbounded acceleration of growth rates.

[6] Levine and Renelt study changes in income while we look at changes in economic freedom, but this does not affect the appropriateness of the regression methodology.

where $gEFj_i$ is the change in the economic freedom measure *j* in country *i* 1975 to 1995; M_i is a vector of standard explanatory variables, which according to previous studies have shown to be robustly related to economic freedom; F_i is the variable if interest, i.e. democracy in our case; Z_i is a vector of up to three possible explanatory variables, which according to previous literature may have an impact on the change in economic freedom; and u_i is an error term. By examining previous empirical studies and testing for several potential explanatory variables, we conclude that the vector M_i should contain EFj_i, which is the initial, 1975, level of economic freedom measure *j*, and regional dummies, since they are the only variables showing a robustly and significant relation to the dependent variable. The regional dummies are Sub-Saharan Africa (*SSA*), Middle East and North Africa (*MENA*), East Asia and the Pacific (*EAP*), South Asia (*SA*) and the base case Latin America and the Caribbean (*LAC*). Initial economic freedom is included to allow for a convergence effect; the lower economic freedom the larger change in economic freedom.[7] F_i is initial democracy and is measured as the average 1973-75 value of either civil freedom or political freedom. In the basic regressions there are no variables included in the Z_i vector; these will be added to the model specification test in the next section. This results in ten models - two models for each economic freedom variable *j* = *sum*, *mon*, *gov*, *tak* or *int*, using either civil freedom or political freedom as the democracy measure. Since all variables refer to the beginning of the estimation period, there is no problem of reverse causality.

4.2 Sensitivity tests

4.2.1 Extreme Points

There are several ways to identify extreme points and several ways to deal with the identified points. This section gives a brief explanation of the identification tests and the robust regression technique used, while Appendix A.1 presents the methods in more detail. An outlier is an observation with a large residual, i.e. a point with a large

[7] It is most probably easier and less costly to liberalize when there is knowledge available based on the experience of countries that have already reached a high level of economic freedom.

deviation from the fitted value. The studentized residual, r_i, measures the residual of the *i*th observation, adjusted for its standard deviation. r_i can hence be interpreted as the *t*-statistic for testing the significance of a dummy, taking the value 1 if the *i*th observation is excluded and 0 otherwise.

Observations that are isolated or "outliers" in the **X** space, where **X** represents the matrix of the independent variables, are high leverage points. These may have a large influence on the fitted regression equation.[8] Hence, a point with a high leverage value may very well have a small residual and can in that case not be identified as an outlier. The leverage method tests the change in prediction of the dependent variable from the whole sample and from the sample with the *i*-th observation deleted.

There are several summary statistics based on an index, increased both by a large residual and by a high leverage point. Here we will use the Cook's Distance, D_i, which can be viewed as the scaled measure of the distance between the coefficient vectors when the *i*th observation is deleted.

If extreme points that may influence the basic regression have been identified, there are reasons to use a robust regression technique to see if the basic result changes significantly or not. The robust regression technique used in this study is the biweight procedure, where weights between 0 and 1 are attached to the residuals, with lower weights placed on large residuals. However, first observations are deleted if they have a Cook's Distance larger than 1. After this initial screening the procedure is iterative; after a regression, weights are calculated on the basis of absolute residuals and then re-estimated using those weights. First, Huber iterations are performed until the change in the Huber weights falls below a tolerance level, then biweight iterations are performed until convergence in the biweights.[9]

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[8] Note that a point has a high leverage if the observation of the independent variable is far from the rest of the data of independent variables. However, this only means that the point has a large *potential* to influence the coefficient estimates. If the point does influence the fitted regression equation depends on the position in relation to the dependent variable. The point can still be perfectly in line with the trend set by the rest of the data, which means that it does not affect the fitted regression.

[9] The reason why both methods are used is that Huber weights have problems dealing with large outliers, and biweights sometimes fail to converge or have multiple solutions. The initial Huber weighting is performed to improve the behavior of the biweights.

4.2.1 Model Specification

To check how robust the coefficients of economic freedom are to changes in the conditioning set of information, we first apply the extreme bound analysis (see Levine and Renelt, 1992). We add up to three new control variables to the vector Z_i described above, which according to the literature may have explanatory value, to each of the ten basic models and then re-estimate the models. Because of the potential problem of endogeniety we instrument the variables by using lagged values. The Z_i variables are log of initial income in 1975 (*logY75*), aid received as a share of GDP during the 1970-75 period (*Aid*), openness measured as imports and exports as a share of GDP 1970-75 (*Open*), economic growth 1970-75 (*Growth*), and a dummy representing a French legal origin (*French*).[10] Initial income is included since a richer country has more resources to manage the reform. The extent of development aid is included since it is often given conditioned upon economic reforms. An open economy is subject to the international competitive pressure, which may result in institutional changes, and is therefore included as a potential explanatory variable. The reason for including growth is that if earlier reforms resulted in increased growth, this positive experience will increase the probability for future liberalization. The legal origin is included since it probably has influenced the political and juridical system in the country.

This results in 25 regressions for each of the ten basic models, with different combinations of the new variables. For each of these new models *z = 1,..,25*, we estimate the parameter for the democracy variable, β_z, and the corresponding standard deviation, σ_z. The lower extreme bound is defined to be the lowest value of $\beta_z - 2\sigma_z$ and the upper extreme bound is the largest value of $\beta_z + 2\sigma_z$. If the lower and upper extreme bounds are of opposite signs, then the variable is not robust according to the extreme bound test.

The extreme bound analysis has been criticized for being too restrictive. Sala-i-Martin (1997a,b) suggests a method looking at the whole distribution of the estimator β_z. We start by assuming a normal density function and calculate beta values and

[10] Most other countries have a British legal origin (*British*).

standard deviations of all *z* models, produced in the same way as explained in the extreme bound case. Thereafter the means, $\overline{\beta}_z$ and $\overline{\sigma}_z$, are calculated as the average of the *z* estimated β values and variances.[11] The cumulative density function CDF(0) can then be constructed using the normal tables, and is used to estimate the robustness of the variables when it comes to model specification.

5 RESULTS

The results for the basic regressions are presented in Table 2. All models, except the model that regresses civil freedom on *gEFsum*, pass a RESET test at the 5% level. The basic regressions show that the long-run results are almost identical for the models using civil freedom and political freedom as a proxy for democracy. The first column represents the regression seen in many previous studies, with the summary index as the measure of economic freedom. The democracy variable is, as in most of these studies, positive and significant. The other columns represent the models with the decomposed parts of the summary index. Democracy only affects two of the categories, *EFgov* and *EFint*, and, as in the case with the summary index, the effect is positive. The effect of democracy on the categories *EFmon* and *EFtak* is insignificant.

The initial level of economic freedom has also been strongly significant in previous studies, which is confirmed in this study for all ten models. It has a negative effect on the change in economic freedom, implying that low initial economic freedom leads to larger changes in economic freedom. Hence, there seems to be a strong convergence effect no matter which of the economic freedom categories is analyzed. The significance of the regional dummies varies depending on the economic freedom variable used.

[11] Sala-i-Martin also calculates the likelihood for all models, and constructs a weighted average of beta and the variance. We do not do this since the goodness of fit, depending on the variables included in Z_i, does not vary considerably in our models.

Table 2: Basic regressions for changes in economic freedom over 20 years (*t*-values in parentheses).

	gEFsum	gEFmon	gEFgov	gEFtak	gEFint
Civil	0.249**	-0.008	0.371***	0.197	0.261*
	(2.430)	(-0.040)	(2.800)	(0.730)	(1.770)
EFj75	-0.973***	-0.907***	-0.867***	-0.920***	-0.643***
	(-7.680)	(-5.580)	(-7.690)	(-7.600)	(-5.770)
SSA	-0.779**	-1.319*	-0.282	-0.500	-0.815
	(-2.060)	(-1.670)	(-0.570)	(-0.530)	(-1.580)
MENA	-1.328***	-0.110	-1.409**	-3.228**	-0.825
	(-2.690)	(-0.110)	(-2.060)	(-2.550)	(-1.190)
SA	-0.671	-0.690	-0.306	1.562	-0.727
	(-1.290)	(-0.690)	(-0.490)	(1.240)	(-0.990)
EAP	1.250***	3.043***	0.461	0.981	1.091
	(2.750)	(3.340)	(0.770)	(0.820)	(1.640)
Constant	4.102***	4.035***	3.015***	5.018***	2.735***
	(5.340)	(3.270)	(3.240)	(3.200)	(3.170)
Adj-R2	0.58	0.45	0.53	0.57	0.44
	gEFsum	gEFmon	gEFgov	gEFtak	gEFint
Political	0.190**	-0.013	0.259**	0.149	0.260**
	(2.270)	(-0.080)	(2.360)	(0.680)	(2.210)
EFj75	-0.946***	-0.909***	-0.809***	-0.916***	-0.671***
	(-7.410)	(-5.500)	(-7.000)	(-7.500)	(-6.090)
SSA	-0.871**	-1.329*	-0.390	-0.603	-0.854*
	(-2.360)	(-1.730)	(-0.800)	(-0.680)	(-1.790)
MENA	-1.534***	-0.115	-1.632**	-3.407**	-0.941
	(-3.290)	(-0.120)	(-2.410)	(-2.900)	(-1.470)
SA	-0.917*	-0.679	-0.688	1.334	-1.135
	(-1.760)	(-0.680)	(-1.080)	(1.050)	(-1.550)
EAP	1.073**	3.048***	0.258	0.842	0.939
	(2.380)	(3.400)	(0.430)	(0.720)	(1.450)
Constant	4.362***	4.051***	3.314***	5.296***	3.001***
	(6.010)	(3.750)	(3.570)	(3.990)	(4.460)
Adj-R2	0.57	0.45	0.51	0.57	0.46

*** = variables significant at the 1% level, ** = the 5% level and * = the 10% level.

So far there seems to be a positive relation between democracy and two of the economic freedom categories, while there is no relation with the two remaining categories. But do the results hold for robustness tests? In Table A.2 in the Appendix, the countries identified as extreme points in each of the ten models are presented using the studentized residual method, the leverage value and the Cook's Distance. Since there are up to 9 extreme points depending on the model and identification test, it is of interest to estimate the models using a robust regression technique to see if the result changes when the influence of extreme points is restricted. The results from biweight regressions are presented in Table 3.[12]

Table 3: Robust regressions. All models also include a constant and control variables for initial economic freedom and regional dummies.

	gEFsum	gEFmon	gEFgov	gEFtak	gEFint
Civil	0.191*	0.053	0.175*	0.130	0.172
t-value	(1.930)	(0.260)	(1.720)	(0.510)	(1.210)
	gEFsum	gEFmon	gEFgov	gEFtak	gEFint
Political	0.162**	0.025	0.154*	0.055	0.219*
t-value	(2.210)	(0.150)	(1.980)	(0.260)	(1.960)

*** = variables significant at the 1% level, ** = the 5% level and * = the 10% level.

The result is similar independent of the democracy proxy used also in the robust regressions. There is, with some exceptions, a general decrease in the explanatory power of democracy compared to the basic results. However, the result from previous studies is still reproduced with a significant effect of democracy on the *gEFsum*. The significant effect of democracy on *gEFgov* also remains, as well as the insignificant effect of democracy on *gEFmon* and *gEFtak*. The explanatory power of the democracy variable is only affected in the model with *EFint* as the measure of economic freedom and civil freedom as the measure of democracy. When using political freedom, the result is robust even for this economic freedom category.

In Table 4, the results from the model specification analysis are presented. First we report the share of number of times the variable is significant at the 5% level. For the extreme bound test, a variable passes if the lower and upper bound is of the same sign, and the critical value of the CDF normal test, the Sala-i-Martin test, is set to 0.95. Concluding from the extreme bound test, the democracy variable is only robust in the *EFgov* models, independent of the measure of democracy, while it is fragile in all other models. However, as mentioned, the extreme bound analysis has been criticized for being too restrictive and it is therefore important to complement this result with the results from the share significant and the Sala-i-Martin method before drawing any firm conclusions. Starting with the share of time the democracy variable is significant, when

[12] All regressions include 58 countries, which means that no observation was deleted because of a Cook's Distance larger than one.

running the *z=25* numbers of models, the results are robust in all models except for *EFint* using civil freedom. In all other cases the democracy variable is significant (insignificant) in all of the regressions when it is significant (insignificant) in the basic model. Using the Sala-i-Martin test, all models seems to be robust to the model specification since the democracy variable passes the 0.95 limit when it is significant in the basic model, but does not pass when it is insignificant in the basic model. A general conclusion from these tests is therefore that the basic results seem to be robust to the model specification, even though the robustness of the model for *EFint* using civil freedom is questionable.

Table 4: Effects on the democracy variable from the model specification tests.

Civil Freedom					
	gEFsum	gEFmon	gEFgov	gEFtak	gEFint
Beta	0.268	0.035	0.408	0.155	0.265
Variance	0.014	0.042	0.026	0.055	0.024
Share sign	1	0	1	0	0.58
Lower	-0.029	-0.477	0.068	-0.473	-0.103
Upper	0.563	0.561	0.831	0.740	0.675
Normal	0.987	0.568	0.994	0.746	0.956
Political Freedom					
	gEFsum	gEFmon	gEFgov	gEFtak	gEFint
Beta	0.194	0.044	0.265	0.068	0.269
Variance	0.008	0.026	0.014	0.027	0.013
Share sign	1	0	1	0	1
Lower	-0.025	-0.348	0.001	-0.388	-0.015
Upper	0.412	0.472	0.585	0.559	0.594
Normal	0.986	0.608	0.987	0.661	0.991

How democracy affects the different measures of economic freedom is summarized in Table 5. The results are the same for all models regardless of whether civil or political freedom is used as a proxy for democracy, with the exception of the sensitivity tests of the last economic freedom category. The results for the model with the *Summary Index* are not surprising. As in previous studies the effect is positive and robust both to extreme points and the model specification. When economic freedom is measured as *Money and Inflation*, democracy has no effect, and this seems to hold even when the model specification is changed or if a robust estimation technique is used to deal with the extreme points. With *Government Operations and Regulations*, democracy is again positive and significant. Democracy is very stable when it comes to the model specification, since it even passes the extreme bound test, but also to extreme points. Using *Takings and Discriminatory Taxation* as the economic freedom measure, the democracy variable is again insignificant and the result passes both robust regressions and model specification tests. In the model with the *Restraints on International Exchange* as the economic freedom measure, democracy is positive and significant in the basic regressions, no matter what proxy of democracy used. However, when using political freedom the result is robust both to extreme points and to the model specification, while when using civil freedom the result is fragile to extreme points and the robustness to the model specification can be questioned.

Table 5: Summary results for the democracy variable depending on the economic freedom measure used.

Economic Freedom Measure	Basic regression	Extreme points	Model specification
Summary Index	Positive	Robust	Robust
Money and Inflation	Insignificant	Robust	Robust
Government Operations and Regulations	Positive	Robust	Very Robust
Takings and Discriminatory Taxation	Insignificant	Robust	Robust
Restraints on International Exchange	Positive	Robust/Fragile	Robust/Low robustness

6 CONCLUSIONS

The purpose of this paper is to empirically study how different categories of economic freedom are affected by democracy, in developing countries. Either civil or political freedom is used as a proxy variable for democracy. The results for the model with the *Summary Index* as the economic freedom measure are not surprising. As in previous studies the effect of democracy on economic freedom is positive and robust, supporting the so-called compatibility view. There seems to be a positive effect of democracy on the categories *Government Operations and Regulations* and *Restraints on International Exchange*, but for the categories *Money and Inflation* and *Takings and Discriminatory Taxation* there is no effect. Accepting the definition of the categories, the results would imply that a higher level of democracy leads to an increased reliance on the market as the allocation mechanism, and to decreased restraints on international trade, while democracy has no effect on the availability of sound money or the tendency for the government to discriminate against one group of citizens.

However, some of these results may be fragile to alternative samples and specifications. The result for the measures *Money and Inflation*, *Government Operations and Regulations* and *Takings and Discriminatory Taxation* are robust both to extreme points and model specification. The results for the model with *Restraints on International Exchange* are robust when political freedom is used as the proxy for democracy. However, using civil freedom, it is fragile to extreme points and the robustness of the model specification can be questioned.

Hence, the compatibility view, predicting a positive effect of democracy on economic freedom, seems to be suitable when the relation between democracy and either of the economic freedom measures *Government Operations and Regulations* or *Restraints on International Exchange*, are analyzed. However, there is no relation between democracy and *Money and Inflation* or *Takings and Discriminatory Taxation*, supporting the so-called skeptical view, which argues that other institutions not connected to the type of regime, are the true determinants. None of the economic freedom measures used in this study seem to be negatively affected by democracy, which would be the prediction of the conflict view.

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APPENDIX

Extreme Point Identification

Studentized Residual

The test statistic looks as follows:

$$r_i = \frac{e_i}{\left(s_{(i)}\sqrt{(1-h_i)}\right)}$$

where e_i is the residual of the *i*th observation and $s_{(i)}$ is the corresponding standard deviation. h_i is defined below.

Leverage Point

High leverage points are points for which the input vector $\mathbf{x_i}$ is far from the rest of the data. The so-called "hat-matrix", $\mathbf{H} = \mathbf{Xinv}(\mathbf{X'X})\mathbf{X'}$, where $\mathbf{X}$ represents the matrix of the independent variables, plays a central role. For any vector $\mathbf{y}$, $\mathbf{Hy}$ is the set of fitted values in the least squares regression of $\mathbf{y}$ on $\mathbf{X}$. $\mathbf{H}$ is also called the prediction matrix since it is the transformation matrix that, when applied to $\mathbf{y}$ produces the predicted values. $(\mathbf{I} - \mathbf{H})$ is hence the ordinary residuals matrix. A high leverage point means a high value of the diagonal value $h_i = \mathbf{x_i}\mathbf{inv}(\mathbf{X'X})\mathbf{x_i'}$. The average of h_i is k/n, k being the number of independent variables and n the number of observations, and an observation is a leverage point if $h_i > 2k/n$, as suggested by Hoaglin and Welsch (1978).

Cook's Distance

The test statistic looks as follows:

$$D_i = \frac{1}{k} r_i^2 \frac{h_i}{(1-h_i)} \frac{s_{(i)}^2}{s^2}$$

where k is the number of dependent variables, r_i is the studentized residual, h_i is the leverage value, s is the root mean square error of the regression and $s_{(i)}$ is the root mean square error when the *i*th observation is deleted. Note that the Cook's Distance can also be written as

$$D_i = \left(\frac{1}{ks^2}\right)\left(\hat{\beta} - \hat{\beta}(i)\right) X' X \left(\hat{\beta} - \hat{\beta}(i)\right).$$

According to Bollen and Jackman (1990), the *i*th observation deserves further investigation if $D_i > 4/n$.

The Biweights Procedure

The biweights can be described with the following function,

$$\omega_i = \begin{cases} \left[1 - \left(u_i/c\right)^2\right]^2 & \text{if } |u_i| \le c \\ 0 & \text{otherwise} \end{cases}$$

where c is a constant and u_i is the scaled residual of the *i*th observation. $u_i = e_i/m$ where e_i is the residual of the *i*th observation, and m is the residual scale estimate. $m = M/0.6745$ where M is the median absolute deviation from the median residual, i.e. $M = med|e_i - med(e_i)|$. Hence,

$$u_i = \frac{e_i}{med|e_i - med(e_i)|}\frac{0.6745}{c}.$$

A small c downweights outliers significantly, while a large c makes the estimator approach the common OLS estimator. $c = 4.685$ is used here.

Appendix - Tables

Table A.1: Countries included.

Sub-Saharan Africa	Middle East and North Africa	Latin America and the Caribbean	South Asia	East Asia and the Pacific
Benin	Algeria	Argentina	Bangladesh	Fiji
Botswana	Egypt	Bolivia	India	Indonesia
Cameroon	Iran	Brazil	Nepal	Malaysia
Chad	Jordan	Chile	Pakistan	Philippines
Cote d' Ivoire	Morocco	Colombia	Sri Lanka	South Korea
Gabon	Syria	Costa Rica		Thailand
Ghana	Tunisia	Dominican Rep		
Kenya		Ecuador		
Malawi		El Salvador		
Mali		Guatemala		
Mauritius		Haiti		
Niger		Honduras		
Nigeria		Jamaica		
Rwanda		Mexico		
Senegal		Nicaragua		
Sierra Leone		Panama		
South Africa		Peru		
Tanzania		Trinidad/Tobago		
Uganda		Uruguay		
Zambia		Venezuela		

Table A.2: Result from the extreme point tests.

	gEFsum		**gEFmon**		**gEFgov**		**gEFtak**		**gEFint**	
	Civ	Pol	Civ	Pol	Civ	Pol	Civ	Pol	Civ	Pol
Stud Res	Panama	Mauritius	Panama	Panama	Mauritius	Mauritius	Haiti	Jordan	Jamaica	Argentina
		Panama			Chile	Chile	Jordan		Pakistan	
									Argentina	
Leverage	India	Pakistan	Pakistan	Panama	Sri Lanka	Pakistan	S. Korea	Fiji	Philippines	Sri Lanka
	Nepal	India	Nepal	Bangladesh	Malaysia	Thailand	Sri Lanka	Sri Lanka	Sri Lanka	India
	Sri Lanka	Sri Lanka	Syria	India	Pakistan	Malaysia	India	Syria	India	Malaysia
	Pakistan	Panama	India	Malaysia	Fiji	Sri Lanka	Syria	India	Malaysia	Nepal
	Fiji	Nepal	Bangladesh	Sri Lanka	Jamaica	Bangladesh	Bangladesh	Bangladesh	Nepal	Panama
	Panama		S. Korea	Nepal	Bangladesh	India	Fiji	Pakistan	Pakistan	
			Fiji		India	Jamaica	Nepal	Nepal	Fiji	
			Sri Lanka		Nepal	Nepal	Pakistan		Panama	
			Panama							
Cooks	Fiji	Venezuela	Fiji		Chile	Nicaragua	Haiti	Jordan	Argentina	Thailand
	Iran	Nicaragua	Brazil		Zambia	Chile	Jordan		Fiji	Argentina
	Venezuela	Brazil	Panama		Nicaragua	Haiti			Bangladesh	Pakistan
	Nicaragua	Iran	Hungary		South Korea	Mauritius			Pakistan	Haiti
	Brazil	Panama	Turkey		Mauritius				Haiti	Fiji
	Panama				Haiti				Iran	Bangladesh
										Iran

Effects of Economic Freedom on Growth and the Environment

- Implications for Cross-Country Analysis

By

Susanna Lundström*

***Abstract*:**
The purpose of this paper is to discuss the effects of specific economic freedom categories on both economic growth and the environment, and present some important considerations for cross-country regressions. First, there is a survey of arguments for positive as well as negative effects of economic liberalization. Measurement problems are then considered followed by a number of model specification issues. Sensitivity tests and potential econometric problems are also discussed. The main conclusion is that decomposition is important since different economic freedoms can be expected to have different effects on growth and the environment, and are dependent on different interacting factors. The theoretical insights have a crucial role when it comes to selecting what empirical issues to take into account since there is a limit to the number of issues possible to consider. Due to the complexity of the links, a lot of effort should also be devoted to sensitivity tests.

