Hartwick's Rule: A Policy Prescription or Description to Combat Energy Crisis?

Nurun Naher
Public Administration and Public Policy, Auburn University

Abstract

The research will reveal that Hartwick's rule, which was formulated as a prescription for resource-rich countries to convert their natural capital into produced capital forever and therefore enjoy a continuous level of consumption, is far from reality. This phenomenon is also supported by available statistics, which reveals that the majority of the countries in the top 40 countries (Natural Resource Reserve) have a significantly lower GDP. To demonstrate this, I used a research strategy that involved gathering data from 29 oil-rich countries and storing it in the WDI-World Bank for a period of 24 years (1995-2019). I've discovered that no resource-rich country has followed Hartwick's rule and accumulated the predicted amount of capital. However, in some resource-rich countries, the factor "Technological progress" has played an important role in narrowing down the difference between produced capital according to Hartwick's rule and produced capital according to the conventional rule. The research uses a rigorous empirical cross section analysis to explore the validity of leveraging technical development to improve the model, in addition to testing with different trends across resource-rich countries. The empirical findings also support the theoretical aspect of the paper stating that a country's total capital formation is not entirely dependent on its natural resource earnings, and that technological progress increases a country's total produced capital regardless of the amount of natural resource reserves it has.

Key words*:* Hartwick's Rule, exhaustible resources, sustainable development, weak sustainability

Hartwick rule: A Policy Prescription or description to combat energy crisis?

Economists always assume that resources are limited, and they try to come up with various models and regulations to make the most use of them. Natural resource management is critical for fueling economic activities throughout generations, as environmentalists are concerned that we are placing future generations at risk of diminishing supplies (Lee et al., 2021; Solow, 1974). Economists propose a solution to the problem of climate change by producing a reasonable quantity of pollution. Natural capital and manufactured capital are interchangeable in nature, according to the concept of weak sustainability. According to Hartwick (1977), based on Solow (1974), inter-generational equity has been preserved in such a way that the utility level remains at an optimal level and produces a constant level of consumption through generations (Hamilton et al, 2006; Hartwick, 1977; Solow, 1974; Solow; 1986;). While a sustainable environment has been a desired state around the world for the past few decades (Zuo et al., 2021), the Hartwick rule essentially validates the idea of weak sustainability. Given the necessity of maintaining nonrenewable resources for the sake of a healthy lifestyle for the general public, it is vital to investigate whether environmental restrictions genuinely add value to this occurrence. As a result, this study will attempt to determine whether the Hartwick rule was a good prescription for countries around the world to continue a sustainable development path after it was presented.

Because the Hartwick rule is based on the exchange of two forms of capital, this analysis will look into the validity of Hartwick's rule by looking at 29 resource-rich countries over a 24-year period (1995-2019). The study will determine what gross capital creation would have been in 2019 if resource-rich countries had implemented Hartwick's rule. Then, using the customary rule, the quantities for 30 nations will be compared to the calculated gross capital formation. Furthermore, the GDP (current US $) of each resource-rich country employed in this study will be compared to the present gross capital formation of those countries to see if there is a close relationship between the two. If a disparity exists, the study explains why it exists or why some resource-rich countries have higher GDP despite not following Hartwick's rule, as well as the component that is accountable for this event. The Solow-Hartwick model, in essence, implies that the population rate and technology remain constant, which is rarely the case in reality. As a result, the requirements are partially eased, and technological development is taken into account, resulting in a more general and fuller model. The above-mentioned question of how a small amount of investment to get a small amount of conversion of natural capital into produced capital still leads to a stable output of gross domestic product that can help to achieve a constant utility across generations is answered by this growth of technological progress. In addition, an OLS linear regression was used to empirically assess the effect of the network readiness index on the huge production of gross capital. The finding is also in line with the study's theoretical framework. The addition of technical advancement (here referred to as Network Readiness Index, 2019) boosts the model's overall relevance and fitness, explaining the majority of the variation in gross capital formation among countries, regardless of natural resource reserves.

Overall, this work adds to the current body of knowledge in the following areas. First, this study looks at how well Hartwick's rule applies to the current context of' ‘sustainable development,' a term that became famous around the world in the 1980s after being used for the first