***Keywords*:** Cross-country regressions, Economic freedom, Economic growth, Environmental quality, Institutions.

***JEL classification*:** C31, E60, N50, O11, P00

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1 INTRODUCTION

Market-based institutions are often mentioned as a crucial component for an efficient resource allocation and economic growth. These institutions are rules, enforcement mechanisms and organizations supporting market transactions, and their purposes are, according to The World Bank (2002), to transmit information efficiently, to enforce property rights and contracts, and to secure competition, which all affect the incentives to participate in a market. Several empirical studies confirm the positive relation between market-based institutions and economic growth (see e.g. Easton and Walker, 1997; De Haan and Sturm, 2000). However, some countries have implemented market-based institutions but the expected growth enhancing effect has been absent, which mainly is explained by the lack of complementary institutions (World Bank, 2002). Moreover, there is a growing concern about the effects of the market-based institutions on other welfare components, such as the environment. The expected effects of market-based institutions on economic growth and the environment are indeed complex, and there is a lack of both theoretical and empirical guidance, especially concerning the environmental consequences.

In this study we will discuss effects of economic freedom, which is often used as a measure of market-based institutions. Increasing economic freedom generally means substitution of public choice for private choice. However, the resulting effects depend on the economic context in which the transformation is done. The public choice may be inefficient due to political failures and the private choice may be inefficient due to market failures, and the trade-off between these failures is far from an easy calculation. Moreover, governments and markets operate in a second best world. The theory of second best tells us that removing one distortion in the presence of other distortions is not necessarily welfare enhancing. The necessary, non-distorted economic context is often taken for granted in economic models but is absent or underdeveloped in a lot of countries - especially in low-income countries. Because of the second best context it is important to look at each economic freedom separately and be aware of the factors interacting with these specific freedoms.

The purpose of this paper is to discuss the effects of different economic freedom categories on both economic growth and the environment, and some important considerations for cross-country regressions. First there is a survey of arguments for positive as well as negative effects of economic liberalization. Second, the empirical implications are presented. Measurement problems are considered, and a number of model specification issues are identified on the basis of the survey of arguments. Sensitivity tests and potential econometric problems are also discussed. The main conclusion is that decomposition is important since different economic freedoms may have different effects on growth and the environment, and may be dependent on different interacting factors. Moreover, theoretical insights have a crucial role in the selection of empirical issues to take into account since there is a limit to the number of issues possible to consider. A lot of effort should also be devoted to sensitivity tests due to the complexity of the economic freedom effects.

The paper is organized as follows. Section 2 introduces the economic freedom data. Section 3 presents the survey of arguments about economic freedom effects on growth and the environment. In Section 4 the empirical implications are discussed and Section 5 concludes the paper.

2 HOW IS ECONOMIC FREEDOM MEASURED?

The evolution of institutional economics was long halted by the lack of relevant data. According to Lin and Nugent (1995), this was due to both a lack of interest in explaining institutions among economists working in high-income countries, where the neoclassical models relatively well describe the growth path, and the fact that institutions are complex, difficult to quantify and change very slowly in many countries. However, since the 80s there has been a growing interest in data on market-supporting institutions, resulting in several measures of economic freedom.[1]

In this paper we will discuss the Economic Freedom of the World (EFW) Index 2002 as the measure of economic freedom (Gwartney and Lawson, 2002). This is because the index has been widely used, it contains measures over a longer period (1970

[1] Scully and Slottje (1991) and Hanke and Walters (1997) present the most common indices of economic freedom and show that they are highly correlated.

to 2000) and has data for more countries than any other measure of economic freedom, and it relies mainly on quantitative measures. The EFW index is constructed out of five categories, or areas, which in turn are aggregations of different measures.[2] The categories are presented in Table 1.

Table 1: Economic Freedom of the World Index 2002

1 Size of Government: Expenditures, Taxes, and Enterprises
- **A** General government consumption spending as a percentage of total consumption.
- **B** Transfers and subsidies as a percentage of GDP.
- **C** Government enterprises and investment as a percentage of GDP.
- **D** Top marginal tax rate (and income threshold to which it applies).

2 Legal Structure and Security of Property Rights
- **A** Judicial independence: The judiciary is independent and not subject to interference by the government or parties in disputes (GCR).
- **B** Impartial courts: A trusted legal framework exists for private businesses to challenge the legality of government actions or regulation (GCR).
- **C** Protection of intellectual property (GCR).
- **D** Military interference in rule of law and the political process (ICRG).
- **E** Integrity of the legal system (ICRG).

3 Access to Sound Money
- **A** Average annual growth of the money supply in the last five years minus average annual growth of real GDP in the last ten years.
- **B** Standard inflation variability in the last five years.
- **C** Recent inflation rate.
- **D** Freedom to own foreign currency bank accounts domestically and abroad.

4 Freedom to Exchange with Foreigners
- **A** Taxes on international trade.
  - **i** Revenue from taxes on international trade as a percentage of exports plus imports.
  - **ii** Mean tariff rate.
  - **iii** Standard deviation of tariff rates.
- **B** Regulatory trade barriers.
  - **i** Hidden import barriers: No barriers other than published tariffs and quotas (GCR).
  - **ii** Costs of importing: The combined effect of import tariffs, license fees, bank fees, and the time required for administrative red-tape raises costs of importing equipment by (10=10% or less; 0=5% or more (GCR).
- **C** Actual size of trade sector compared to expected size.
- **D** Difference between official exchange rate and black market.
- **E** International capital market controls.
  - **i** Access of citizens to foreign capital markets and foreign access to domestic capital markets (GCR).
  - **ii** Restrictions on the freedom of citizens to engage in capital market exchange with foreigners - index of capital controls among 13 IMF categories.

5 Regulation of Credit, Labor, and Business
- **A** Credit Market Regulations.
  - **i** Ownership of banks: Percentage of deposits held in privately owned banks.
  - **ii** Competition: Domestic banks face competition from foreign banks (GCR).
  - **iii** Extension of credit: Percentage of credit extended to private sector.

[2] The categories and how they are measured have been changed several times, but this paper refers to the 2002 version of the EFW index.

iv Avoidance of interest rate controls and regulations that lead to negative real interest rates.
v Interest rate controls: Interest rate controls on bank deposits and/or loans are freely determined by the market (GCR).

B Labor Market Regulations.
i Impact of minimum wage: The minimum wage, set by law, has little impact on wages because it is too low or not obeyed (GCR).
ii Hiring and firing practices: Hiring and firing practices of companies are determined by private contract (GCR).
iii Share of labor force whose wages are set by centralized collective bargaining (GCR)
iv Unemployment Benefits: The unemployment benefits system preserves the incentive to work (GCR).
v Use of conscripts to obtain military personnel.

C Business Regulations.
i Price controls: Extent to which businesses are free to set their own prices.
ii Administrative conditions and new businesses: Administrative procedures are an important obstacle to starting a new business (GCR).
iii Time with government bureaucracy: Senior management spends a substantial amount of time dealing with government bureaucracy (GCR).
iv Starting a new business: Starting a new business is generally easy (GCR).
v Irregular payments: Irregular, additional payments connected with import and export permits, business licenses, exchange controls, tax assessments, police protection, or loan applications are very rare (GCR).

Note: GCR = *Global Competitiveness Report*; ICRG = *International Country Risk Guide*

Source: (Gwartney and Lawson, 2002)

The concept of institutions in this paper is broad, following the wider approach of for example Sala-i-Martin (2002).[3] Some of the EFW categories, such as security of property rights or regulations of business, are fairly straightforward as institutional measures. Other categories may be perceived as having more of a "policy" character, but should be interpreted as proxy variables of actual institutions. International trade reforms, for example, can be seen as institutional changes since they change the rules of the games for those affected (Rodrik, 2000a), and access to sound money is a measure of macroeconomic "rules" of stabilization. Nevertheless, it is important to consider the different characters of the measures, since they differ not only when it comes to the possibilities of changing them and the time lags between the changes and effects in the economy.

[3] By institutions Sala-i-Martin (2002) means "… various aspects of law enforcement (…), the functioning of markets (…), inequality and social conflicts (…), political institutions (…), the health system (…), financial institutions (…) as well as government institutions (…)."

3 A SURVEY OF ARGUMENTS

In this section important arguments for positive as well as negative effects on growth and the environment are presented.[4] Note that we only consider the *direct* effects and will not discuss *indirect* effects.[5] The purpose of this section is not to give clear-cut answers about the effects of economic freedom. The purpose is to give a broader perspective than most previous literature, and thereby highlight the potential problems that must be considered in a cross-country analysis using the index.

3.1 Size of Government

This category is constructed to reflect to what extent a country relies on individual choice and markets rather than on the political process to allocate resources, goods and services. What is considered to be the optimal size of the government depends largely on the perception of how well the government pursues its tasks, which in turn is largely dependent on the assumed underlying motives of the policy makers. If one accepts a standard public-choice perspective where the government is seen as consisting of purely selfish individuals, it is natural that the conclusion will be rather different compared to the conclusions made from the view of a benevolent government that tries to maximize an ethically grounded social welfare function.

According to public choice arguments, the government is an inefficient institution for resource allocation. Olson (1982) argues that the state redistributes money according to the pressure from interest groups, i.e. resources are allocated to rent-seeking activities instead of production. Olson also argues that due to the lack of competition in public enterprises, the principle will be budget maximization instead of profit maximization. This slows down society's capacity to adopt new technologies and reallocate resources in response to changing conditions. Assuming socially optimal prices, privatization would hence reallocate resources so that, given the same

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[4] For social consequences, see for example Bourguignon and Morrisson (1992), and for income inequality, see Berggren (1999).

[5] The environment may for example be indirectly affected by changes in the income level due to changes in economic freedom, but this is not the focus of this paper. The impact of income on the environment has been investigated extensively in the literature of the environmental Kuznets curve (see e.g. Grossman and Krueger, 1995).

production, less resources would be used and less waste (and pollution) would be created. The extent of government inefficiency presented by the public choice theory is influenced by the level of corruption, bureaucracy and other factors that affect the quality of governance (Mauro, 1995; La Porta et al., 1999b).

There may also be efficiency-reducing effects in the private market by a large government size. First, the tax structure imposed on the private market creates dead-weight losses. Second, the decreased competitive pressure created by the smaller size of the private market decreases incentives for firms to reduce costs and to innovate (Scherer, 1992; Vickers, 1995). Moreover, competition is not only an efficient way to allocate resources given the institutional context prevailing, but it also modifies existing institutions. Since institutions affect relative prices, a demand among firms and lobby groups for new, more efficient institutions will be created (World Bank, 2002, Ch.7).

However, most economists agree that the government does have some efficiency-enhancing roles, even though what these are, and the extent of them, is disputed. According to a standard public finance perspective (see e.g. Atkinson and Stiglitz, 1980) it is efficiency improving if the government provides goods with public-good character, such as the judiciary, schools, hospitals, sanitation facilities and recreation areas. However, this effect depends on the response from the private (domestic and foreign) capital if the public investments were absent, which might be assumed to differ depending on the type of good. A second often mentioned efficiency-enhancing role of the government is to correct market prices that do not reflect the social costs by, for example, using taxes or subsidies. These taxes or subsidies may increase allocation efficiency, as in the case of environmental taxes on pollution, but may also increase growth, as in the case of subsidies to research.[6] Still, there are of course many examples of the opposite, where regulated prices reduce efficiency and are bad for the environment. Third, the redistributive role of the state may increase

[6] However, as noted by Coase (1960), in a situation with no transaction costs between agents and well-defined property rights, a free market still implies efficient resource allocation. A tax on the externality would then reduce efficiency. In reality, however, transaction costs are often very high. Note also that even if there are government interventions these must not, depending on the type of intervention, imply a significantly increased government size. For example, if the solution to the socially sub-optimal prices is regulations or tradable pollution permits instead of a tax, the government size category will only increase due to the enforcement costs these solutions may imply.

efficiency indirectly by increasing social stability, which otherwise may consume large parts of the society's resources (Rodrik, 1999). There are also arguments for direct effects on efficiency through, for example, expenditures on job matching and education for the unemployed. If this increases the tightness of the labor market, it might increase productivity and catalyze structural changes (Pissarides, 1990). Hence, the government may provide some goods more efficiently than the private firms, and for the government to undertake these efficiency-enhancing actions it needs resources which makes a certain level of taxes necessary.

However, given that the most basic efficiency-enhancing functions of a market economy are the first priority of governments, then at higher levels of government spending the marginal productivity of the government's projects is lower. At the same time, government investments crowd out private firm investments, which may be more productive when the government invests outside its core functions. We may therefore expect a hump-shaped relation between government size and economic growth (Barro, 1990). The expected form of this hump-shaped relation, and hence the expected effect from changes in the government size at a certain initial level, is determined by the underlying view of government efficiency relative to market efficiency.

3.2 Legal Structure and Security of Property Rights

This category measures to what extent the citizens and their properties, including the fruits of their own work and their innovations, are protected. First, secure and transferable rights of assets and contracts are investment generating and hence growth enhancing, since owners can be sure that they will receive the benefits of their investments (World Bank, 2002).[7] The investment costs are often realized on shorter terms, while the long run benefits have to be reduced by a risk premium. The risk reducing effect may also have environmental effects since long-term investments are the nature of many environmental projects. For example, land degradation and resource exhaustion are to a large extent results of badly defined property rights. High risks

[7] Note that the key word of secure property rights is "control" rather than "ownership" (Rodrik, 2000b). Hence, what this category measures is a strong enforcement mechanism by a reliable legal structure rather than a the specific type of ownership.

encourage short-term extraction of natural resources and excessive grazing or harvesting on land, instead of conservation (Mink, 1992).[8] Second, with secure property rights, the allocation of assets will be efficient and hence growth promoting. Assets will be transferred to the owners with the highest expected profits. Hence, enforced property rights are a precondition for market solutions to the allocation of resources, which also includes the market solution for environmental problems (see e.g. Bromley, 1990). However, many assets, such as the atmosphere and oceans, have no clear boundaries and are therefore "open access" to all countries. Since the judicial authority (that can implement better property rights) works at the country level and the individual country therefore has the incentive to free-ride, there must be an international body to enforce better defined property rights of these assets (Barrett, 1990).

But does stronger property rights always increase productivity or at least welfare? One problem may be that stronger private property rights in general may decrease the government's ability to impose environmental regulations. Moreover, protection of property is an institution creating a monopoly situation for the economic actor owning the right. This may create inefficiencies if the asset has no rivalry in consumption. For example, an entrepreneur will only have incentives to innovate, or to invest in a recreation area, if he or she can control the returns from the innovation or the investment. However, once these are done, then the efficiency of a society would increase if all producers could use the innovation or all consumers could use the recreation area. One solution is to implement strong intellectual property and land rights, in combination with subsidies to the spreading of new innovations, or visits to the recreation site.[9]

A functioning legal structure and secure property rights are to a large extent a necessary, complementary institution to all the other economic freedom categories

[8] However, for a short-term extraction to occur, alternative investment possibilities or the possibility to put the money in foreign bank accounts must exist.

[9] This is however more problematic between countries. In a static perspective, intellectual property rights are sometimes argued to be more beneficial to high-income countries than to low-income countries, which are often net importers of new technology and build a lot of their technological progress on diffusion. High-income countries would in that case profit relatively more from the monopoly pricing, at the expense of low-income countries that are meeting a higher price and seldom profit from the innovation rents (World Bank, 2002, Ch.7). However, in the long run all countries may benefit from the progress of the technological frontier.

(Rodrik, 2000b). For example, without secure property rights the incentives to invest will be low even though the credit market is deregulated. However, the effects of stronger ownership are also conditional on complementary institutions or factors not always present (Lin and Nugent, 1995). For example, higher security of property may not increase growth in the absence of good credit possibilities and access to new technology.

3.3 Access to Sound Money

This category measures the "friction" in the exchange process created by low access to "sound" money. Briault (1995) gives an overview of the costs of inflation, or rather unanticipated inflation, which is the main component of this category. First, instability of prices increases risk and hinders long-term investments, as in the case of insecure property rights. Second, insecure price development has redistributive effects on the present assets. Lenders are adversely affected by inflation, while borrowers profit. This redistributive effect shifts resources from productive to rent-seeking activities which, as in the case of government allocation, create inefficiencies in the economy. Another redistributive effect is when the government prints money to improve its government budget, which erodes the savings, and hence investment possibilities, of the citizens. Access to sound money is also improved by the possibility of owning foreign currency bank accounts, since the adverse effects of inflation are lower when foreign currency with lower risk is available as a substitute (Gwartney and Lawson, 2002).

There are however some potential, but disputed, negative effects of low-inflation strategies to be aware of. First, Keynesians argue that possibilities for expansionary government policy during a shorter period might be what save a country from a deeper depression. However, monetarists would argue that the Keynesian principle of high government expenditures during recession and low government expenditures during a boom would be unsuccessful since individuals and companies adjust their expectations and wage requirements. Hence, according to monetarists the government should always prioritize low inflation and restrict the possibilities of expansionary fiscal policies. Second, it is difficult to identify the true natural rate of unemployment. In a situation where the rate is lower than predicted, a low inflation policy represses the economy and leads to lower growth than potentially possible. Finally, some inflation is natural and not growth reducing since product quality improves.

Again, complementary institutions matter. For example, the effects of inflation differ depending on the exchange rate regime. Higher inflation compared to other countries may be detrimental if the exchange rate that is fixed. The higher price of export goods affects the country's competitiveness and employment negatively. However, very simplified, with a floating exchange rate, the price increase may be covered by a depreciation of the exchange rate and may therefore not affect the international competitiveness.[10]

3.4 Freedom to Exchange with Foreigners

For the same reasons supporting exchange inside country borders, individuals should, according to the EFW index, be free to exchange their property across the borders. First, there are efficiency effects from trade liberalization. The most straightforward efficiency effect is the larger market and the gains for both trading partners if they produce according to their comparative advantages.[11] Another benefit is that the interaction with foreigners and their products may ease the diffusion of technology (Edwards, 1997; Frankel and Romer, 1999), and this may in combination with international competition enhance the productivity of the domestic firms (Bigsten et al., 2000). Competition among countries could also lead to institutional changes in order to attract businesses from abroad. If there are inefficient institutions preventing domestic firms from responding to the international competitive pressure, these firms may demand the government to implement institutional reforms that eliminate these inefficiencies (World Bank, 2002, Ch.7). All these mechanisms increase resource efficiency in a country, and, given socially optimal prices, this also includes environmental resources (Heerink et al, 1996). Moreover, since deregulation of the international capital market allocates capital to countries where the marginal product of

[10] However, there is still a cost by an increased price of imports.

[11] However, for an exchange to work efficiently there is a need for agreed upon rules and standards (North, 1990). Hence, even if a country's rules work efficiently inside the country, they might not be efficient when trading with partners from other countries with different institutional settings. A system of standards is a common institution created to reduce information and enforcement costs across borders; it therefore increases resource efficiency for all parts.

capital is the highest, the global efficiency increases (Obstfeld, 1998). This may create new markets and technological opportunities for all countries, at least in the long run. However, in a static view, the growth rate might increase in some countries and decrease in others. Given the same investment risks, capital would be floating from high-income countries with a large capital stock (i.e. low marginal product of capital), to low-income countries with a small capital stock (i.e. low marginal product of capital).[12]

Second, trade liberalization results in new terms-of-trade, which in turn affects the input and output composition in a country. For example, the pressure of an exchange rate reform is often created in a situation of overvalued currency, where imports are relatively cheap and exports uncompetitive. An exchange rate reform may therefore be expected to result in a relative increase in the production of export goods. However, there might be a need for institutions supporting the supply response of the export sector if it has a history of low incentives and inefficiency due to the lack of competition. For example, without a proper infrastructure a country may not benefit from openness because of high transport costs (Craft and Venables, 2002). Hence, it might be necessary to complement the new trade opportunities with government expenditures on public goods such as roads, railways and telecommunications, given that the private market does not provide these investments. The exchange rate reform may also affect the environment, but the final effect depends of course on the composition of imports and exports in a country, and the complementary measures to internalize negative externalities. Another example connected to the terms-of-trade effect is the so-called "pollution haven" effect, which may have positive as well as negative effects on the environment depending on the economic and institutional structure of the country. Trade results in specialization, and, according to the pollution haven hypothesis, countries with less strict environmental regulations are more likely to attract capital connected to dirty industries. Hence, export-promoting regimes, in combination with weak preferences for the environment may experience an expansion of pollution and

[12] However, if the capital risk is very high (for example because of a bad legal structure) as in many low-income countries, then the marginal product of capital would be lower for a given capital stock. Liberalization of capital markets could then lead domestic private investors to invest abroad, even if the domestic capital stock were relatively small.

waste intensive production, and vice versa for countries with high preferences for the environment.

3.5 Regulation of Credit, Labor, and Business

This category is intended to represent to what extent regulations restrict entry into markets and interfere with the freedom of individuals to engage in voluntary exchange. The free entry principle is crucial for a market economy to reach the efficient resource allocation, and the category is in this sense a measure of competition. Firms are less likely to enter a market if the production and exit costs are too high, and different sorts of regulations may affect both of these costs (World Bank, 1995).[13] However, some regulations might increase the market's possibility to grow, or at least be acceptable from a social welfare efficiency point of view, as long as they are not excessively numerous, complex or costly relative to the income level in a country (World Bank, 2002, Ch.7).

Credit. By deregulation of the credit market, a competitive market of risk taking is created, i.e. risk is allocated to those who are willing to bear it. Efficient lending created by the competitive credit market may reduce the information costs between borrowers and lenders, and the cost of money transaction. This lowers the cost of capital and, given secure property rights, promotes investments.[14]

Labor. Labor market regulations may have resource efficiency effects. First, entries and expansions of firms, affected by rules of firing employees, might be hindered by high exit costs, obstructing necessary structural changes in society. Second, labor regulations affect the individual's right to use his or her labor "asset." By increasing the price of labor above the marginal cost of the individual, or by forcing people into military training, the input factor available for production decreases below

[13] The reason for excessive welfare decreasing regulations would, according to the public choice perspective, be a result of interest groups with non-proportional political power. Moreover, since regulations are a source of bribes, corrupt politicians may be favoring the rent-seeking activities related to regulations (Mauro, 1995).

[14] However, the financial system is fragile, since it is in the business of pooling, pricing and monitoring risks. If prudent regulations, such as minimum capital requirements from the credit institution itself, are absent or badly enforced then the risk may be too high, which affects growth negatively (World Bank, 2002, Ch.4).

the potential level. The labor union has in some countries been an influential interest group in the wage-setting process. Gottfries (1992) argues that this has improved the position of the already employed workers, but that the higher costs for firms may have decreased the incentives to invest, and thereby decreased the employment possibilities for the unemployed workers.

There might also be a risk effect from labor regulations. Firing regulations and minimum wages create a safety net among employees and thereby reduce the uncertainty about future incomes. Some would argue that this affects the work incentives, and hence the productivity of the work force, negatively. However, others argue that the higher risk of large income reduction decreases growth-enhancing investments in for example human capital (World Bank, 2001, Ch.8). With short-term employment opportunities without safety nets, these investments may be prevented since the household labor force is needed to generate income when such possibilities exist. The higher risk may also create environmental problems by the increased population pressure. In poor countries, children contribute to the production of the household and hence provide alternative security. Rodrik (2000b) argues that market-oriented development is likely to release people from their traditional social safety nets such as the church, the village hierarchy, lifetime employment, etc., and that it is important for development to complement reforms with alternative social insurances.

Finally, a large part of a country's citizens belong to the labor force, and an economic freedom reform that leads to a short run downturn in production and employment, in combination with relaxed labor regulations, might create social unrest. These conflicts may hurt economic growth much more than keeping the labor regulations, at least until the initial period is over.

Business. Market concentrations normally drive the economy away from the efficient allocation, and reduce potential productivity and economic growth. The purpose of deregulation of businesses is to make it easier for new firms to enter markets, which increases competition and hence resource efficiency. However, regulations such as appropriate health, safety and environmental regulations may also be beneficial for productivity. A common example is that better worker health may increase labor efficiency, and decrease sick leave.[15]

Competition can sometimes serve as a substitute for regulations, since, among other reasons, it makes up an efficient bankruptcy system with its pressure on inefficient firms to go into liquidation (Aghion et. al, 1999). Moreover, competition may in some cases substitute for costly environmental regulations. Instead of imposing a limit on each firm's emissions, it is possible to set a limit for emissions of the whole sector and introduce a competitive market for tradable pollution permits. The firms with the most cost efficient abatement technology would then reduce emissions, since they would be willing to sell the permits at a lower price. However, competition and regulations may also be complements. For example, concentrated ownership may be a consequence of weak anti-trust legislation (La Porta et al., 1999a).

Finally, a certain rate of market concentration might increase growth due to economies of scale, for example in the case of high-risk basic research. Moreover, in a second best world without policies to correct for the distortions, a monopoly or highly concentrated market might be closer to the socially optimal price and quantity. For example, if the price on pollution were too low it would lead to excessive production in a competitive market, while a monopoly would restrict production to a level below the competitive quantity to maximize its profits, independent of the pollution cost.

4 EMPIRICAL CONSIDERATIONS

As is clear from the survey of arguments in Section 3, there are often no clear-cut conclusions regarding the effects of different economic freedom categories on economic growth or environmental quality. A discussion of different arguments is however essential to identify empirical implications, that in turn can be used to clarify the links. This section therefore emphasizes important issues for cross-country research in the

[15] Another, often disputed, argument according to the Porter hypothesis is that environmental regulations might increase productivity since firms are forced to reorganize their production (Porter and van der Linde, 1995).

area.[16] In reality, there is a limit to the number of possible empirical issues to consider, and the theoretical insights have a crucial role when it comes to selecting what issues to take into account.

4.1 Measurement Problems

Before drawing any conclusions about the reliability of empirical studies using economic freedom data, it is important to critically discuss the measurement methods. Many measures of economic freedom rely on qualitative data (Hanke and Walters, 1997). Typically, a sample of knowledgeable persons is included in a survey where they are asked to rank countries according to their perception of the economic freedom component in question. The individual scores are then averaged to produce a "consensus ranking." This process involves a lot of uncertainties since the expertise, the perception of what is important in determining economic freedom and the relative weight attached to these factors might differ substantially across countries.

The EFW index relies primarily on quantitative measures, even though qualitative measures have been used where there is no quantitative data available, or where the qualitative technique has been judged to be more suitable (for example in the category *Legal structure and security of property rights*). There are several advantages when relying on quantitative measures. First, the risk of subjectivity in the scoring process, as mentioned above, decreases. Moreover, the index can be constructed for a long period. This is crucial for an empirical analysis of institutional effects since it is likely that institutions have effects over a long period of time.

Even if there is no subjective variation in the scores among countries, there are still subjective influences in the choice of variables, the economic freedom quantification and the weighting process. No economic freedom category is directly observable; each is therefore measured by several proxy variables. The choice of which variables to include to represent a specific economic freedom category, is of course

[16] It is not an exhaustive presentation of all important econometric consideration in cross-country regressions. The empirical analysis should of course include the standard diagnostic checking, for example.

disputable.[17] It is important to be aware of the "distortion" with which the proxy variable mirrors the underlying economic freedom. If this distortion is thought to be larger than the subjective risks of a qualitative measure, then the latter may be preferred.

The transformation of a specific proxy variable into an economic freedom score can be done in several ways. This includes subjective decisions such as the maximum and minimum value, and the number of scores possible. As an example of a continuous variable, take the measure *Transfers and subsidies as a percentage of GDP*. It is transformed into an economic freedom score by taking $(V_i - V_{\max})/(V_{\max} - V_{\min})$ multiplied by 10. V_i is country *i*'s transfers and subsidies as a percentage of GDP, and $V_{\max}$ and $V_{\min}$ represent the maximum and the minimum value of the measure during the 1990 base year. In other cases $V_{\max}$ and $V_{\min}$ are simply assigned different numbers - for example 40 and 6 in the case of *General government consumption spending as a percentage of total consumption*. There is no reason to believe that the values $V_{\max}$ and $V_{\min}$ were assigned unrealistic values, but this choice does leave room for subjectivity. Another transformation procedure simply gives discrete scores according to subjective criteria, for example in the case of *Freedom to own foreign bank accounts domestically and abroad*. The rating 10 was given when there was no restriction on foreign bank accounts domestically or abroad, and 0 when there was. If the accounts were permissible domestically but not abroad, the value of 5 was assigned. For most variables the subjectivity problem arises in the choice of the criteria for different rankings. However, there are examples of measures when there is room for subjectivity in the interpretation of the criteria as well.[18]

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[17] The question of what economic freedom really means and should measure, i.e. which categories should be included, is not in the scope of this paper. See Sen (1993) for a discussion of the possibilities and limits of individual freedoms in a market economy, and De Haan and Sturm (2000) for a discussion of the economic freedom measures.

[18] An example is the measure *Price controls*. According to Gwartney and Lawson (2002), "Countries were given a rating of 10 if no price controls or marketing boards were present. When price controls were limited to industries where economies of scale may reduce the effectiveness of competition (e.g. power generation), a country was given a rating of 8. When price controls were applied in only a few other industries, such as agriculture, a country was given a rating of 6. When price controls were levied on energy, agriculture, and many other staple products that are widely purchased by households, a rating of 4 was given. When price controls applied to a significant number of products in both agriculture and manufacturing, the rating was 2. A rating of zero was given when there was widespread use of price controls throughout various sectors of the economy."

Problem of weighing may occur both in the process of aggregating the proxy variables into the different economic freedom categories, and in the aggregation of the categories into a single economic freedom score. The weighing is necessary since the absolute notion of economic freedom becomes meaningless if the absolute score of the category is based on a vector of measures, all having the purpose of measuring different aspects of the same problem. One common procedure is to let experts agree upon the weights, another is to use objective methods such as the instrumental variable (hedonic) approach or the principal component technique (Scully, 1992). In earlier versions of the EFW index, three indices that differed in aggregation techniques were used. One index was weighted by country experts, another by experts in the different categories and the third index, the one finally settled for, applied the principal component technique. The idea of this technique is to construct an index, out of several measures that are proxies for the same variable, by weighting them according to one or several linear functions that account for most of the variance in the measures (see for example Maddala, 2001, for a more detailed description). An important advantage of the principal component analysis is the objectivity. On the other hand, when two components (i.e. measures) are highly correlated, this technique tends to assign low weights to both components. However, including both of these components is desirable in order to offset measurement errors. Therefore, simple averages of the measures have been used in the 2002 issue of the EFW index. This indirectly implies that all measures contribute equally to the determination of the economic freedom category.

Finally, we have the problems of ordinal measures (see Boadway and Bruce, 1984, for a more general presentation). If the economic freedom data is ordinal, it is in principle not possible to compare an increase in one category from one unit of economic freedom to two units, with an increase in the same category from five to six units. Moreover, it is not possible to compare an increase from five to six units in one category with an increase from five to six units in another category. However, if the economic freedom data is cardinal it is possible to compare both levels and changes in economic freedom, within as well as among categories. The underlying measures in the EFW index are, with a few exceptions, cardinal. However, when rescaling the measures into categories, with freedom scores from 0 to 10, there is no longer an absolute scale.

An implication of the ordinal problem would be that an OLS regression is of no use since it assumes cardinal measures. Another implication would be that, even though the result of the OLS regression is accepted, it is not possible to draw any conclusions about the relative marginal effect of the economic freedom categories. It is not possible to say that it is more efficient to change one category than another, even though the coefficient is higher for one category, since the change in one unit of freedom is different between the two categories. However, the categories in the EFW index are scaled so that they represent a reasonable “policy relevant” interval, and assuming strict ordinality of these measures would be too restrictive. Treating the variables as cardinal measures in an OLS regression and discussing the relative effects of different categories is therefore of interest.

To conclude, the EFW index has well developed approximations of different economic freedom categories. Even though the categories are not perfectly cardinal, cross-country regressions do have the potential to produce results of acceptable reliability. However, there are some unavoidable problems such as some degree of subjectivity in the choice of measures included in the categories, the criteria attached to the scores, and the aggregation technique. It is therefore important to test the regression results by using other data sets with different approaches as well.

4.2 Model Specification Issues

4.2.1 Levels or Changes?

Suppose that the dependent variable in the regression is the growth rate, and that *changes* in the economic freedom variables are included as explanatory variables. This would entail an assumption that as long as there are changes in the economic freedom level, there will be effects on the growth rate. If the level of economic freedom is not changing there is no effect on the growth rate, implying that a change has only temporary effects on growth. One way to interpret this is to refer to the neoclassical growth models where higher economic freedom increases the country’s potential production, or the *steady-state income level*, and thus increases the rate of convergence. However, as the country approaches the new steady state, the growth rate decreases to the old rate of productivity growth. Hence, the steady state growth is exogenous, at least in relation to economic freedom. If the *levels* of the economic freedom variables are regressed on growth, then a higher level of economic freedom is assumed to have a permanent effect on the growth rate. This follows the rationale of the endogenous growth theory where policy variables are assumed to affect the growth of the productivity variable. A higher level of freedom would hence affect the level of *steady-state income growth*, i.e. give a different potential growth rate (toward which the countries converge). In reality both of these interpretations hold; economic freedom has temporary effects on productivity that increase the volume of investments until the marginal return to capital has returned to its initial value, but also permanent effects since many categories affect the incentives for productivity improvements.

Jones (1995) argues that theories relating a stationary variable to a non-stationary variable should be rejected, and is thereby questioning the endogenous growth theory. Hence, regressing for example secondary school enrollment on growth would be inappropriate. He argues that it is unreasonable to assume that a positive trend in the stationary variables would predict a continuing acceleration of the growth rate. The same critique can be used on growth regressions including the level of economic freedom. According to Jones it is still possible to say that the reason one country has a higher growth rate, or faster change in environmental quality, than another country depends on the different levels of economic freedom in the two countries. On the other hand, it is not possible to say that increasing economic freedom in one country would permanently increase the growth rate in that country.

Hence, according to this view, using the change in economic freedom seems to be the most appropriate specification. However, the Jones critique does not have to be that severe in our case. First of all, there is a natural upper limit of economic freedom and therefore also an upper limit of the effect on the steady state growth rate. If constant effects still seem unreasonable, then it is possible to include non-linear specifications so that improved institutions may have a declining effect on the growth rate (see Section 4.2.2). Second, one might of course argue that the results from a level specification are only valid for the studied period and that the result can then reflect both temporary convergence effects and permanent steady-state effects. Even if the mean economic freedom of the countries in the sample remains, the level effect on the growth rate may be lower in a later period when the temporary effect is reduced. Note also that the choice of specification is subject to causality problems. For example, regressing growth on changes in economic freedom in the same period is problematic (see Section 4.4.3). For this reason one might still prefer a level specification of economic freedom, despite the above mentioned interpretation problems.

4.2.2 Non-linearities

The functional form of the economic freedom categories is another issue that is important to consider. The functional form can to a certain extent be determined by using econometric tests, but should as far as possible be based on economic theory. It is not evident that the relation between economic freedom and growth, or the environment, is linear as often assumed, and the appropriate specification may differ among categories. For example, as we have discussed, there could be a hump-shaped relation between the size of government and growth. Moreover, a certain economic freedom category may only have a small effect on growth at low degrees of freedom, but a large effect at high degrees of freedom, or only have an effect if a critical level of freedom is reached. For example, increasing access to sound money from a very low level might not have an impact on the agents in the economy since their trust in the government, based on previous behavior, is still low. However, there may also be cases where the opposite holds, i.e. where the effects of increasing economic freedom from very low degrees of freedom have larger impacts than increases at higher degrees of freedom. Trade liberalization, for example, may have a diminishing effect on both growth and the environment. Opening an economy from a very low level of trade freedom would probably change the structure of production drastically due to the possibilities to concentrate on the comparative advantages. At higher levels of trade liberalization, a further increase might still increase growth by increasing the scale of the market, but the structural effects have probably diminished.

4.2.3 The Time Dimension

Another important question when discussing the relevance of market-based institutions is the time dimension. First, there might be a problem of output response heterogeneity. The EFW index is a mix of more "basic" institutional variables (with higher transformation costs) such as security of property rights, and more "flexible" institutional variables (with lower transformation costs) such as free trade. The time span between the institutional change and the output effect depends on the ability of the economic structure and people's minds to adjust to the new economic conditions, and this may differ considerably among economic freedom categories. In a regression the appropriate lag length can therefore be assumed to differ among the categories. For example, the time lag of the growth effect from increased trade liberalization is probably shorter than for the growth effect from increased security of ownership.

The problem of determining the appropriate lag structure is also related to the path-dependent mechanism in institutional building. It creates a friction of institutional change depending on historical institutions and norms. An efficient institution for growth or the environment complements the institutional framework, as it is today and how it is assumed to evolve in the conceivable future. Hence, it is important to decide if it is the short-run or the long-run consequences that are of interest, since they might differ substantially. One example is the liberalization of the credit market, where the first reaction might be to put the savings in a foreign bank account (even though the capital stock is lower in the domestic market). However, as the accountability improves and the risks decrease, the capital flow may turn in the other direction, and in the long run the domestic investments may have increased.

Second, the optimal pace of change of the economic freedom variables may be different. Some theories suggest that a drastic reform is the most efficient in the long run, while others argue for a gradual reform for the best long-run results. As mentioned, it may take time for the rest of society to adjust the underlying institutional structure to the new economic freedom level, and there might be reasons for why this recession should be avoided. Privatization of public enterprises may for example create unemployment before private investors have responded to the new opportunities. If the change is too drastic, social unrest might be created affecting growth negatively. It could therefore be relevant to interact the number of years the reforms were conducted with the category in question.[19]

Third, the sequence in which reforms are made may be crucial.[20] One example is the importance of reducing energy subsidies before trade liberalization to avoid energy intensive industry to establish, only to be forced to shut down after a price correction (Munasinghe, 1996). Suppose that we look at how changes in economic freedom during a ten-year period affected the change in environmental quality the following ten years. There might have been a greater environmental quality improvement in a country that implemented more secure property rights before a trade regime change, than in a country where the trade regime change came first, even though the changes were the same in the countries when looking at the entire ten year interval. The order of the reforms can be controlled for with dummy variables. Another way is to identify the exact years of the reforms and if, for example, the trade reform preceded the legal reform, then the trade freedom variable should be interacted with the property right level in the initial year.

Finally, it may not be the degree of a specific institutional variable that is important for growth or the environment, but the stability of that variable over time. An example is the effect of the enforcement of property rights on both growth and the environment. The effects probably do not depend exclusively on the level of the enforcement mechanisms but also on the stability since the effects are created by trust in the legal system. Hence, by including the number of years the economic freedom categories have been at certain levels, the variance, or the frequency of change, of the economic freedom categories might in some cases be more revealing.

4.2.4 Interactions

As mentioned, disaggregating the economic freedom index is important since the categories may have different effects on growth or the environment, but also because their effect depends on different interacting factors. The efficiency and the possibility of

[19] If this is troublesome to identify, then a possible proxy could be to measure the total change and the number of changes, during the time span in question. The larger the change and the fewer the jumps, the more drastic the reform.

[20] This has been studied to some extent when it comes to the relation between economic freedom and growth (see e.g. Edwards, 1994; Kaminski and Schmukler, 2002).

an institutional change may be dramatically different depending on the surrounding complementary institutions or on the economic, social and ecological context (Lin and Nugent, 1995). The success is hindered or catalyzed depending on whether the new institution supplements or undermines the present structure.

First, the categories can be both complements and substitutes to one another, and may also increase or decrease each other.[21] For example, increasing the security of property rights (higher freedom) may lead to a larger government size due to the increased expenditures on the judiciary (lower freedom). Low economic freedom in one category can therefore be a sign of successful development of another economic freedom variable. However, economic freedoms may also enforce each other. For example, trade liberalization (higher freedom) and the resulting pressure from international competition, may force the government to decrease regulations (higher freedom). Moreover, categories can be substitutes to one another. For example, in the case of the environment, improved property rights (higher freedom) ease negotiations between the affected parties and the government may therefore choose to decrease environmental taxes (even lower freedom). The empirical solution is to include the categories separately but also interacted with each other. If the interaction terms are significant, the marginal effects of the categories are then dependent on the level of the other categories.

Second, the importance of institutions may vary with the development level.[22] For example, the ability to pay for public services (and probably also the goals of the government) changes with the income level. Another example is that if the positive growth effect of openness is due to technological diffusion, the closer the country is to the technological frontier, the smaller the growth effect of decreased trade restrictions.

Third, market-based institutions are embedded in a country specific set of non-market institutions, formal or informal, and other country specific factors. Factors such as religion, social capital, legal origin, ecological fragility, natural resource dependence, inequality, etc., are often left to be captured by the error term in cross-country regressions. However, even if they are not expected to have a direct effect, they might

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[21] See Section 4.4.2 on the multicollinearity problems that these interactions might create.
[22] See Section 4.4.3 for the potential causality problems this might create.

interact with the effects of the economic freedom categories. For example, if the informal institutions, such as the social capital stock, work as substitutes for the economic freedom in question, the marginal effect may be lower the higher the level of the informal institution.

4.2.5 Relative Performance

Since capital is important for growth, the assumptions of the behavior of the worldwide capital flows are crucial when looking at cross-country growth regressions. Capital flows to the country where the marginal return is the highest, and this return can be affected by, for example, institutional improvements. Hence, it may only be the *relative* performance of a country's institutions that is important. If all countries reform, there may not be an effect on growth or the environment.

Several questions arise with this approach. Is it in relation to the world leading country or a sub-set of countries that the relative institutional level matters? We may for example expect the level relative to the competing countries' level to be the crucial one. Which countries these are is determined by several factors affecting the transaction costs among countries, such as geographic distance and cultural differences. Moreover, is the relative performance more relevant for some economic freedom categories than others? If the extent of foreign investments is mainly related to the capital risk level in a country, it may be argued that the crucial variables are *Legal structure and security of property* and *Access to sound money*. It is indeed an interesting topic for further research to study whether it is the absolute scores of economic freedom or the relative scores that matter for growth and the environment, even though the effects are empirically difficult to separate.

4.3 Sensitivity Tests

In order to identify a correct model specification it is, as mentioned, important to have a theoretical intuition about the channels through which economic freedom works. However, because of the complexity of the links, there should be an emphasis on sensitivity tests of the result with respect to the model specification. This is also true with respect to extreme points, or changes in the sample. Due to the strong path dependence and the difficult task of identifying and measuring all relevant variables, extreme points tests might be in order to eliminate or weigh down the countries that have a very special economic and institutional setting. The robustness tests of the model specification and the sample can also serve as indications of the severity of some potential econometric problems (see Section 4.4).

4.3.1 Model Specification Tests

One useful method to test the model specification is the extreme bound analysis or variants of it (Leamer, 1983; Levine and Renelt, 1992; Sala-i-Martin, 1997).[23] With an extreme bound analysis the robustness of the result is tested by estimating a number of different regressions on a varying conditioning set of explanatory variables. If the significance of the variable of interest (in our case an economic freedom category) is sensitive to the conditioning set, one may, among other things, suspect a poorly specified functional form, or multicollinearity.

Another technique that can be useful to deal with model uncertainty in cross-country regressions is the Bayesian Model Averaging (BMA) method (see e.g. Doppelhofer et al, 2000; Fernandez et al, 2001). No specific model or key variables (as in the extreme bound case) are advocated. Instead all interferences are averaged over potential models with weights according to their posterior probabilities. Given the number of variables that might influence growth and the environment, and the difficulties of identifying these, this approach may be fruitful, at least as a start. However, the lack of theoretical assumptions about the underlying model in BMA analysis draws attention from specification problems (such as non-linearities and interaction terms) other than which variables should be included.

4.3.2 Extreme Points Tests

Methods such as bootstrapping are used to study the robustness of the result to the sample in general (see e.g. Greene, 1997). With bootstrapping, new samples are created

[23] See, for example, De Haan and Sturm (2000) for the sensitivity of a summary index of economic freedom to the inclusion of other growth variables, and Carlsson and Lundström (2002) for the sensitivity of a specific economic freedom category to the inclusion of other categories.

by drawing, with replacement, from the original sample. The distribution of the new coefficient estimates can then be analyzed.

There are several ways to identify specific outliers or influential observations (see Chatterjee and Hadi, 1998, for an overview). Without going into any details, it is important to note that only identifying large residuals (i.e. outliers in relation to the fitted regression equation) is not enough. Observations that are isolated in the space of the explanatory variables values have a high leverage, and may therefore have a strong influence on the fitted regression equation.[24] Hence, a point with a high leverage value may very well have a small residual and can in that case not be identified as an outlier. There are several summary statistics based on an index, increased both by a large residual and a high-leverage point.[25] If extreme points that may influence the basic regression are identified there might be reasons to use robust regression techniques to see whether or not the basic result changes significantly.[26] Different robust regressions use different techniques to weight the observation according to their extreme point character.

A problem with the traditional single-case outlier detection methods is the so-called "masking-effect," which means that they are likely to miss an outlier if there are other outliers in the neighborhood. Deleting one of the extreme points would in that case not affect the regression results, even if the group is far from the rest of the data. By, for example, using the robust regression technique by Rousseeuw and Leroy (1987), it is possible to identify the most coherent part of the data set and thereby identify the outliers.[27]

4.4 Potential Econometric Problems

4.4.1 Parameter Heterogeneity

The problem of heterogeneous parameters is valid for more or less all cross-section regressions (see e.g. Brock and Durlauf, 2001; Kenny and Williams, 2001). The indirect

[24] Note that a point has a high leverage if the observation of the independent variable is far from the rest of the data of independent variables. However, the point can still be perfectly in line with the trend set by the rest of the data, which means that it does not affect the fitted regression equation.
[25] Examples are the Cook's Distance or the Welsch-Kuh's Distance.
[26]An example is the biweight procedure. Another, more drastic, option is to delete the extreme points.
[27] See Sturm and De Haan (2001) for an application on economic freedom and growth.

assumption of parameter homogeneity in OLS cross-country regressions implies that all parameters describing the dependent variable should be the same for all countries. Hence, the effect of increasing economic freedom in one country is the same as the effect in another country. Because of the heterogeneous nature of countries and the complexity of their economic, social and ecological structure (making it difficult to identify all possible control variables), this assumption may seem inappropriate (Temple, 1999).[28] It might therefore be reasonable to divide the initial sample into sub-samples (as long as the number of observations is reasonable) and analyze countries that are assumed to obey the same growth model.[29] This approach is more flexible than controlling for differences by including dummy variables for different country characteristics, but at the same time there is a loss in degrees of freedom with smaller samples.

We might also want to reconsider the model specification, since it may capture part of the parameter uncertainties (Temple, 2000). What is actually done when, for example, allowing for non-linearities or interactions terms, is allow countries to have different slopes, depending on the current level of economic freedom or the levels of other important factors in the country. However, there might be a natural restriction when it comes to the degrees of freedom, which makes it impossible to include all relevant specifications.

By accepting the possibility of parameter heterogeneity, the possibility of outliers is also accepted, independent of measurement errors (Temple, 2000). Given that an appropriate model has been identified, then outliers can be taken care of by, for example, reweighing the large outliers. However, outliers can also be an indication of parameter heterogeneity. One way to test whether the model is appropriate is to look for group-wise outliers (see Section 4.3.2). The identified outliers can very well be extreme points because they have another institutional set-up then the rest of the data. When

[28] If panel data is available, a fixed or random effect model may be one way to approach the problem of parameter heterogeneity, since it allows the intercept to differ between countries (Brock and Durlauf, 2001). If the country specific term is interacted with a variable, we also allow for differences in the effect of this variable between countries. It is also possible to approach the problem with a random coefficient model, which directly allows for differences in the parameter estimations (Hildreth and Houck, 1968).

[29] For example high- and low-income countries, or socialist and non-socialist countries.

only this sub-group of countries is regressed, or when including a group-specific dummy, the regression may produce robust results.

4.4.2 Multicollinearity

One of the most obvious conclusions from the survey of arguments is that the different categories may have different effects on economic growth and the environment, both when it comes to the sign and the amplitude of the effect. Relating growth or environmental quality to the general economic freedom index can of course be of interest in itself. In addition, an index reduces some potential problems such as multicollinearity and missing values. However, the possibilities of turning the results into practical policies or further research topics are highly restricted. There is of course a limit to the extent of disaggregation, but it is in principle possible to continue as long as the categories are proxies of separate underlying institutions or do not affect each other considerably, i.e. as long as there is no severe problem of multicollinearity.

As already indicated, economic freedoms may have a self-enforcing element or may be inversely related to one another (see Section 4.2.4). If one of the economic freedom categories is highly correlated with another category, the *t*-values of these categories might be overestimated. Hence, excluding one category may make another significant, or the joint effect may be significant. There are criteria for detecting multicollinearity: for example the variance inflation factor and the condition number. However, these criteria only look at the correlation structure of the explanatory variables, even though the severity of multicollinearity also increases if the standard errors of the estimated regression coefficients are high, or if the total sum of squares is low. Maddala (2001) concludes that the criteria "… are only measures of how bad things are relative to some ideal situation, but the standard errors and *t*-ratios will tell a better story of how bad things are." Hence, there is no ideal test to detect multicollinearity. If there are reasons to believe that multicollinearity can cause problems, there should be an emphasis on sensitivity tests such as the extreme bound analysis (see Section 4.3.1). If the problem of interest is multicollinearity among the economic freedom categories, it is possible to get an indication of the severity by choosing one of the categories as the variable of interest and treating the other categories as potential explanatory variables in the conditioning set. Another consequence of multicollinearity is that the parameters are sensitive to the inclusion and exclusion of observations. Therefore, parameter stability tests such as bootstrapping may be relevant (see Section 4.3.2).

4.4.3 Endogeneity and Causality

The problem of endogeneity caused by the fact that the economic freedom variables may affect the other explanatory variables, is not the main focus of this paper since we look at the direct effects of economic freedom. However, it is important to be aware of the loss of information ignoring the indirect effects implies, since the indirect effects of the variable of interest (in our case economic freedom) may even be larger than the direct effects. The disadvantage with a reduced form is that we lose the ability to distinguish the different channels through which institutions affect growth, although we do capture both the direct and indirect effects. Another potential endogeneity problem, already mentioned in Section 4.2.4, is that there might be endogenous relations among the economic freedom categories, creating multicollinearity.

Causality is related to the question: Do the independent variables cause the dependent variable or is it the other way around? It is easy to think of a situation where economic growth might affect economic freedom. The most straightforward example is perhaps the fact that growth makes the country richer and thereby more capable of covering the transformation costs of a reform. It is also possible that environmental quality affects economic freedom. Take the case when open access land is exhausted and the government implements better ownership rights in an attempt to hinder soil erosion. One way to test for causality is to use the Granger non-causality test.[30] The idea is to analyze whether the independent variables precede the dependent variable, or the dependent variable precedes the independent variable (see Maddala, 2001). The test has been criticized and should not be considered as a test giving a complete answer to the causal links (see e.g. Convway et al., 1984).

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[30] See Heckelman (2000) and Dawson (forthcoming) for the causality between economic freedom and growth.

To minimize the potential problem with causality we could use a multiple equation system or instrument the variables in question (see for example Maddala, 2001). One solution is to regress the initial levels of economic freedom, or changes in economic freedom in a preceding period, on growth or environmental change in the following period. It is when the periods of the independent variable and the dependent variable overlap that we should be cautious. However, a problem connected to the use of lagged economic freedom variables as instruments is that these might as well be subject to reverse causality if they are dependent on expected future growth and environmental quality.

4.4.4 Non-Country Specific Effects

Easterly (2001) argues that factors other than country specific factors play a central role in growth regressions, at least for low-income countries during their 1980-1998 growth slow-down. He mentions factors such as terms of trade shocks, the US real interest rate, capital flows and the growth performance of industrial countries. Another potential explanation is skill-biased technical change that favored already industrialized countries (Acemoglu and Zilibotti, 2001). There are hence arguments that these external factors need to be given more attention relative to national factors (both when regressed on growth and on the environment) even though time period dummies in the cross-country regressions can capture them to some extent. This is especially true in low-income countries, which are often based on primary production and therefore subject to factors such as weather fluctuations and diseases. The proper measure in a growth regression is change in *potential* output and not actual output (Solow, 2001). Hence, external factors influencing the growth *potential*, both in steady state and during convergence, should be included.

5 CONCLUSIONS

The purpose of this paper was to discuss the effects of specific economic freedom categories on economic growth and the environment, and implication for cross-country analysis. The central question is not whether or not countries should undertake economic freedom reforms in general; it is rather a question of what kinds of economic freedoms should be addressed, in what institutional context, at what pace and in what sequence. This is a very complex task, but if these dimensions are neglected the possible research and policy conclusions become restricted.

There are a number of empirical issues that are important to consider if we want to find reliable research and policy implications. These include awareness of measurement problems and model specification issues such as important interaction terms and non-linear effects. It is not possible to include all the empirical considerations, since it would eliminate the degrees of freedom. Theoretical insights are therefore of crucial importance in the choice of the most relevant issues, depending on the countries included and the variables of interest. Moreover, sensitivity tests should play a central role since the complexity of the links makes it impossible to identify all relevant variables.

The need for further knowledge of the links between market-based institutions and welfare is still very large. Pritchett (2001) states: "The inevitable problem is that the level of specificity at which most growth economists need to work is far greater than can ever be adequately informed by growth regressions," but concludes that "growth regressions are incredibly useful in providing a general empirical background of stylized facts about the world." Even though the interactions are very complex there does seem to be room for insights from cross-country regression, not only when it comes to the impacts on economic growth but also on the environment. It is evidently more difficult to find theoretical connections between economic freedom and the environment since the economic freedom institutions are designed to increase growth, but cross-country regressions might reveal some of the more general links. A regression with well-based theoretical hypotheses both when it comes to included variables and the functional form, and that has been shown to be robust to the model specification and extreme points, should give a reliable indication of the market-based institutions of importance. However, general policy conclusions should of course be based on country-specific analysis as well as cross-country regression.

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Economic Freedom and Growth: Decomposing the Effects

By

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Abstract
Most studies of the relation between economic freedom and growth of GDP have found a positive relation. One problem in this area is the choice of economic freedom measure. A single measure does not reflect the complex economic environment and a highly aggregated index makes it difficult to draw policy conclusions. In this paper we investigate what specific types of economic freedom measures that are important for growth. The robustness of the results is carefully analysed since the potential problem with multicollinearity is one of the negative effects of decomposing an index. The results show that economic freedom does matter for growth. This does not mean that increasing economic freedom, defined in general terms, is good for economic growth since some of the categories in the index are insignificant and some of the significant variables have negative effects.

Keywords: Economic growth, Economic freedom.

JEL classification: O10, O40

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The Effects of Economic and Political Freedom on CO_2 Emissions

By

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and

Susanna Lundström*

***Abstract*:**

In this paper we investigate the effects of political and economic freedom on CO_2 emissions. As far as we know this is the first cross-country study of the relationship between economic freedom and environmental quality. Economic freedom is measured in several ways. We find that increased price stability and legal structure decrease emissions in countries with a small industry share of GDP, but increases emissions in countries with a large industry share of GDP. The decreasing effect from increased use of market is significant but non-robust, and increased freedom to trade does not have any significant effect. The effect of political freedom on CO_2 emissions is insignificant, most probably since CO_2 emissions is a global environmental problem and hence subject to free-riding by the individual countries.

***Keywords*:** Carbon Dioxide, Economic Freedom, Institutions, Political Freedom.

***JEL classification*:** O10, O40

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1 INTRODUCTION

Global warming has been put forward as a major environmental problem with most scientists considering man-made emissions of carbon dioxide (CO_2) to be the main contributor to the global warming problem. In the literature on the environmental Kuznets curve most studies have found a monotonically increasing relationship between income and emissions, while some of the studies have found a cubic (N shaped) relationship, but the turning points are often outside the observed sample (see e.g. Holtz-Eakin and Selden, 1995; Cole et al., 1997; Moomaw and Unruh, 1997). Among economists, there is a fairly strong consensus that economic, and also political, freedom is positively correlated with economic growth. These hypotheses have also been supported in several studies (see e.g. Barro, 1991; Islam, 1996; Gwartney et al., 1999; de Haan and Sturm, 2000).[1] In the light of these results and their policy implications of promoting economic and political freedom, it is of interest to test empirically how increased freedom affects CO_2 emissions. There can be both direct and indirect (through income) effects of freedom on the level of emissions.[2] The purpose of this study is to analyze the less examined first effect, i.e. the direct effect from changes in economic and political freedom on CO_2 emissions, using a panel data set of 75 countries on CO_2 emissions from 1975-1995.

The paper is organized as follows. The relationships between economic and political freedom and CO_2 emissions are discussed in Section 2. The data is presented in Section 3. Section 4 contains the model specification. In Section 5 the results of the estimations are reported and the robustness of the result is analyzed. The final section concludes the paper and discusses the identified direct results in relation to the indirect results found in previous studies.

[1] It should be noted that the stability of the results have been questioned (see e.g. Levine and Renelt, 1992). However, Sturm and de Haan (2001) show that increases in economic freedom are robustly related to growth. Carlsson and Lundström (2002) find that the robustness of the relationship differs between economic freedom measures. Moreover, many studies have concluded that the effects of political freedom on economic growth mainly work through its effects on economic freedom, which in turn effects growth (see e.g. Barro, 1996).

[2] Note that we only study the *direct* effect of freedom on emissions. There may, as mentioned, be *indirect* effects from economic freedom via GDP, but also from political freedom via its effect on economic freedom.

2 FREEDOM AND CO_2 EMISSIONS

2.1 Economic Freedom

Economic freedom is often mentioned as a crucial component for providing incentives resulting in an effective use of resources. We are here interested in how different economic freedom variables, that have been found to be important for economic growth, affect CO_2 emissions.[3] We present three hypotheses regarding the effects. (i) *The Efficiency Effect*. Under the assumption that economic freedom results in efficient and competitive markets, we may expect a negative correlation between economic freedom and CO_2 emissions. For a given production level, fewer resources would be used and less waste produced due to cost minimizing reasons. First, liberalization may result in an efficient use of resources that have a price. This price can, of course, be affected by policies such as a tax correcting for an externality. Second, an efficient market may better meet political regulations and the desires of consumers. The second reason is simply due to competition; in order to survive, firms have to react to changes in the market environment. Clearly, this effect is only relevant if there are environmental regulations, or a demand for cleaner production/goods from the consumers. Because of the global public good character of CO_2 emissions, and hence free-riding possibilities for the individuals as well as the countries, it is not very likely that resource efficiency is primarily directed towards reductions of CO_2 emissions. At the same time, CO_2 emissions are directly related to energy use, and cost minimizing efforts may therefore still result in reduced emissions. (ii) *The Trade Regulation Effect*. Taxes and restrictions on trade lower economic freedom. Trade liberalization may result in a more effective resource allocation as a result of the competitive pressure in international markets. However, there might also be a so called "pollution haven" effect. Trade results in increased specialization, and countries with a large share of capital-intensive production and less strict environmental regulation are more likely to specialize in dirty industries. Therefore, even though global pollution is constant, some countries will

[3] Another type of variable that is indirectly related to economic freedom is environmental regulations (see e.g. Hilton and Levinson, 1998). These are not explicitly included in our study since we are interested in

increase their emissions and some will decrease their emissions. Hence, there are two effects from trade liberalization, the efficiency and the "pollution haven" effect, thus the final expected effect on emissions per unit produced is ambiguous. The effect of increased efficiency is expected to decrease CO_2 emissions, while the pollution haven effect can be both positively and negatively related to emissions depending on the structure of the economy. (iii) *The Stability Effect.* It is likely that increased price stability leads to more efficient investment and consumption decisions. A stable macroeconomic environment also encourages longer investment horizons. Many environmental investments, or efficiency enhancing investments, pay off in the future, and will not be made without a belief that the economy will be stable until the profits are received. Hence, a stable macroeconomic environment may decrease emissions. Another important part of the stability effect is the property rights structure. The importance of security of property rights and viability of contracts has been emphasized in the growth literature and lately also in the growth-environment literature (see e.g. Panayotou, 1997). With more secure property rights individuals can make long-term, efficiency-enhancing investments. However, an increased stability, in terms of a more stable macroeconomic environment or more secure property rights, may also result in increased investments and consumption in general. Again, because of the public good character of CO_2 emissions, it is not very likely that investments are primarily directed towards reductions of CO_2 emissions. However, there might still be an effect on emissions through changes in investments related to energy use.

It is possible, and even likely, that the effect of changes in economic freedom on CO_2 emissions depends on the composition of production in a country, or the pollution intensity of production (see e.g. Antweiler et al. 2001). For example, an increased freedom to trade may, as we have discussed, result in an increased specialization, and hence increased emissions in a pollution intensive country. The effect of an increased stability may also, in a similar manner, depend on the composition, i.e. that increased stability results in increased specialization. On the other hand, the efficiency effect can be expected to be higher for pollution intensive countries.

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the effects of reforms implemented to increase economic growth and not directly to improve the environment.

2.2 Political Freedom

A political and civil system in which an individual's demand for environmental quality can be expressed might be crucial for the environmental quality in a country. Deacon (1999) discusses reasons for a positive correlation between political freedom and environmental quality, and argues that non-democratic regimes are more likely to underprovide public goods, such as environmental quality, compared to regimes that are more democratic. The underlying reason for this is the assumption that the political elite receives a disproportionate share of the country's income, which often implies that they bear a disproportionate share of the cost of the environmental regulation. At the same time, this group receives a proportionate share of the benefits of pollution control. Congelton (1992) presents a similar model with similar arguments to those of Deacon, and in addition argues that less democratic regimes tend to have a shorter planning horizon. However, it does not follow from this that there has to be a positive correlation between political freedom and the environment. In a system with representative legislature the role of interest groups is enhanced. If this effect is biased against environmentally unfriendly solutions, such as subsidies to energy intensive industry, CO_2 emissions could increase with political freedom. The effect of political freedom on the environment may also be insignificant; in particular if it is a global environmental problem such as CO_2 emissions, since the individual country has an incentive to free-ride. At the same time, emissions of global pollutants can be correlated with other environmental problems, so there could still be an effect from political freedom. Moreover, the preferences within a country for global environmental quality can be high because of the risk of global instability or for altruistic reasons, for example, of which the increased number of climate (and other environmental) conventions might be an indication.

The relationship between political freedom and the environment has been studied in a number of papers. Most studies have found a positive relationship between political freedom and environmental quality, but none of these have studied CO_2 emissions. Empirical studies have found a positive relationship between political freedom and the probability to sign international conventions regarding reductions of global pollutants (Congleton, 1992; Fredriksson and Gaston, 1999). However, these international agreements have only recently started being implemented, and therefore it is not likely that political freedom has yet had a significant effect on the level of emission today.

3 DATA

All data, except the CO_2 emissions data and the freedom data, come from the *1999 World Development Indicators CD-Rom* (World Bank, 1999); the CO_2 emissions data are originally from the Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory. CO_2 emissions, measured in metric tons per capita, are emissions from the burning of fossil fuels and the manufacture of cement. They include contributions to the carbon dioxide flux from solid fuels, liquid fuels, gas fuels, and gas flaring. The GDP data are converted into international dollars using purchasing power parities.

The data on economic freedom are from *Economic Freedom of the World: 2000 Annual Report* (Gwartney et al., 2000). The main components of the economic freedom index are personal choice, protection of property and freedom of exchange. The index of economic freedom is divided into seven categories. Each index is measured on a scale between 0 and 10, where 10 is the highest level of freedom. We use the categories corresponding to the hypotheses presented in Section 2. The category *Economic structure and use of market* (*EFeff*) represents the Efficiency Effect. This category is a measure of the share of government production and allocation.[4] The Trade Regulation Effect is represented by the category *International exchange: Freedom to trade with foreigners* (*EFtrade*).[5] The average of the two categories Monetary Policy and Price Stability, and Legal Structure and Property Rights, henceforth called *Price stability and Legal security* (*EFstab*), represents the Stability Effect. The category Monetary Policy and Price Stability measures the protection of money as a store of value and medium of exchange and the category Legal Structure and Property Rights measures the security of

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[4] *Economic structure and use of market* consists of the variables: 1) government enterprises and investment as a share of the economy, 2) the extent of price controls, 3) the top marginal tax rate and 4) the use of conscripts to obtain military personnel.

[5] *Freedom to trade with foreigners* consists of the variables 1) Taxes on international trade and 2) Non-tariff regulatory trade barriers.

property rights and the viability of contracts.[6] The economic freedom data have been reported every fifth year since 1970, but not all countries have been included since 1970.

The political freedom variables are measures based on the Freedom House indices of political and civil freedom (Freedom House, 1999). The political freedom index measures whether a government came to power by election or by gun, whether elections, if any, are free and fair, and whether an opposition exists and has the opportunity to take power at the consent of the electorate. The civil freedom index measures constraint on the freedom of the press, and constraints on the rights of individuals to debate, to assemble, to demonstrate, and to form organizations, including political parties and pressure groups. Since they are highly correlated we use the average of these two indices, henceforth called *Political freedom* (*POL*). The political freedom index is measured on a scale between 1 and 7, where 7 is the highest level of freedom.[7]

Table 1. Descriptive statistics for countries included in the estimations.

	Mean	**Std.**	**Min**	**Max**
CO_2, kg per capita	4266.540	5093.240	42.22	25267.00
GDP, 100 dollar per capita	58.079	56.601	2.68	273.32
Structure and use of markets (EFeff)	3.933	1.809	0	8.64
Freedom to trade with foreigners (EFtrade)	5.930	2.233	0	9.84
Price stability and Legal security (EFstab)	6.419	2.183	0	9.88
Political freedom (POL)	4.781	1.814	1	7.00
Industry sector share of GDP	31.983	8.516	9.88	59.29
Annual GDP growth	3.142	4.334	-12.43	14.67
Number of observations	319			

The sample includes 75 countries for the period 1975-1995. The data is unbalanced, due to missing observations mainly on economic and political freedom.

[6] *Monetary Policy and Price Stability* contains the variables 1) average annual growth rate of the money supply during the last five years minus the growth rate of the real GDP during the last ten years, 2) standard deviation of the annual inflation rate during the last five years and 3) annual inflation rate during the most recent year. *Legal Structure and Property Rights* consists of the variables variables: 1) risk of confiscation, 2) risk of contract repudiation by the government and 3) institutions supportive to the principles of rule of law.

[7] The variable is rescaled since 1 is the highest level of political and civil freedom and 7 the lowest level, in the original data set.

Descriptive statistics are presented in Table 1. Note that CO_2 per capita is in kg emissions per capita and GDP per capita is in hundreds of dollars per capita. CO_2 per capita is measured as a moving average of the current and the previous three years. Additional control variables included in the regressions are also reported in Table 1.

The correlation matrix for the freedom variables, GDP and CO_2 emissions is presented in Table 2. We see that both economic and political freedoms are correlated to a certain extent and that the economic and political freedom variables are all positively correlated with both GDP per capita and CO_2 emissions.

Table 2. Correlation matrices for variables included in estimations

	GDP	**POL**	**EFtrade**	**EFeff**	**EFstab**	**Industry**	**Growth**	**CO_2**
GDP	1.00							
POL	0.58	1.00						
EFtrade	0.63	0.37	1.00					
EFeff	0.42	0.30	0.40	1.00				
EFstab	0.61	0.45	0.55	0.28	1.00			
Industry	0.14	0.06	0.29	0.04	0.08	1.00		
Growth	-0.05	-0.13	-0.05	-0.05	0.10	0.11	1.00	
CO_2	0.74	0.45	0.60	0.31	0.53	0.31	-0.10	1.00

4 MODEL SPECIFICATION

We assume that CO_2 emissions per capita is a polynomial function of income per capita, and a function of the different economic freedom measures and political freedom discussed above. We also want to control for a composition effect on emissions, by including the industry sector's share of GDP as an explanatory variable. This share is a measure of the relation between capital and labor in the country. Finally, the growth of GDP is included to allow for effects of rapidly expanding countries. All models are estimated with country and time specific effects.[8] As we discussed previously, the effect of economic freedom may also depend on the composition of the economy. In order to account for this we investigate whether the effect of economic freedom on CO_2

[8] The country specific effects are assumed to capture effects such as geographical characteristics, fossil fuel availability and prices, energy endowments and tastes. The time specific effects are assumed to capture effects such as changes in the world price of oil and technological change. We also estimated the models with the world price on oil instead of the fixed time effects, but the coefficient for the oil price was consistently insignificant.

emissions depends on the share of the industry sector, relative to GDP, in the country or not. All economic freedom variables are therefore allowed to interact with the industry sector's share of GDP.

In the growth-environment literature the two common specifications are linear and log-linear, with at least a quadratic GDP/log(GDP) variable in order to allow for a turning point, but some studies even include a cubic GDP/log(GDP) variable. However, using a PE-test, both functional forms can be rejected with the present CO_2 data – both for a quadratic and a cubic GDP/log(GDP) specification. In addition, none of the specifications pass a RESET test. Therefore, we apply a Box-Cox regression, where CO_2 emissions per capita are transformed in the following fashion: $\frac{(CO_2)^{\lambda}-1}{\lambda}$. Since the choice of the functional form of the GDP variables is not straightforward, we present the results from four different models. The results for economic freedom do differ somewhat between specifications, and these differences are discussed in the following section.

5 RESULTS

Table 3 presents the result of the Box-Cox regression models. Note that only the models with a cubic term pass the RESET test at the 5% level. The economic freedom variables are jointly significant in all models. Because of the Box-Cox transformation and the different transformations of the GDP variable, interpreting and comparing the results regarding the relationship between GDP and CO_2 emissions is not straightforward. We therefore plot the estimated relationship between GDP and CO_2 emissions. The resulting graphs are presented in the Appendix. All models, apart from the first one, predict a non-negative relationship between the scale of the economy and the level of emissions. This result is in line with the results in previous studies. The composition effect, measured by the Industry sector share of GDP, is also positive, i.e. an increased share of industry production increases emissions. The effect of GDP growth is insignificant in all models.

Table 3. Results of Box-Cox estimations

	Model 1	**Model 2**	**Model 3**	**Model 4**
	Coefficient (P-value)	Coefficient (P-value)	Coefficient (P-value)	Coefficient (P-value)
GDP	0.0680 (0.000)	0.1894 (0.000)		
GDP^2	-0.0002 (0.000)	-0.0011 (0.000)		
GDP^3		0.000002 (0.000)		
ln GDP			3.7448 (0.000)	-0.5944 (0.581)
$(\ln GDP)^2$			-0.0937 (0.043)	1.3666 (0.001)
$(\ln GDP)^3$				-0.1435 (0.001)
Structure and use of markets (EFeff)	0.2189 (0.272)	0.2836 (0.174)	0.0020 (0.987)	0.1244 (0.337)
EFeff * Industry sector share	-0.0103 (0.098)	-0.0130 (0.050)	-0.0037 (0.330)	-0.0072 (0.076)
Freedom to trade with foreigners (EFtrade)	-0.0159 (0.922)	0.0508 (0.762)	0.1490 (0.154)	0.0754 (0.474)
EFtrade * Industry sector share	0.0005 (0.913)	-0.0025 (0.618)	-0.0029 (0.350)	-0.0019 (0.545)
Price stability and Legal security (EFstab)	-0.4385 (0.026)	-0.3783 (0.053)	-0.3518 (0.007)	-0.2800 (0.025)
EFstab * Industry sector share	0.0141 (0.018)	0.0109 (0.062)	0.0086 (0.021)	0.0060 (0.094)
Political freedom	-0.0243 (0.701)	-0.0405 (0.538)	0.0351 (0.384)	0.0261 (0.520)
Industry sector share of GDP	0.0836 (0.008)	9.1600 (0.005)	1.9310 (0.284)	2.9712 (0.112)
Annual GDP growth	-0.0222 (0.116)	-0.0199 (0.166)	-0.0143 (0.108)	-0.0110 (0.214)
Lambda (λ)	0.2203 (0.000)	0.2357 (0.011)	0.1745 (0.011)	0.1808 (0.009)
RESET $\sim \chi^2_{a,3}$	11.11	3.46	9.17	2.72
LR test EF $\sim \chi^2_{a,6}$	15.70	15.30	30.78	25.63

Among the economic freedom variables, only *Price stability and Legal security* has a significant effect on the level of CO_2 emissions. The interaction term between the industry sector share and the degree of freedom for this variable is also significant in all models. The coefficient for *Price stability and Legal security* is negative, indicating that an increased degree of economic freedom decreases CO_2 emissions. However, the coefficient for the interaction term is positive. This implies that the decreasing effect on

CO_2 emissions is lower for a country with a large industry sector share and this it is even positive at a sufficiently high level of industry share. For Model 2, the combined effect is -0.06 at the mean value of the industry share.[9] The interaction term between *Structure and use of market* and the industry sector share is also significant in three of the models. The coefficient is negative, implying that an increase in the degree of freedom decreases CO_2 emissions, and that this decreasing effect is larger for a country with a large industry sector. The coefficient for the variable *Freedom to trade with foreigners* is not significant in any model, not even when it interacts with the industry sector share.

The estimated *Political freedom* coefficient is insignificant in all models. Previous studies have found a negative, and significant, relation for other pollutants, but as we have discussed, the public good character of CO_2 emissions for the individual country makes this type of emission rather different from other types of emissions.

Even though the results are fairly coherent in the different models it is of course unsatisfactory that the significance of the freedom variables differ slightly between the specifications. On the other hand, the category *Price stability and Legal security* is significant in all specifications, and can in that sense be seen as more robust. We also test the robustness of the results in terms of sensitivity of the sample. This is done with a jack-knife type of procedure, where one country is deleted from the sample at a time; hence 74 new models are estimated. Then the share of the number of times each variable is significant, at the 10% level, is calculated. The restricted sample models are estimated based on the Box-Cox transformation obtained from the full sample model since we want to test the sensitivity for a given functional form. The tests show that the significance of the interaction term between *Structure and use of market* and the industry sector share is sensitive to the sample. It is only in the linear model with a cubic GDP term that the share of the number of times that the coefficient is significant is larger than 0.9. In all other models the share is between 0.01 and 0.35. Consequently, we do not find the results regarding a significant effect of this category as robust. *Price stability and Legal security* is also sensitive to the sample in some models, but to a

[9] In our sample the maximum industry share (*Ind*) is 59, the minimum is 10 and the mean is 32 (see Table 1). The combined effect for *EFstab* is (b_1+ b_2*Ind*) where b_1 is the coefficient for *EFstab*, and b_2 is the

lesser degree than the other freedom categories. In the linear model with a cubic GDP term the share is 0.88, but in all other models the share is higher than 0.9. In the two models with a cubic term, the interaction term is also sensitive to the sample.

6 CONCLUSIONS AND DISCUSSION

The purpose of this study was to analyze the direct effects of different economic freedoms and political freedom on CO_2 emissions. Among the economic freedom variables, *Price stability and Legal security* have a decreasing effect on the level of CO_2 emissions for countries with a small industry share of GDP, but an increasing effect in countries with a large share. A possible explanation for this is that increased stability and security increases investments in the production where the country has a relative advantage. The effect of increased investments on emissions in turn depends on the pollution intensity; therefore in a country with high (low) pollution intensity, increased investments are likely to increase (decrease) emissions. When testing our results for robustness, this economic freedom category was the only one that had a robust significant effect on CO_2 emissions. The decreasing effect of *Structure and use of market* was non-robust and *Freedom to trade with foreigners* was insignificant. Moreover, we found that *Political freedom* does not significantly affect CO_2 emissions. A negative relationship between democracy and environmental degradation has been found for several other pollutants, but we cannot confirm the results for CO_2 emissions. We believe that one explanation is that even if several democratic countries have signed international agreements regarding reduction of CO_2 emissions, these have not yet been implemented. Therefore, one may expect a significant effect of political freedom on future levels of CO_2 emissions.

One interesting question is whether CO_2 emissions increase or decrease if we consider both the direct effects of economic freedom and the indirect effects through GDP, which in turn effects emissions. This turns out to depend on the specific category analyzed. For example, Carlsson and Lundström (2002) find that both *Legal structure and Security of private ownership* and *Structure and use of markets* has a significant,

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coefficient for the interaction term. b_1 is approximately –0.38, and b_2 is approximately 0.01 (see Table 3).

and robust, positive effect on GDP growth.[10] However, a simple back of the envelope calculation then reveals that if we convert the marginal increase in growth and the corresponding increase in GDP during a 10 year period, the indirect (positive) effect is larger than the direct (negative) effect for *Price stability and Legal security* but the indirect (positive) effect is smaller than the direct (negative) effect for *Structure and use of market*.[11] Hence, there seems to be an increasing overall effect of economic freedom on CO_2 emissions from *Price stability and Legal security*, but an overall decreasing effect from *Structure and use of market*, although the latter effect is small.

A natural extension of this work is to study other types of environmental measures and their relationship with political and economic freedom. The size and sign of these effects can be expected to differ, depending on the public good character of the environmental good, or the character of the good from which the emissions occur.

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[10] Note however that the effect of some economic freedom categories on GDP is negative and robust, and some are insignificant.

[11] The marginal effect of *Legal structure and Security of private ownership* on GDP growth is 0.358. If this category is increased by one unit, all else equal, mean GDP would be $1.00358^{10}*58.1=60.2$ after 10 years, instead of 58.1 without the change. The effect of GDP on emissions is for Model 2 $0.1894*GDP–0.0011*GDP^2+0.000002*GDP^3$ (see Table 3). Hence, the difference in emissions for GDP=58.1 and GDP=60.2 is about 0.12. The increase in Box-Cox transformed emissions by 0.12 units from this indirect effect can then be compared to the direct effect of –0.03 (for Model 2). The overall effect on transformed emissions of a unit increase in this economic freedom category would hence be 0.09. *Structure and use of market* has a marginal effect on growth equal to 0.214. Following the same calculations as above the indirect effect on emissions would be 0.08, which could be compared to the direct effect of –0.13 (for Model 2). Hence, in this case the overall effect on transformed emissions of an increase in economic freedom would be –0.05.

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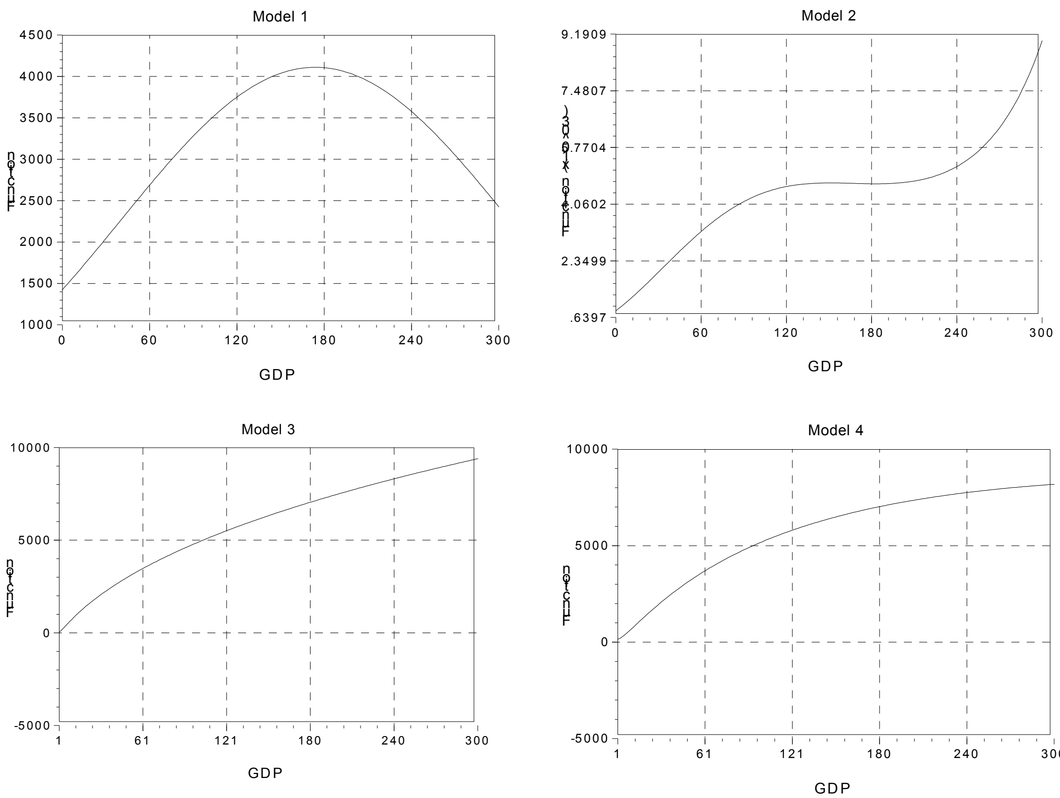
APPENDIX

Figure 1. Fitted relationship between CO_2 emissions and GDP per capita



Technological Opportunities and Growth in the Natural Resource Sector

By

Susanna Lundström*

***Abstract*:**
Both technological and natural resource possibilities seem to evolve in cycles. The "Resource Opportunity Model" in this paper introduces the technological opportunity thinking into natural resource modeling. The natural resource industries' choice between incremental, complementary innovations, and drastic, breakthrough innovations, will give rise to long-run cycles in the so-called familiar resource stock, which is the amount of natural resources determined by the prevailing paradigm. Incremental innovations will increase the exhaustion of the stock, and drastic innovations will create a new paradigm and, thereby, new technological opportunities and a new stock of familiar resources. Drastic innovations are endogenously affected by the knowledge level and induced either by scarcity of technological opportunities or by scarcity of resources. Generally, increased innovation ability increases the knowledge stock and cumulative income over time, but does not affect the sustainability of the resource stock even though the intensity of the resource cycles increases. However, too low innovation ability might drive the sector into technological stagnation, and resource exhaustion in the long run; and too high innovation ability might drive the sector into extraction stagnation, and resource exhaustion in the short run.

***Keywords*:** Cycles, Economic growth, Induced innovations, Natural resources, Paradigm shifts, Technological opportunities.

***JEL classification*:** O11, O13, O31, Q30, Q43, N50

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1 INTRODUCTION

The typical dynamics of the abundance of many natural resources are characterized by periods of pessimism with restricted resource opportunities, which are finally replaced by new eras of optimism (see e.g. Simon, 1997), even though there are examples of stagnation (see e.g. Ponting, 1994). The periodic pattern of innovations, and hence economic growth, has also been accepted as a stylized fact. Drastic innovations are followed by periods of less revolutionary innovations. Hence, both technological and natural resource opportunities seem to evolve in cycles, which give rise to several interesting questions about their possible interrelations. Are the effects of innovation on resources different depending on the type of innovation? Can technological change be the source of both prosperity and stagnation in natural resource industries? Are limited natural resources or technological opportunities the driving force of technological shifts?

Several authors highlight the importance of analyzing the underlying mechanisms of changes in resource abundance. David and Wright (1997) argue that resource abundance is not exogenously given by geological conditions, since it is to a large extent an endogenous social construction. They give several examples of how the combined effects of legal, institutional, technological and organizational responses to resource scarcity created a highly elastic supply for American mineral products between 1850 and 1950. In a survey of technological change and the environment, Jaffe et al. (2000) conclude that the "modeling of how the various stages of technological change are interrelated, how they unfold over time, and the differential impact that various policies may have on each phase of technological change" is of great importance to be able to understand the interaction between innovations and the environment. It is the purpose of this paper to model the innovation decisions of the natural resource sector using the technological opportunity approach, which is one way to create a long-run cyclic pattern of natural resources, and thereby to identify the crucial variables at different stages.[1]

[1] It is not the purpose of this paper to model the effects of resource-saving technologies on the demand side, i.e. end-use technologies. These are, of course, of importance, but to keep the dynamics of supply responses tractable, this effect will only be discussed in the section where price changes are analyzed.

Previous models of innovations and natural resources have usually modeled jumps in the extractable resource stock by assuming a Poisson process with a constant probability of discovery (see Krautkraemer, 1998, for an overview). In some models the frequency of discovery or innovation activity is exogenous, but in others it is a function of research expenditures. As the known stock decreases, the cost of extraction increases and investments in research become profitable. Once the discoveries of new sources or new technologies are made, costs decrease and there is a new period of extraction without any innovation activity.

In this paper, however, the innovation activity is not a discrete but a continuous process, just like extraction, even though the type of innovations might differ from period to period. The focus is therefore on the choice of the type of innovation: incremental or drastic. Research could be of different characters: revolutionary or non-revolutionary, resource consuming or resource creating. However, few studies make this distinction.[2] Moreover, the uncertain outcome of the innovation process does not have to be modeled as completely random, but preferably as endogenously influenced by the level of technical knowledge. Another shortcoming of previous models is the inducing mechanism. Many innovations in the natural resource sector do seem to be induced by the scarcity of resources. However, one should not overlook the fact that many drastic innovations occurred without any physical resource restrictions (Jaffe et al., 2000). In the model developed in this paper this is explained by restrictions on technological opportunities.

The cyclic pattern of innovations is in Olsson (2000, 2001) explained by a theory of technological opportunities, i.e. the abundance or scarcity of technological opportunities. Incremental innovations are developed from a stock of technological opportunities. The more this stock is exhausted, the lower the returns to this activity. Consequently, at some point innovators turn to drastic innovations, which introduces new technological opportunities. This approach is especially suitable for the natural

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[2] One exception is Smulders and Bretschger (2002) who present a model where one type of innovation is undertaken at a certain moment in time, either a revolutionary general purpose technology, or a diffusion process of this new technology. However, it is rather cycles in pollution, not resource stocks, that is modeled and the inducing mechanism is increasing costs (as in the traditional models) because of environmental taxes, and not innovation constraints.

resource sector in which the scarcity thinking is crucial. Therefore, this paper adds a stock of natural resources to this model and studies simultaneously the interaction between technology and natural resources.

Drastic innovations in the natural resource sector can either be connected to the introduction of a new, unexpected technical solution or to the finding of a new type of resource. Some clear-cut examples of major breakthroughs of importance for the natural resource industry are the energy system shifts between horse power, wind power, coal, oil and nuclear power. The common feature of these drastic innovations is that they gave rise to sequences of "follow-up" or complementary innovations. These are non-revolutionary, or incremental innovations in the sense that they are only combinations of already existing ideas. By introducing oil as an energy resource, the mechanical revolution became possible; the steam engine revolutionized the mining industry, etc. It is through these incremental progresses, the combination of a new idea and old knowledge, that the drastic innovation becomes fruitful.

In the Resource Opportunity Model (ROM) presented in this paper, the choice of the natural resource producer is, as mentioned, not between extraction and innovations, but between the types of innovations, even though extraction affects this choice.[3] The alternation between incremental innovations and drastic innovations will give rise to long-run cycles in the so-called familiar resource stock, which is the stock of natural resources determined by the prevailing paradigm. Incremental innovations will increase the exhaustion of the stock, while drastic innovations will create a new paradigm and thereby a new stock of familiar resources. Drastic innovations are not only induced by resource constraints, but also by incremental innovation constraints, as in the technological opportunity model. That is, they are now created either by scarcity of technological opportunities or by scarcity of natural resources. The expected success of these drastic innovations, in introducing new technological and resource opportunities, is not constant but endogenously determined by the increasing stock of knowledge, and the society's ability to innovate.

[3] The focus of this paper is on the structural parts of the model, which to some extent results in strong simplifications on the behavioral part with the purpose of clarifying the main points.

The inclusion of restricted resources opens up the analysis for stagnation outcomes. The drastic innovation jumps in resource availability can be more or less successful, which either increases or decreases the probability of economic stagnation caused by technological constraints. Moreover, the rate of incremental innovations might differ, increasing or decreasing the probability of stagnation caused by a too intensive extraction.

The cyclic behavior of the resource stock will also be connected to economic growth in the resource sector. The incremental phase of technological development follows the pattern of exogenous growth models with decreasing returns to scale, both in technological opportunities and natural resources. On the other hand, the sharp increase in marginal returns is dependent on the endogenously determined knowledge level and not really on a “manna from heaven” change in technology. The drastic innovation is therefore characterized by endogenous technological change. This combination of both exogenous and endogenous growth periods may give us new insights about natural resource scarcity.

The main message of this paper is that technological opportunities affect resource dynamics and that sustained growth is only possible if research keeps increasing technological and resource opportunities enough. The general result is that an increased level of ability to turn technological opportunities into innovations does not affect the sustainability of the resource stock (even though the fluctuations increases), but increases the knowledge stock and the total extraction, and hence the stock of income. However, an innovation ability level that is too low might lead the sector to technological stagnation and resource exhaustion in the long run, and a level that is too high might lead the sector to extraction stagnation and resource exhaustion in the short-run.

Section 2 gives the background of the ROM by presenting the definitions of the resource stocks and innovations, plus the idea of innovation cycles. Section 3 introduces the ROM, first by presenting the modeling of technological opportunities and the resource stock dynamics during different types of innovation periods, then by modeling the profits that determine the type of innovation period, and finally by connecting the dynamics to economic growth. The results are presented by simulations in Section 4.

Alternative assumptions and stagnation outcomes are analyzed in Section 5. Section 6 concludes the paper.

2 BACKGROUND

2.1 Resource Stocks

First of all, it is important to make clear the distinction between familiar and potential resources. *Familiar resources* are the physical quantity of resources, discovered or undiscovered, under the prevailing paradigm, i.e. resources that in some way are seen as useful given the normal science at that time. *Potential resources* are the physical quantity of resources that might be seen as useful resources under other paradigms.[4]

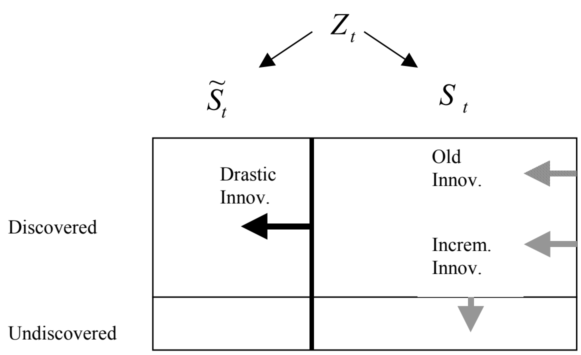
The *familiar resource stock*, S_t, includes all familiar resources and it is cycles in this stock that are the focus of this paper. The stock includes both discovered and undiscovered resources. The "discovered familiar resource stock", is the stock often referred to in previous studies of natural resources and growth, i.e. the stock of familiar resources available for extraction. The "undiscovered familiar resource stock" includes familiar resources, i.e. they are known according to the prevailing paradigm, but they have to be physically discovered before they can be extracted. Incremental innovations increase the extraction rate and hence speed up the decrease in the stock of familiar resources, while a paradigm shift increases the quantity of familiar resources, either by introducing an unexpected technology that improves the availability of already familiar resources or by adding to the number of types of familiar resources. The effects of innovations will be further explained in the next section.

Figure 1 helps clarify the definition of S_t. $\widetilde{S}_t$ is defined as the *potential resource stock*, including the physical quantity of resources available under all possible future paradigms. Z_t is then the *total resource stock* , i.e. $Z_t = S_t + \widetilde{S}_t$, and the only actual restriction on resources by this definition would be the thermodynamic laws.

[4] The concepts "normal science" and "paradigm shifts" are borrowed from Kuhn (1962). Normal science is conducted until enough anomalies are discovered. The anomalies can no longer be ignored which induces a paradigm shift. The new normal science then created includes the earlier ignored anomalies. Normal science in the ROM is incremental innovations and a paradigm shift is a drastic innovation.

However, in this paper we will, as a simplification, assume that $\tilde{S}_t$ is unlimited.[5] Note that $\tilde{S}_t$ also includes discovered and undiscovered resources.

Figure 1: Resource Stocks



Assume that the total resource stock we are interested in is the stock connected to the use of energy. Then examples of discovered familiar resource stocks are oil sources whose physical locations are known. They are sources ready to be extracted using the technological knowledge at that time, or sources that you expect to be able to extract using non-revolutionary incremental extraction innovation. Examples of undiscovered familiar resource stock are oil sources not yet physically discovered but are expected to be identified using incremental discovery innovation. They differ from the potential resource stocks, which are not expected to be available at all. They are added to the familiar resources by a completely unexpected new paradigm. An example of a discovered potential resource stock in the energy context is uranium. The finding of nuclear power made uranium become a resource. Uranium was discovered long before but not seen as a resource. An undiscovered potential resource might be an oil source not even conceivable under the current paradigm. With a new revolutionary technology such as oil drilling at sea, large sources became possible to discover.

[5] In the "very-long-run" the long-run waves in S_t would also be negligible and the availability of familiar resources would be more or less constant. If, however, we had included the thermodynamic restrictions on Z_t, there would probably be a downward sloping trend and not a constant.

2.2 Innovations

The view of the innovation process as consisting of both small non-revolutionary and large revolutionary innovations, is shared by many researchers (see e.g. Schumpeter 1934, 1942; Kuhn, 1962; Dosi, 1988; Jovanovic and Rob, 1990; Mokyr, 1990; and Helpman and Trajtenberg, 1998). Olsson (2001) presents three kinds of technological innovations related to knowledge in general: incremental innovations, drastic innovations and potential innovations.[6,7] *Incremental innovations* are non-revolutionary changes in technology generated by combining various elements of old knowledge. The costs and risks are low, and the innovations are carried out by profit-seeking entrepreneurs. Incremental innovations are the "normal activity" in the technology field and are only bounded by the prevailing technological paradigm. *Drastic innovations* are revolutionary new ideas that combine new knowledge, potential innovations, with the old knowledge. The costs and risks are high, but the financial rewards can be substantial. Most importantly, the drastic innovations open up for new technological possibilities due to the new knowledge, creating a new technological paradigm. However, the returns and the success of the innovations are uncertain and the risks of free-riding are high. The *potential innovations* are the pieces of new knowledge that drastic innovations can connect to the prevailing paradigm. These are considered to be anomalies at first, since they do not fit into the normal science in the old knowledge. They are not a result of systematic entrepreneurship but of random findings, often while conducting normal science.

In this study we look at the technological innovations on the supply side affecting the natural resource sector. Potential innovations are "islands" outside the natural resource knowledge. A potential innovation might have been used in another sector but may still be irrelevant to the science of natural resources. This is actually the typical situation for the natural resource industry which is not a research intensive

[6] These are similar to other concepts such as micro and macro inventions (Mokyr, 1990), or secondary and fundamental innovations (Aghion and Howitt, 1998). The concepts are also related to the so-called technology "lock-in", where a particular technology might create path dependence for the follow-up innovations (Dosi, 1988; Jaffe et al., 2000).
[7] Olsson (2001) defines potential innovations as discoveries but because of the possible confusion with resource discoveries we will use potential innovations.

sector, but instead innovative when it comes to implying technological solutions from other parts of the economy (Simpson, 1999). Note that a potential innovation can be either a completely new technology or a completely new type of resource.

As we will see, the drastic innovations are induced by the low returns to incremental innovations, which in the ROM is either due to a low level of technological opportunities or a low level of physical resource availability.[8] To put it another way, the low productivity of extraction cannot be improved enough by the few technological opportunities left. Since drastic innovations are assumed to be induced by low returns in the natural resource industry, we assume they have positive effects on the stock of resources. First, if the potential innovation was a technology, the new knowledge may have made the already familiar resources last longer by a more efficient technology than was available, or even conceivable, under the previous paradigm.[9] Second, if the potential innovation was a resource, the new paradigm may have made materials previously unknown or judged as non-valuable "become" familiar resources.[10] The drastic innovations can in some sense be interpreted as general purpose technologies since they have the potential to influence large parts of the economy. A drastic innovation in the ROM could be seen as a general purpose technology, but only in the sense that it affects large parts of the natural resource sector.

Incremental innovations are connected to the already familiar resources known under the current paradigm.[11] They can be divided into two categories: incremental extraction technology and incremental discovery technology. Incremental extraction innovations increase the efficiency, and hence the rate of extraction, of the discovered

[8] This assumption is of course only valid for the drastic innovation connecting the potential innovations to knowledge in the natural resource sector and not to drastic innovations in a more general sense. Note that the possibility of natural resource scarcity inducing a completely new technology (i.e. a potential innovation not connected to knowledge in any sector) is possible but it could, as mentioned, also be a technology already used in other sectors but induced to be used in the natural resource sector.

[9] An example from the petroleum industry is the introduction of the computer making new imaging technologies possible, which made it possible to map oil sources previously hidden (Bohi, 1999).

[10] A straightforward example is, as mentioned, the discovery of uranium as a source of energy by the drastic innovation of nuclear power.

[11] Of course even incremental innovations may have a drastic innovation character, i.e. combining old ideas may have revolutionary impacts. In reality it might be difficult to separate the two innovations. However, we define drastic innovations as innovations introducing completely new knowledge to the natural resource sector.

resources.[12] Incremental discovery innovations increase the efficiency in finding undiscovered sources of the already familiar resources, which also affects the rate of extraction.[13] Notice that while a drastic innovation introduces completely unpredicted sources, a source discovered from an incremental innovation is not surprising in the same sense. In the latter case there is much less doubt about the existence of the source, knowing that the non-revolutionary technology of identifying the source was simply lacking.

Hence, under the prevailing paradigm there is a certain set of familiar resources, of which some sources are discovered and some are not, and the exhaustion of these are increased by incremental innovations. However, drastic innovations can introduce a new stock of familiar resources by establishing a new paradigm.

2.3 Innovation Cycles

There is a large body of literature on growth cycles connected to innovation (see Stiglitz, 1993, and Aghion and Howitt, 1998, Chapter 8, for an overview). Some studies analyze the effect of growth cycles on the innovation pattern (see e.g. Stadler, 1990), while others study the impacts of changes in innovation on growth (see e.g. David, 1990; Juhn et al., 1993; Bresnahan and Trajtenberg, 1995; and Helpman and Trajtenberg, 1998). However, for this study it is important to find a model that formalizes the distinctions between drastic and incremental innovations and their different impacts on growth, and that endogenizes the frequency and the success of the drastic innovations instead of just letting them occur in a stochastic process. I will therefore follow the tradition of studies like Jovanovic and Rob (1990), Boldrin and Levine (2001) and Olsson (2001) where the driving force of the growth cycles is the trade-off between new major innovations and refinements of old ones.

Olsson (2001) presents a model to explain the cyclic behavior of technology and economic growth that puts technological opportunities in the center of the analysis

[12] An example is when the traditional vertical oil drilling technique was replaced by horizontal drilling, making it possible to approach a reservoir from any angle and hence drain it more thoroughly (Bohi, 1999).

[13] An example from the coal industry is the development of the longwall mining, which made it possible to more efficiently exploit deeper and thinner seams of coal (Darmstadter, 1999).

rather than changes in firm and consumer behaviors. Unlike other work in the area, technological opportunities are modeled explicitly and determined endogenously. Rational innovators choose between two basic strategies: to carry out incremental or drastic innovations. The choice depends on which innovation gives the highest expected profit. During periods of normal activities, rational entrepreneurs use the existing technological opportunity to make non-revolutionary, incremental innovations. The technological opportunities are limited by the prevailing paradigm, so as the opportunities becomes exhausted, profits and economic growth decrease. Eventually, profits from incremental activities fall below the expected profits from the revolutionary, drastic innovations. This shifts the interest of the entrepreneurs, and the cluster of drastic innovation activities introduces a new technological paradigm with new technological opportunities. Once again incremental innovation becomes profitable. It is hence through the incremental innovations that the drastic innovation diffuses into the economy.

3 THE RESOURCE OPPORTUNITY MODEL

An important difference between the dynamics of technology as presented in Olson's general technological opportunity model and the ROM presented here is, as mentioned, the driving force of technological development and the effect of technology on resources. In the previous case it was the scarcity of technological opportunities that created incremental innovation constraints and drove the economy into a shift, while it is the scarcity of resources *or* technological opportunities that create incremental innovation constraints in this model. The resource stock is a rival good needed for production and consumption outside the resource sector, and therefore always tends to decline. Because of this complementarity between resources and production, the resource stock determines the size of the market in which incremental innovations can be applied. Hence, the market for incremental innovations continuously shrinks until a drastic innovation creates new resources and technological opportunities. Note that both these scarcities are only indirectly driving the technological changes by their effects on the entrepreneurs' expected profits from incremental versus drastic innovations.

We begin by presenting the dynamics of technological opportunities. We then describe the resource stock dynamics and its connections to innovations depending on the type of innovation in that period. After that, we look at the changes in innovation profits, which determine whether innovations are incremental or drastic in the following period. Finally, a simple growth function of the natural resource sector is presented. Since an analytical solution of the model would be intractable, we will present the result using simulations in Section 4.

3.1 Technological Opportunities

There are three fundamental variables of technology: A_t, B_t and D_t.[14] A_t is the technology stock, or the set of all known technological ideas at *t*. B_t is the technological opportunities, and D_t is the success of the drastic innovation in terms of increase in the amount of technological opportunities. The knowledge stock evolves in the following way. A technological opportunity exists if it is possible to connect two technologically close ideas. By connecting two ideas you create a new idea that in turn can be used for new combinations. These unions of old ideas are the incremental innovations and they systematically add new knowledge and thereby increase A_t**;** but at the same time they decrease the technological opportunities left to explore, B_t. Hence, at each point in time there is a stock B_t, the technological opportunity, which is the stock of potential ideas left to exploit until A_t is maximized under the current paradigm.

As B_t becomes close to exhaustion, entrepreneurs realize that the profits from incremental innovations are coming to an end, and when these profits drop to the level of expected profits from the more uncertain drastic innovations, the entrepreneurs switch over to these activities instead. This phenomenon can be described as follows. Apart from incremental and drastic innovations there is the third component in the technological advancement - potential innovations. These ideas outside A_t, regarded as irrelevant, do not directly contribute to new knowledge since they do not have any

[14] See Olsson (2000, 2001), on which this section is based, for a more extended discussion and a set theory approach of the innovation dynamics.

immediate commercial value. For this new knowledge to be used as normal science it has to be connected to the old knowledge, A_t, by a drastic innovation, D_t. As mentioned above, entrepreneurs turn to drastic innovation activities when there is a small B_t left to explore by incremental innovations. A successful drastic innovation that connects a potential innovation with A_t, introduces new technological opportunities and a new B_t can be explored. This is called a technological paradigm shift and some of the old anomalies, the potential innovations, are now included in the normal science stock A_t. Definition 1 gives a formal definition of a technological paradigm shift.

Definition 1 If $B_t > B_{t-1}$ then a *technological paradigm shift* has occurred at *t*.

After a technological paradigm shift a new period of systematic incremental innovations begins.

Let us assume that $\phi_t = 1$ in a period of incremental innovations, and $\phi_t = 0$ in a period of drastic innovations.[15] Note that a period could be seen as a period longer than a year.[16] As mentioned, entrepreneurs have a myopic behavior and form their decision only on the basis of the expected profits in the next period. If the profits from drastic innovations are higher than the profits from incremental innovations, all entrepreneurs shift their efforts to drastic innovation activities that period. The determinants of ϕ_t will be further discussed in Section 3.3. The two sources of change in B_t, namely (i) incremental innovations that decrease B_t and (ii) drastic innovations that increase B_t, can formally be described as in Equation 1.[17]

$$B_t = B_{t-1} - \phi_t \delta B_{t-1} + (1 - \phi_t) D_t \tag{1}$$

[15] The assumption that only one type of technological innovation takes place at the same time is a simplification to reduce the complexity of the model.

[16] Hence, a period of drastic innovations may also include the possible downturn in the economy before the new technological opportunities are adopted. This paper will however not model this explicitly.

[17] X_t refers to the stock of X in the end of period t. Therefore, X_{t-1} is the stock available for use in the beginning of period *t*.

Thus, during periods of incremental technological progress, the stock of technological opportunities declines according to $B_t - B_{t-1} = -\delta B_{t-1}$, where δ is a measure of the capacity of society to exploit intellectual opportunities, i.e. the ability to innovate. δ is mainly a function of the number of innovators and the human capital level, but also of underlying institutions such as the educational system, corporate laws and the general attitude towards rationalism and scientific curiosity. δ is modeled as a constant, and since B_t decreases every period of normal science the entrepreneurs get less and less output from incremental activity.

During periods of drastic innovations $B_t - B_{t-1} = D_t$, i.e. the paradigm shift increases the technological opportunities with the random variable D_t, which can be used for incremental innovations in the next period. $E_{t-1}(D_t) = f(\delta, A_{t-1})$ describes the expected technological "success" of the drastic innovation and increases in both δ and A_{t-1}. Hence, the periods of incremental innovations are highly predictable while the outcome of a paradigm shift is not.

Equation 2 describes the dynamics of the knowledge stock.

$$A_t = A_{t-1} + \phi_t \delta B_{t-1} \qquad (2)$$

During periods of incremental innovation the knowledge stock increases with the amount of technological opportunities that are turned into new innovations ($A_t - A_{t-1} = \delta B_{t-1}$). During periods of drastic innovations the knowledge stock is constant ($A_t - A_{t-1} = 0$). Even though there are new technological opportunities created by a drastic innovation, they can only be turned into new knowledge during a period of incremental innovations.

We will now turn to the resource stock and see how its dynamics are connected to the waves of technology, and how this in turn affects economic growth. We are interested in the knowledge and technological opportunities related to the natural resource sector, so in the rest of this paper A_t and B_t will refer to these more specific stocks. As we will see, δ and D_t are crucial determinants for long-term resource availability and economic growth.

3.2 Resource Stock Dynamics

In the ROM, a paradigm shift is induced either by a small B_t or by a small familiar resource stock, S_t. We know about the dynamics of B_t, but what determines changes in S_t? During both incremental and drastic innovation periods there is extraction determined by old knowledge, and hence S_t decreases independent of technological changes in the natural resource sector in that specific period. The effects of technological changes on S_t are dependent on the type of innovation period, i.e. on ϕ_t. The dynamics of S_t are presented in Equation 3.

$$S_t = S_{t-1} - \mu A_t S_{t-1} + (1-\phi_t)\lambda D_t, \tag{3}$$

where μ is a parameter representing the effect of the technological level on the physical resource quantity and λ is a parameter representing the effect of drastic innovation on the physical resource quantity.[18] The extraction rate is a function of the stock of innovation at the end of period t, A_t. Using the expression for knowledge in Equation 2 we get:

$$S_t = S_{t-1} - \mu A_{t-1} S_{t-1} - \phi_t \mu \delta B_{t-1} S_{t-1} + (1-\phi_t)\lambda D_t. \tag{4}$$

Let us call the second term on the right hand side the knowledge stock effect, the third the incremental innovation effect and forth the drastic innovation effect. During incremental innovation periods ($\phi_t = 1$) we have $S_t = S_{t-1} - \mu A_{t-1} S_{t-1} - \mu \delta B_{t-1} S_{t-1}$, i.e.

[18] A more general model would take into account that old vintages of technology are of limited use when it comes to extraction of new familiar resources. This would imply that the effect of the aggregate technology on the resource stock is reduced as the technological level increases, i.e. $(\partial \mu_t / \partial A_t) > 0$. However, the assumption would still be that the final effect of aggregated technology on the extraction rate is positive.

the resource stock is continuously decreasing by the knowledge stock effect and the incremental innovation effect. As long as $\mu(A_{t-1} + \delta B_{t-1}) < 1$, the resource stock is not depleted during the period, i.e. $S_t > 0$.[19] During drastic innovation periods ($\phi_t = 0$) we have $S_t = S_{t-1} - \mu A_{t-1} S_{t-1} + \lambda D_t$. The resource stock still tends to decrease because of the extraction possible due to the knowledge stock from previous periods, but the stock may now show a net increase by the drastic innovation effect. This gives us a second definition:

Definition 2 If $S_t > (1 - \mu A_{t-1}) S_{t-1}$ then a *resource paradigm shift* has occurred at *t*.

A resource paradigm shift always follows a technological paradigm shift. However, because of the continued extraction through the knowledge stock effect, the resource stock does not have to increase (it decreases if $\mu A_{t-1} S_{t-1} > \lambda D_t$) as a consequence of a paradigm shift, even though technological opportunities always increase (see Definition 1).

The *knowledge stock effect*, $\mu A_{t-1} S_{t-1}$, affects the stock during both periods since there is extraction taking place regardless of the innovation activities. Since all incremental innovations add to the knowledge, the effect on the extraction rate is due to all previous innovations, i.e. the sum of innovations during $t \in [0, t-1]$. The knowledge stock, A_{t-1}, is non-decreasing over time but the knowledge stock effect may decrease if the resource stock decreases, since the marginal resource effect of knowledge is μS_{t-1}.

During periods of incremental innovations, extraction of S_t increases with the *incremental innovation effect*, $\mu \delta B_{t-1} S_{t-1}$. This effect on the extraction rate is due to the

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[19] This would imply that, since A_{t-1} is non-decreasing as t increases, all societies would end up with depleted resources at some t. Pessimists would maybe argue that this is the case: if technology that is powerful enough is available, the myopic behavior of individuals will lead to resource depletion. However, in this study we will, by choosing a small enough μ, only analyze the time interval where a society's innovation ability must be close to its maximum (δ close to 1) to reach such critical levels of technology. A country with a lower ability to innovate will reach these extraction rates after a longer time interval than included in this study, and then other precautionary principles may have arisen.

amount of incremental innovations during t, i.e. δB_{t-1}. First, improved extraction technology decreases the extraction costs per unit of the discovered resources, and thereby increases the rate of extraction. Second, discovery technology may improve with incremental innovation, lowering the costs of discovery per unit, which increases the transformation rate of undiscovered resources to discovered, and hence extractable, resources.[20] This negative effect of incremental innovation on S_t decreases during the period for two reasons. First, the rate of technological improvements decreases since the amount of technological opportunities decreases (less idea combinations possible). Second, the resource stock decreases and the remaining technological opportunities can only be applied to a smaller amount of resources. The marginal resource effect of technological opportunities is $\mu\delta S_{t-1}$, i.e. it decreases as S_{t-1} decreases.

During periods of paradigm shifts, there is a possible positive effect on S_t through the *drastic innovation effect*, λD_t. This is the result of the same entrepreneurial effort that simultaneously leads to an increase in the technological opportunity set of a size D_t, as described in Equation 1. S_t might increase for two reasons: (i) discoveries of more efficient technology make the already familiar resources last longer, and (ii) earlier potential resources become familiar resources. λ is a parameter representing the effect of the drastic innovations on the physical resource quantity.[21] The expected value of D_t is non-decreasing in time since it is a function of δ and A_{t-1}, and the knowledge stock is, as mentioned, non-decreasing in time.

To summarize, during the process of incremental innovation the familiar resource stock continuously shrinks. The familiar resource stock or the technological opportunities tend to get exhausted. At a certain point (determined by the relative profits from incremental and drastic innovation shown in the next section) the critical level of resources or technological opportunities is reached. Drastic innovations then become more profitable and increase not only the physical amount of familiar resources, but also

[20] The type of technological change that occurs during the incremental innovation period (extraction technology which decreases S_t or discovery technology which keeps S_t constant) depends on the expected profits from the two technological improvements. This creates short-run waves in the stock of discovered familiar resources not modeled in this paper.

[21] $\lambda \geq 0$ since the drastic innovation is induced to relax resource scarcity.

the technological potential to extract the familiar resources. With a successful drastic innovation, these effects take the natural resource sector away from the critical level and create new possibilities for incremental innovations.

Looking at a time period $t = 0$ to $t = T$, what determines if the resource stock has increased, decreased or remained constant is the relationship between the amounts added from drastic innovations and total extraction. Hence,

$$if \quad \lambda \sum_{0}^{T} (1-\phi_t) D_t(\delta, A_{t-1}) \quad \begin{cases} > \\ < \\ = \end{cases} \quad \mu \sum_{0}^{T} (A_{t-1} + \phi_t \delta B_{t-1}) S_{t-1} \quad then\, S_t \; is \begin{cases} increased \\ decreased \\ unchanged \end{cases} \quad at\; t = T \cdot \qquad (5)$$

The main reasons to analyze the interactions between technology and natural resources as dependent on the type of innovation, are the following: the types of innovation are induced by different kinds of scarcity, their success is dependent on different institutional arrangements and they result in different resource availability effects. Incremental technology is induced by straightforward “profit scarcity”, i.e. the continuous thrive for lower costs in a competitive market. Profit maximization is the indirect reason for drastic innovations as well, but the directly inducing mechanism is a low S_{t-1} or a low B_{t-1}. The success of incremental extraction or discovery technology depends mainly on non-revolutionary, entrepreneurial incentives. Drastic technology, however, is a public good with free-riding problems and high risks involved. When it comes to the resource availability effects, incremental technology decreases S_t while drastic innovations increases S_t.

3.3 Determinants of the Innovation Period

In the previous sections we have identified the three state variables B_t, A_t and S_t, whose equations of motion are shown in Equations 1, 2 and 4. We will now look closer at the profitability during the two innovation periods, depending on these variables. They are important since the expected profits determine the innovation direction during the next period, i.e. ϕ_t. Innovators are assumed to be risk neutral and their planning horizon is only one period ahead. They form their innovation decision on the information available at the beginning of the period and do not revise this decision until the next period.[22]

The total profit (Π_t) of the natural resource industry is $\Pi_t = p(S_{t-1} - S_t) + (1-\phi_t)\Pi_t^{ID}$, i.e. the profit from extraction where the costs are assumed to be zero, plus the direct profits from the drastic innovation in the case of a paradigm shift. This can also be expressed as profits from the knowledge stock effect (Π_t^A) and profits from innovations (Π_t^I): $\Pi_t = \Pi_t^A + \Pi_t^I$, where Π_t^I is either profits from incremental innovations (Π_t^{II}) or drastic innovations (Π_t^{DI}). $\Pi_t^A = p\mu A_{t-1}S_{t-1}$ where p is the price index of the resource that we for now assume is constant (see Section 5.2 for an extended price effect analysis). The extraction costs are, as mentioned, assumed to be zero since they are small compared to the costs of drastic innovations.

Since the profits from the knowledge stock effect are present independent of the type of innovation in that period, this effect is not of interest when it comes to determining the type of innovation activity. The determinant of the innovation activity looks as follows:

$$\Pi_t^I = \phi_t \Pi_t^{II} + (1-\phi_t)\Pi_t^{DI} \qquad \text{where} \quad \phi_t = \begin{cases} 1 & if \quad \Pi_t^{II} > \Pi_t^{DI} \\ 0 & if \quad \Pi_t^{II} \le \Pi_t^{DI} \end{cases}, \tag{6}$$

which means that Π_t^I is maximized with regard to ϕ_t, given the dynamics of the three stock variables B_t, A_t and S_t.[23] The profit maximization hence determines where the

[22] Hence, the decision is more of a "rule of thumb" based on what gives the highest profits at that moment, than a continuous profit maximization problem. In the long run these principles give the same result, but the discontinuous decision opens up the possibility of stagnation during a running period. A rationale for this is the confidence that, since new revolutionary discoveries have solved the depletion problems previously, the depletion possibility may be ignored. Moreover, decisions are path-dependent, and livelihood may therefore be dependent on a continuing unsustainable extraction rate. Finally, open access conditions may pertain in the natural resource sector making it optimal to deplete the resource completely.

[23] Note that it should have been the expected profits that were maximized, but we will simplify the analysis by assuming non-stochastic profits.

ability to innovate, δ, should be used, which is the same as determining where the innovators and their human capital should be allocated.

The profits from incremental innovations are determined by variables already known at $t-1$, so the expected profits equal the actual profits. Profits from incremental innovation evolve according to Equation 7.

$$\Pi_t^{II} = p\mu\delta B_{t-1}S_{t-1} \tag{7}$$

The incremental profits are simply the product of the extraction based on incremental innovations and the price level. Π_t^{II} will always be lower after periods of incremental innovation because of decreasing technological opportunities and resources, but is usually higher after a period of drastic innovations. These dynamics are more thoroughly explained in Appendix 1.

The profits from drastic innovations are highly simplified. In reality the actual profits are uncertain, and might even be negative, even though the expected profits might be constant.[24] However, in this model the expected profits equal actual profits as a simplification. This does not change the results except for leaving out the possibility of very high or strongly negative growth during the temporary drastic innovation period. The profits from drastic innovations can therefore be expressed as in Equation 8.

$$\Pi_t^{DI} = \overline{\Pi} \tag{8}$$

where $\overline{\Pi}$ is a constant. Note that the profit from a drastic innovation is the direct profit to the entrepreneurs, i.e. the profit from the patent. However, the increase in technological opportunities and natural resources from this drastic innovation, i.e. the success of the innovation, will produce extraction profits in future periods.

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[24] Olsson (2001) models the profits from drastic innovations as $\Pi_t^{ID} = R - c$, where R is random revenue, with zero and maximum profit equally likely, and c is a substantial cost. Hence, even though the expected profits from drastic innovations are constant, as in this paper, the actual profit might vary a lot and even become negative. These stochastic assumptions are, however, not needed for the purpose of this paper.

We can now determine the breakeven point between the different innovation periods by equating their profits, i.e. $\Pi_t^{II} = \Pi_t^{DI}$. The product of the stock of familiar resources and the technological opportunities left at this breakeven point is a constant $(SB)^*$ and is described in Equation 9.

$$(SB)^* = \frac{\overline{\Pi}}{p\mu\delta} \tag{9}$$

The breakeven point for the familiar resource stock increases with profits from drastic innovations, but decreases with the price of the resource, the effects on the quantity of resources from incremental innovations and the capability of turning technological opportunities into innovations, since these decrease the profits from incremental innovations. Interestingly, the shift can be induced, and thus generate more familiar resources, even in a situation with abundant resources, if there is a lack of technological opportunities. This is the case of a *technological opportunity induced shift*. This shift can however be delayed because of a large resource stock, since even small progresses in incremental technology give high pay-offs with abundant resources. On the other hand, if there is a small stock of resources a shift may occur even if there are a lot of technological opportunities. In this case we have a *resource induced shift*. This is derived logically from the assumption that profits from incremental innovations in the natural resource sector are dependent on how much resources are left on which to apply the new technology.

3.4 Economic Growth

Income growth, g_t, for the natural resource sector is presented in Equation 10 and is simply defined as the proportional rate of change in profits in this sector. As we will see, the growth rate is mainly determined by the changes in the extracted amount of resources, but also by the direct profit in the case of a drastic innovation.

$$g_t = \frac{\Pi_t - \Pi_{t-1}}{\Pi_{t-1}} \tag{10}$$

Assuming that we had drastic innovations in period $t-1$ ($\phi_{t-1} = 0$), the growth rates in period t can be described as in Equation 11 and 12. Assuming instead that we had incremental innovations in period $t-1$ ($\phi_{t-1} = 1$), the growth rate in period t can be described as in Equation 13 and 14. g_t^{II} is the growth rate if there are incremental innovations at t ($\phi_t = 1$), and g_t^{DI} is the growth rate if there are drastic innovations at t ($\phi_t = 0$).[25]

$$g_t^{II}(\phi_{t-1} = 0) = \frac{p\mu[A_{t-2}(S_{t-1} - S_{t-2}) + \delta B_{t-1}S_{t-1}] - \overline{\Pi}}{p\mu A_{t-2}S_{t-2} + \overline{\Pi}} \tag{11}$$

$$g_t^{DI}(\phi_{t-1} = 0) = \frac{p\mu A_{t-2}(S_{t-1} - S_{t-2})}{p\mu A_{t-2}S_{t-2} + \overline{\Pi}} \tag{12}$$

$$g_t^{II}(\phi_{t-1} = 1) = \frac{A_t}{A_{t-1}}\frac{S_{t-1}}{S_{t-2}} - 1 \tag{13}$$

$$g_t^{DI}(\phi_{t-1} = 1) = \frac{S_{t-1}}{S_{t-2}} - 1 + \frac{\overline{\Pi}}{p\mu A_{t-1}S_{t-2}} \tag{14}$$

The growth rate from a drastic innovation period to an incremental innovation period, $g_t^{II}(\phi_{t-1} = 0)$, is expected to be large since we know the drastic innovation was successful.[26] $\phi_{t-1} = 0$ means that Equation 4 gives $S_{t-1} - S_{t-2} = -\mu A_{t-2}S_{t-2} + \lambda D_{t-1}$ and Equation 1 gives $B_{t-1} = B_{t-2} + D_{t-1}$. The successful drastic innovation in the preceding period, i.e. the large D_{t-1}, therefore induces substantial increases in $S_{t-1} - S_{t-2}$ and B_{t-1}. Hence, as long as the profit from the preceding drastic innovation is not extremely large, the growth potential will be large for the incremental innovation period.

[25] See Appendix 2 for more detailed calculations on the growth rates and the conditions for positive or negative growth.
[26] An unsuccessful drastic innovation would be followed by another drastic innovation period.

The growth rate from one drastic innovation period to another drastic innovation period, $g_t^{DI}(\phi_{t-1}=0)$, is small. As mentioned, $S_{t-1}-S_{t-2}=-\mu A_{t-2}S_{t-2}+\lambda D_{t-1}$ if $\phi_{t-1}=0$. With an unsuccessful drastic innovation at $t-1$, which is the case when period t is also a drastic innovation period, the increase in the resource stock is very small. The knowledge stock effect might even outweigh the innovation effect on the resource stock. Hence, growth might be both positive and negative, but in both cases the rate is small.

The growth rate from one incremental innovation period to another incremental innovation period, $g_t^{II}(\phi_{t-1}=1)$, is positive if the percentage increase in knowledge is larger than the percentage decrease in the resource stock during the incremental innovation period, and vice versa. This depends to a large extent on the choice of parameters, since $(A_t/A_{t-1})=1+\delta B_{t-1}/A_{t-1}$ and $(S_{t-1}/S_{t-2})=1-\mu A_{t-1}$, if $\phi_t=1$ (see Equations 2 and 3).[27] However, we do know that during a time interval of incremental innovation periods the growth rate will decrease, since the positive effect on the knowledge stock decreases with decreases in B_{t-1}, and the negative effect on the resource stock increases with increases in A_{t-1}. However, this decrease in the growth rate becomes smaller and smaller every incremental innovation period since there will be less and less technological opportunities and resources.

The growth rate from an incremental innovation period to a drastic innovation period, $g_t^{II}(\phi_{t-1}=1)$, is expected to be small, especially if the extraction rate was large in the preceding incremental period.[28] Since $(S_{t-1}/S_{t-2})=1-\mu A_{t-1}$ if $\phi_t=1$, we know that the probability of a drastic innovation to increase the growth rate decreases over time, since the knowledge stock (and hence the extraction rate) increases over time.

The cumulative income in the natural resource sector during a period from $t=0$ to $t=T$, Y_T, is the sum of profits as is shown in Equation 15.

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[27] Remember that $A_{t-1}=A_{t-2}+\delta B_{t-2}$, i.e. the resource stock decreases both by a knowledge effect and an innovation effect.

[28] In that case the profits level during the preceding period might have been substantial even though the expected profit for a new incremental innovation period is very low.

$$Y_T = \sum_{t=0}^{T} \Pi_t = \sum_{t=0}^{T} \left\{ p\mu\left(A_{t-1} + \phi_t \delta B_{t-1}\right) S_{t-1} + \left(1 - \phi_t\right)\overline{\Pi} \right\} \tag{15}$$

This income stock is highly correlated with the total extraction of S_t. Y_T is of interest since it indicates the potential value of the resource sector during a certain time interval.

4 SIMULATION RESULTS

In this section we will analyze the results from the dynamics presented in the previous sections by simulations, and discuss the possibilities of stagnation. The effects depend, to a large extent, on the uncertain outcome of the paradigm shift, i.e. on the success (D_t) of the drastic innovation period.[29] Figure 2 gives an example of how the dynamics of S_t might look depending on the outcome of D_t (see Equation 4), and Figure 3 illustrates the cycles of g_t (see Equations 11, 12, 13, and 14) during the same period.[30] Notice first that the drastic innovation occurs at different levels of the resource stock, i.e. the value of S^* changes depending on the amount of technological opportunities left at that moment. This reflects the fact that a drastic innovation is either technological opportunity induced or resource induced. We will first analyze what happens during a period of drastic innovations, and then the implication of this on the following period.

If the drastic innovation was successful, in the sense that it contributed enough to the technological opportunities, B_t, and to the resource stock, S_t, by a large D_t, the economy would be saved from the critically low levels of S_t and a new era of economic growth would be starting (see Periods 0, 2, 5, 10, 13, and 16 in Figure 2). What happens is that D_t increases S_t directly by λD_t, and the higher the B_t, the lower the critical level S^*, since $S^* = \overline{\Pi} / p\mu\delta B_{t-1}$. Both of these effects increase the possibilities for

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[29] Note that the cycles would prevail if D_t was assumed to be deterministic. The cycles would be more uniform, only increasing over time because of the increase in A_{t-1}.

[30] For all simulations we have used $\delta = 0.5$, $\mu = 0.02$, $\lambda = 500$, $p = 10$, $\overline{\Pi} = 100$, $B_0 = 2$, $S_0 = 1000$, $A_0 = 10$ and $Y_0 = 10000$. $D_t = RAND(1 + A_t/1000)(1 + 10\delta)$ where $RAND$ is a random number between 0 and 1. Alternative assumptions will be discussed in Section 5.

incremental innovations.[31] If, however, the drastic innovation only led to a small paradigm shift, then S_t would increase only slightly and maybe not even exceed the new lower critical level S^* (see Period 9). In that case the paradigm shift was not large enough to compensate for the decrease in S_t due to the knowledge stock effect (which continues independent of the type of innovation period).

Figure 2: The dynamics of the familiar resource stock and drastic innovations. $\delta = 0.5$ and $(BS)^* = 100000$.

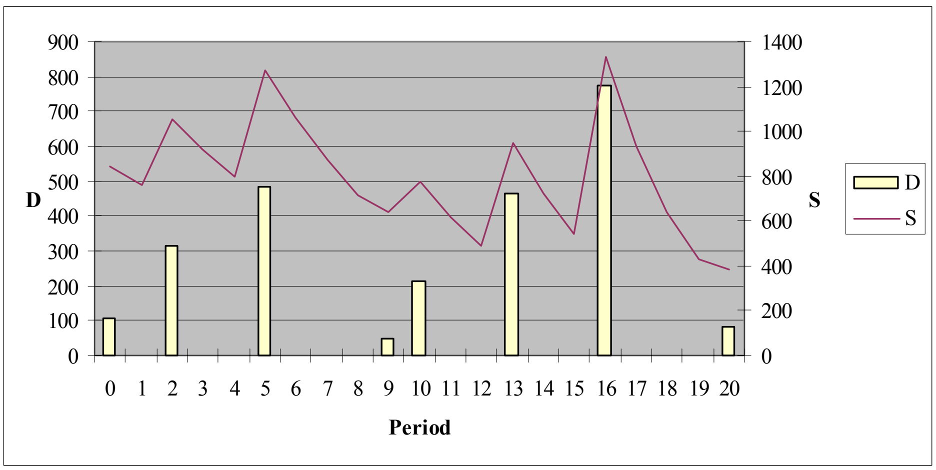
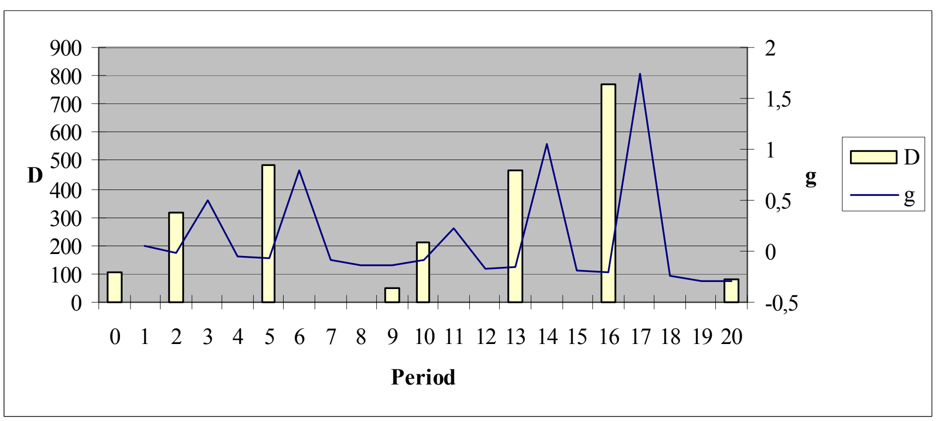


Figure 3: Economic growth in the natural resource sector and drastic innovations.



[31] During the period of incremental innovations, S_t decreases and S^* increases, "closing the gap" for these kinds of innovations.

The profit from the drastic innovation is independent of the success of the innovation, since this profit is assumed to be constant. Hence, the growth rate depends on the preceding period's profits in relation to this constant (see Equation 12 and 14). As mentioned in the previous section, both these growth rates are most often small.

So, what happens in the period following a drastic innovation period? The economy continues with a period of incremental innovations if $B_{t-1}S_{t-1} > (BS)^*$, since incremental innovations then have higher expected profits.[32] This incremental innovation period leads to a new drastic innovation once the critical level $(BS)^*$ is reached again (see Period 1, 3-4, 6-8, 11-12 and 17-19). The endogenously induced growth rate following a successful drastic innovation is high, since the new B_t and S_t speed up extraction (see Equation 11). The growth rate then decreases for every new incremental innovation period, since there are decreasing returns both with respect to B_t and S_t (see Equation 13).

If, however, $B_{t-1}S_{t-1} < (BS)^*$, there would be a new period of drastic innovations immediately after the preceding one, since expected profits from drastic innovations still are higher than profits from incremental innovations. Hopefully this new drastic innovation is more successful so that a period of incremental innovations is profitable again. However, since there is always extraction in terms of the knowledge stock effect, $B_{t-1}S_{t-1}$ continues to decrease during the drastic innovation periods and the gap between the actual level of $B_{t-1}S_{t-1}$ and the critical level $(BS)^*$ increases.[33]

The evolution of A_t and Y_t (see Equations 2 and 15) during the period illustrated above is presented in Figure 4. A_t increases with δB_{t-1} during periods of

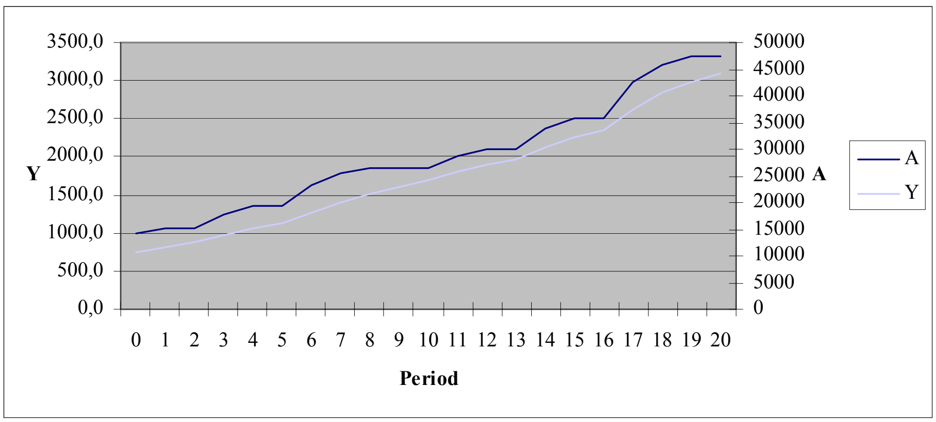
[32] However if the extraction rate is very high, there might be a case where the resource stock is depleted and economic growth in the natural resource sector ceases. This is called the *extraction stagnation case* and is discussed further in Section 5.1.

[33] Low expected success of drastic innovation therefore increases the possibilities of getting trapped in a situation where the needed size of the drastic innovation increases, making it harder and harder to exceed S^* again. This process may continue until S_t is exhausted and the growth rate in the natural resource industry drops to zero This is called the *technological stagnation case* and is discussed further in Section 5.1.

incremental innovation and is constant during drastic innovation periods. Y_t increases during both types of periods.[34]

Remember that a higher A_t affects both the expected success of the drastic innovation and the knowledge stock effect. We therefore have a non-decreasing effect on the probability of drastic innovation success and the stock effect over time (see the increasing trend of D_t in, for example, Figure 2). The size of these intertemporal effects depends to a large extent on the ability to innovate, δ, as we will see in the next section.

Figure 4: The dynamics of the knowledge stock and the income stock.



5 ANALYSIS

5.1 Effects of Changes in the Innovation Ability

A crucial variable is δ, the ability to turn technological opportunities into innovations. Assume that δ differs in societies, for example, because of different educational systems. What would happen, during a longer period, to a given resource, knowledge and income stock, depending on the societies' δ? A direct effect of a higher δ is a

[34] Remember that Y is cumulative income, or profits in the natural resource sector. Hence, even if the total profits, Π, decreases from one period to another, i.e. $g < 0$, Y will always increase.

higher rate of incremental innovations, given the technological opportunities. This also means that the cumulative effect on A_t increases. Both of these effects increase the depletion rate of the resource stock, S_t. Technological opportunities are exploited at a faster rate, which increases the rate of extraction in each period, and the higher A_t intensifies the knowledge stock effect over time. Hence, an increased δ is in this sense negative for the familiar resource stock.

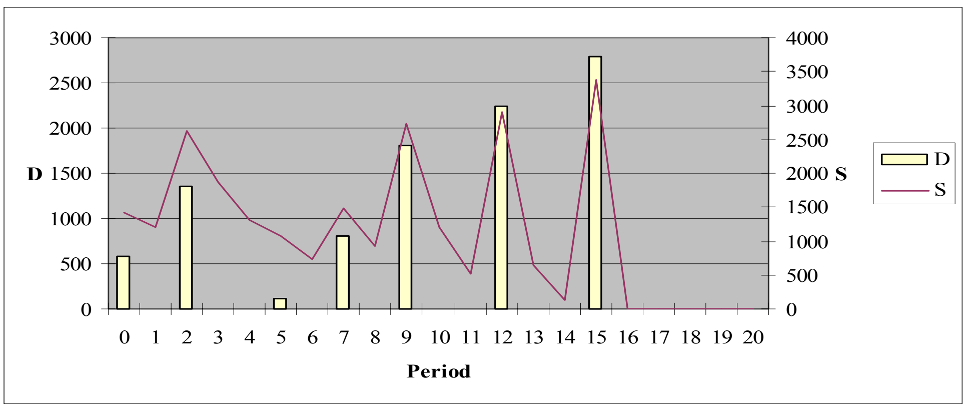
There are however positive effects as well. A higher δ increases the probability of a drastic innovation success (D_t), increasing the amount of technological opportunities each period. The probability of success increases also over time since δ also affects A_t, which is non-decreasing.

Hence, regardless of a society having a low or a high δ, we could expect a sustainable resource stock, as long as the drastic innovations are fruitful enough to compensate for the increased extraction rate (see Equation 5). The only difference is that the frequency and amplitude of the cycles with a high δ are larger than with a low δ. There are however other important differences in the two cases. As mentioned, since the technological opportunities add to the knowledge stock while being used up, an increased δ also increases A_t. Moreover, even though the sustainability of the resource stock is probable in both cases, the total amount extracted and hence the cumulative income Y_t, are larger with a high δ. Therefore, in a society with a high δ we could expect a sustainable resource stock with high fluctuations, a large knowledge stock and a high level of cumulative income (because of a large total extraction). In a society with a low δ there could also be a sustainable resource stock but with low fluctuations, a small knowledge stock and a low cumulative income (because of a small total extraction).

The analysis above referred to the increases or decreases of δ in a certain interval. Let us instead turn to the extreme cases. A δ that is too high drives the resource sector to the *extraction stagnation* case, and a δ that is too low drives the sector into the *technological stagnation* case. With a very high δ, the possibility of unsuccessful drastic innovations becomes negligible, especially over time, since A_t

increases dramatically. However, the speed of depletion of S_t also increases drastically, both because of the direct effect on incremental innovations and the indirect effect on the knowledge stock effect, and hence the probability of extraction stagnation increases. These effects are functions of the amount of resources left from the previous period. Hence, even though the resources decrease drastically during the prevailing period, the rate of extraction is not adjusted, which makes the depletion outcome possible. Figure 5 gives an example of resource exhaustion in the short run because of a high δ.[35] The amount of S_t and B_t are large in Period 15, because of a successful drastic innovation, and through a myopic decision of a large extraction rate, stagnation is a fact in Period 16. Hence, $\mu(A_{t-1} + \delta B_{t-1}) > 1$ for $t = 16$.

Figure 5: The dynamics of the familiar resource stock in the extraction stagnation case. $\delta = 0.95$ and $(BS)^* = 52632$.



With a very low δ the probability of a successful drastic innovation is also very low, and hence the probability of technological stagnation increases. This leads to a large number of drastic innovations, since the probability for a paradigm shift to compensate for the decrease in S_t (due to the knowledge stock effect) is very small, i.e. the probability of a new drastic innovation period is high. Since no technological opportunities are used up during drastic innovation periods, there is no increase in A_t

[35] Notice the different scales of D_t and S_t compared to Figure 2.

which otherwise would have increased the probability of a larger D_t. This in turn may have compensated for the increased gap between the higher $(BS)^*$ and the lower $B_{t-1}S_{t-1}$. Figure 6 gives an example of a declining resource stock in the long run because of a low δ, i.e. the case of $\lambda\sum_0^T(1-\phi_t)D_t(\delta, A_{t-1}) < \mu\sum_0^T(A_{t-1}+\phi_t\delta B_{t-1})S_{t-1}$.[36]

Figure 6: The dynamics of S_t in the technological stagnation case. $\delta = 0.1$ and $(BS)^* = 500000$.

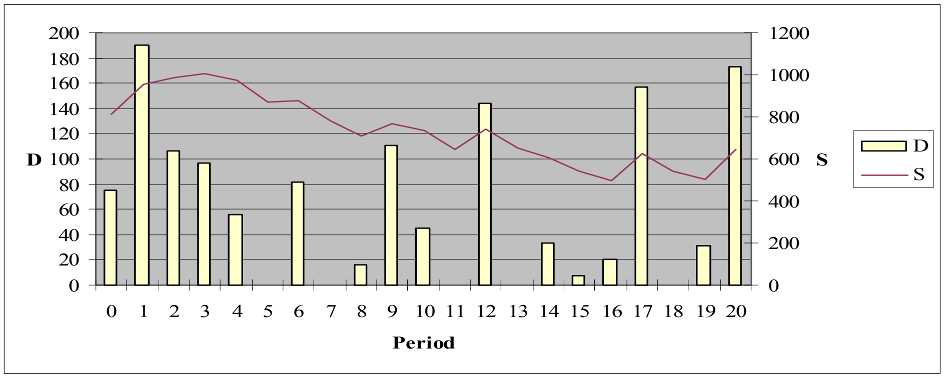


Figure 7 illustrates the effects of different δ on the change in the stock of familiar resources, knowledge and cumulative income over 20 periods. Note that it is the change in the stock over the whole period that is examined. Hence, as long as the value is larger (smaller) than one, the stock has grown (declined). The initial stocks are the same in all cases. At a low δ the change in S_t is below 1, i.e. the resource stock has decreased significantly because of the high probability of technological stagnation.[37] The outcome of an unsuccessful drastic innovation is probable throughout the period, and the resource stock is driven towards depletion in the long run by the knowledge stock effect and the incremental innovation effect during the few periods of incremental innovation, even though these effects decrease as S_t decreases. Note that since δ is low, the depletion rate is also low, which means that the stock might not be completely

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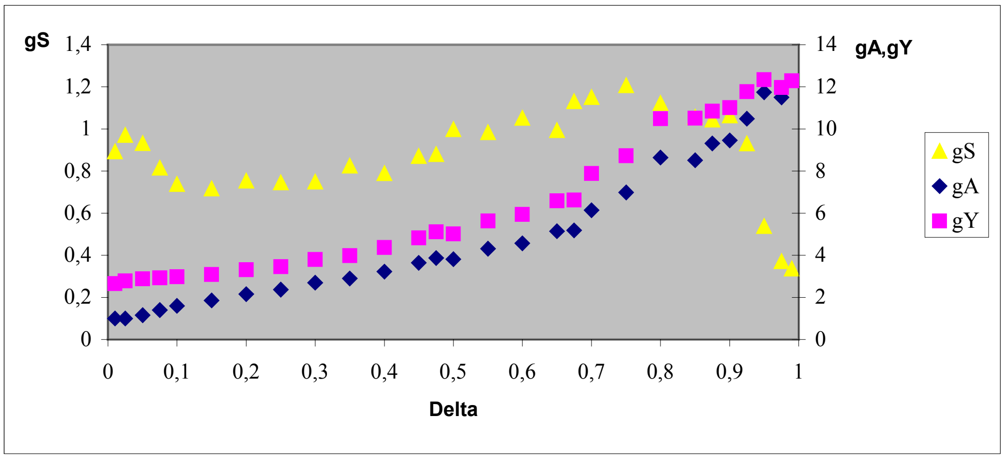
[36] Again notice the different scales of D_t and S_t compared to Figure 2 and Figure 5.

[37] At extremely low levels of δ there are only drastic innovations, since $(BS)^*$ is so much higher than the initial stock of $B_{t-1}S_{t-1}$.

exhausted after the 20 periods. Neither A_t nor Y_t, which is mainly determined by the total extraction, increases much because of restricted amounts of technological opportunities. Then there is the intermediate interval where the resource stock is unchanged or increased at the end of the period. An increased δ means a sustainable (or even increasing) S_t, although with intensified cycles, and larger stocks of both A_t and Y_t. At very high levels of δ, S_t approaches zero, reflecting the high probability of resource exhaustion in the short run because of too intensive extraction.

Figure 7: Effects of the innovation ability on the growth of the familiar resource stock, the knowledge stock and the cumulative income.



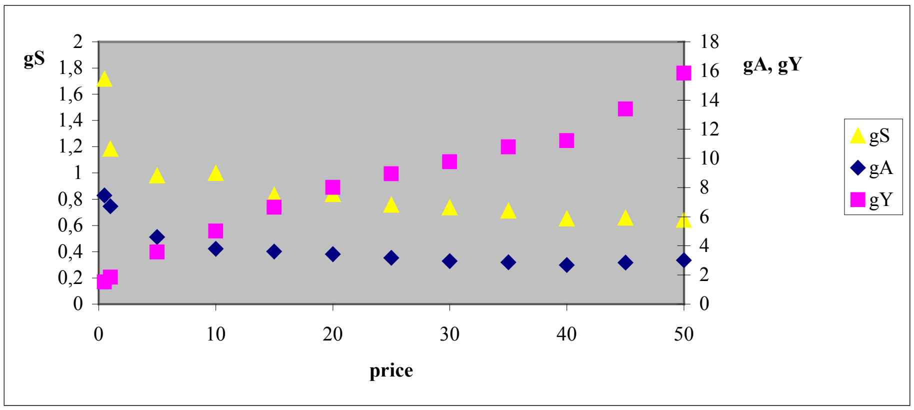
For each value of δ we run 20 simulations, and the points in the figure represent the average value from these. $gX = X_T / X_0$ represents the change in the stock during the whole period, where $X = A, Y, S$, i.e. the stock of knowledge, income or familiar resources. X_0 is the stock at Period 0, which is the same in all simulations, and X_T is the average of the last three periods.

5.2 Effects of Changes in the Resource Price

In the basic analysis we treated the resource price as constant. However, the price may be higher because of a higher demand that may be a result of, for example, a large population or a high general technological level, which gives a high resource demand per capita. The price may also be lower because of a low demand caused by structural changes decreasing the importance of the resource sector, or because of the development of more resource efficient end-use technologies. In this section we will first discuss how the price level that is still assumed to be constant throughout the 20 periods, affects the stocks and the total extraction. Then we will discuss how the resource cycles would be affected if we assumed that the price of a natural resource left in the ground increased as the resource becomes exhausted, i.e. $\partial p_t / \partial S_t < 0$.

Figure 8 shows the effect on the resource and knowledge stock and the cumulative income over 20 periods, depending on the price of the familiar resources.

Figure 8: Effects of price changes on the growth of the familiar resource stock, the knowledge stock and the cumulative income.



For each value of p_t we run 20 simulations, and the points in the figure represent the average value from these. $gX = X_T / X_0$ represents the change in the stock during the whole period, where $X = A, Y, S$, i.e. the stock of knowledge, income or familiar resources. X_0 is the stock at Period 0, which is the same in all simulations, and X_T is the average of the three last periods.

The familiar resource stock decreases with the price. The critical resource level at which it is worth switching to the insecure drastic innovations, is lower since even small extracted amounts may pay off with the high price. The extraction rate is not affected by a higher price, but the periods of incremental innovations are longer. Total extraction during the whole period may therefore decrease with a higher price level. This may help explain why the development of new resources or of new resource technologies is sometimes hard to induce by an increased price of the remaining resources. The continued extraction of these becomes more profitable. It is important to keep in mind that turning to new solutions in new paradigms is not in the option set of the innovators as long as the profits from innovations are not critically low.

Also when it comes to the knowledge stock and cumulative income, the price matters. A high price level decreases the search for a new paradigm, and the lack of an increase in technological opportunities dampens the increase in the knowledge stock. However, a high price increases the profits from extraction, even though the total extraction may decrease, and hence enforce the increase in the income stock.

But what happen if there are price changes between the 20 periods analyzed? According to Hotelling's rule the price of a resource increases as the resource decreases (Hotelling, 1931). This conclusion has been criticized not the least because of the induced resource efficiency technology in the rest of the society, and the entrepreneur's faith in incremental discovery technology, which dampens the increase in the price. However, accepting the Hotelling's rule, what would happen to the ROM? First of all, the critical level $(BS)^*$ would no longer be constant throughout the periods analyzed. The declining extraction as S_t and B_t decline during incremental innovations would increase the price, and the critical level would therefore decline. This means that the number of incremental innovation periods between paradigm shifts would increase. Since the lower S_t is compensated by a higher p_t, there are incremental profits to be made even though the amount extracted is low. Moreover, the possibility of a drastic innovation being unsuccessful increases, since even though it could cause S_t and B_t to increase, the critical level would also increase due to the lower price.

Hence, even though there might be a price change after each period, we would still have the cyclic pattern of natural resources. Also, even though the probability of an unsuccessful drastic innovation would increase because of increasing critical levels during drastic innovation periods, the incremental innovation opportunity created by a successful innovation would increase, because of declining critical levels during incremental innovation periods.

6 CONCLUSIONS

Cycles in the resource stocks have in previous models usually been explained by exogenous and random arrivals of new sources or innovations, or by the choice between extraction and innovation. The model in this paper introduces the technological opportunity thinking into natural resource modeling by the so-called Resource Opportunity Model, which provides a new explanation for the cyclic pattern of resource availability. The cycles are created by the natural resource sector's profit maximizing choice between the types of innovations: incremental or drastic. Incremental innovations are non-revolutionary, or complementary, innovations that make the drastic innovations diffuse into the production under decreasing returns. Drastic innovations are major breakthroughs that give new possibilities for incremental innovations.

Incremental innovations increase the efficiency of extraction and discovery of already familiar resources under the prevailing paradigm, which increase the rate of exhaustion. When the incremental innovation constraints, and hence profits from this kind of innovation, reach a critical level, drastic innovations become profitable. This shift to drastic innovations is induced either by scarcity of technological opportunities or scarcity of resources, and not only by resource scarcity as is often assumed in previous models.

A drastic innovation, a paradigm shift, increases the quantity of familiar resources, either by introducing an unexpected technology that improves the availability of already familiar resources, or by adding to the number of types of familiar resources. These two forces create a new familiar resource stock, offsetting the decreasing returns from incremental innovations, and enable continued extraction and economic growth. The expected success of this resource-creating innovation is not a constant as is often assumed in previous studies, but endogenously determined by the level of knowledge and innovation ability in the natural resource sector.

This way of modeling innovations in the natural resource sector results in a cyclic behavior of technological opportunities, resource abundance and economic growth, as long as the success of the drastic innovations is large enough compared to the levels of extraction. However, if there are too many unsuccessful paradigm shifts, the resource sector will collapse because of technological stagnation and drive the sector toward long-run resource exhaustion. Stagnation also becomes the case when the speed of extraction during an incremental innovation period is too high, leading to short-run resource exhaustion. Generally, however, an increased level of ability to turn technological opportunities into innovations does not affect the sustainability of the resource stock, even though the fluctuations increase. The knowledge stock increases with the innovation ability and so does the cumulative income, since the total amount of extraction increases. However, an innovation ability level that is too low might drive the sector into technological stagnation, and resource exhaustion in the long run, and a level that is too high might drive the sector into extraction stagnation and resource exhaustion in the short run.

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APPENDIX 1

To make the dynamics clearer we will look at how the level of Π_t^{II} is determined by the nature of innovation in the previous period, $t-1$. First we need to determine the level of B and S at $t-1$, depending on the nature of innovation at $t-2$. By substituting B_{t-1} and S_{t-1} into the expressions in Equation 7 we get the profits from incremental innovation at t as follows:

$$\Pi_t^{II} = \begin{cases} p\mu\delta[(1-\delta)B_{t-2}][S_{t-2} - \mu A_{t-2}S_{t-2} - \mu\delta B_{t-2}S_{t-2}] & \text{if increm. innov. at } t-1 \\ p\mu\delta[B_{t-2} + D_{t-1}][S_{t-2} - \mu A_{t-2}S_{t-2} + \lambda D_{t-1}] & \text{if drastic innov. at } t-1 \end{cases}$$

The profits from extraction at t are for sure lower than at $t-1$, if $t-1$ was an incremental innovation period. A period of drastic innovations at $t-1$ can give positive effects on the profits if the drastic innovation was successful enough, i.e. if D_t was large enough to outweigh the knowledge stock effect. In this last case, we see that a paradigm shift both increases the technological opportunities, B, and the physical quantity of resources, S.

APPENDIX 2

Equation 10 and 6 gives:

$$g_t = \frac{\Pi_t - \Pi_{t-1}}{\Pi_{t-1}} = \frac{\left(\Pi_t^A + \phi_t \Pi_t^{II} + (1-\phi_t)\Pi_t^D\right) - \left(\Pi_{t-1}^A + \phi_{t-1}\Pi_{t-1}^{II} + (1-\phi_{t-1})\Pi_{t-1}^D\right)}{\left(\Pi_{t-1}^A + \phi_{t-1}\Pi_{t-1}^{II} + (1-\phi_{t-1})\Pi_{t-1}^D\right)}.$$

Drastic innovation period followed by an incremental innovation period.

Assume $\phi_{t-1} = 0$, and $\phi_t = 1$ then

$$g_t^{II}(\phi_{t-1} = 0) = \frac{\left(\Pi_t^A + \Pi_t^{II}\right) - \left(\Pi_{t-1}^A + \Pi_{t-1}^D\right)}{\left(\Pi_{t-1}^A + \Pi_{t-1}^D\right)} = \frac{\left(p\mu A_{t-1}S_{t-1} + p\mu\delta B_{t-1}S_{t-1}\right) - \left(p\mu A_{t-2}S_{t-2} + \overline{\Pi}\right)}{\left(p\mu A_{t-2}S_{t-2} + \overline{\Pi}\right)}.$$

Following Equation 2 we know that $A_{t-1} = A_{t-2}$ if $\phi_{t-1} = 0$. Hence,

$$g_t^{II}(\phi_{t-1} = 0) = \frac{p\mu[A_{t-2}(S_{t-1} - S_{t-2}) + \delta B_{t-1}S_{t-1}] - \overline{\Pi}}{p\mu A_{t-2}S_{t-2} + \overline{\Pi}} \qquad \text{(Equation 11)}$$

$$g_t^{II}(\phi_{t-1} = 0)\begin{cases} > 0 \\ < 0 \end{cases} \quad if \quad p\mu[A_{t-2}(S_{t-1} - S_{t-2}) + \delta B_{t-1}S_{t-1}]\begin{cases} > \\ < \end{cases} \overline{\Pi}.$$

Drastic innovation period followed by a drastic innovation period.

Assume again that $\phi_{t-1} = 0$ but $\phi_t = 0$, then

$$g_t^{DI}(\phi_{t-1} = 0) = \frac{(\Pi_t^A + \Pi_t^D) - (\Pi_{t-1}^A + \Pi_{t-1}^D)}{(\Pi_{t-1}^A + \Pi_{t-1}^D)} = \frac{(\Pi_t^A + \overline{\Pi}) - (\Pi_{t-1}^A + \overline{\Pi})}{(\Pi_{t-1}^A + \overline{\Pi})} = \frac{p\mu A_{t-1}S_{t-1} - p\mu A_{t-2}S_{t-2}}{p\mu A_{t-2}S_{t-2} + \overline{\Pi}}.$$

Again we know that $A_{t-1} = A_{t-2}$. Hence,

$$g_t^{DI}(\phi_{t-1} = 0) = \frac{p\mu A_{t-2}(S_{t-1} - S_{t-2})}{p\mu A_{t-2}S_{t-2} + \overline{\Pi}} \qquad \text{(Equation 12)}$$

$$g_t^{DI}(\phi_{t-1} = 0)\begin{cases} > 0 \\ < 0 \end{cases} \quad if \quad S_{t-1}\begin{cases} > \\ < \end{cases} S_{t-2}.$$

Incremental innovation period followed by an incremental innovation period.

Assume now that $\phi_{t-1} = 1$ and $\phi_t = 1$, then

$$g_t^{II}(\phi_{t-1} = 1) = \frac{(\Pi_t^A + \Pi_t^{II}) - (\Pi_{t-1}^A + \Pi_{t-1}^{II})}{(\Pi_{t-1}^A + \Pi_{t-1}^{II})} = \frac{p\mu(A_{t-1} + \delta B_{t-1})S_{t-1} - p\mu(A_{t-2} + \delta B_{t-2})S_{t-2}}{p\mu(A_{t-2} + \delta B_{t-2})S_{t-2}}$$

$$= \frac{(A_{t-1} + \delta B_{t-1})S_{t-1}}{(A_{t-2} + \delta B_{t-2})S_{t-2}} - 1.$$

Following Equation (2) we know that $A_{t-1} = A_{t-2} + \delta B_{t-2}$ if $\phi_{t-1} = 1$, and $A_t = A_{t-1} + \delta B_{t-1}$ if $\phi_t = 1$. Hence,

$$g_t^{II}(\phi_{t-1} = 1) = \frac{A_t S_{t-1}}{A_{t-1}S_{t-2}} - 1. \qquad \text{(Equation 13)}$$

Moreover, Equation (3) gives us $\left(S_{t-1}/S_{t-2}\right)=1-\mu A_{t-1}$ and Equation (2) $\left(A_t/A_{t-1}\right)=1+\delta B_{t-1}/A_{t-1}$, if $\phi_t=1$. We therefore have

$$g_t^{II}\left(\phi_{t-1}=1\right)=\left(1+\delta B_{t-1}/A_{t-1}\right)\left(1-\mu A_t\right)-1.$$

Hence,

$$g_t^{II}\left(\phi_{t-1}=1\right)\begin{cases}>0\\<0\end{cases} \quad if \quad \left(1+\delta B_{t-1}/A_{t-1}\right)\left(1-\mu A_t\right)\begin{cases}>\\<\end{cases} \quad 1.$$

Incremental innovation period followed by a drastic innovation period.

Finally, assume again that $\phi_{t-1}=1$ but $\phi_t=0$, then

$$g_t^{DI}\left(\phi_{t-1}=1\right)=\frac{\left(\Pi_t^A+\Pi_t^D\right)-\left(\Pi_{t-1}^A+\Pi_{t-1}^{II}\right)}{\left(\Pi_{t-1}^A+\Pi_{t-1}^{II}\right)}=\frac{\left(p\mu A_{t-1}S_{t-1}+\overline{\Pi}\right)-p\mu\left(A_{t-2}+\delta B_{t-2}\right)S_{t-2}}{p\mu\left(A_{t-2}+\delta B_{t-2}\right)S_{t-2}}=$$

$$=\frac{A_{t-1}S_{t-1}}{\left(A_{t-2}+\delta B_{t-2}\right)S_{t-2}}+\frac{\overline{\Pi}}{p\mu\left(A_{t-2}+\delta B_{t-2}\right)S_{t-2}}-1.$$

Again we know that $A_{t-1}=A_{t-2}+\delta B_{t-2}$ if $\phi_{t-1}=1$, which gives,

$$g_t^{DI}\left(\phi_{t-1}=1\right)=\frac{S_{t-1}}{S_{t-2}}+\frac{\overline{\Pi}}{p\mu A_{t-1}S_{t-2}}-1. \qquad \text{(Equation 14)}$$

Finally, since $\left(S_{t-1}/S_{t-2}\right)=1-\mu A_{t-1}$ if $\phi_t=1$, we have

$$g_t^{DI}\left(\phi_{t-1}=1\right)=\frac{\overline{\Pi}}{p\mu A_{t-1}S_{t-2}}-\mu A_{t-1}.$$

Hence,

$$g_t^{DI}\left(\phi_{t-1}=1\right)\begin{cases}>0\\<0\end{cases} \quad if \quad \frac{\overline{\Pi}}{p\mu A_{t-1}S_{t-2}}\begin{cases}>\\<\end{cases} \quad \mu A_{t-1}.$$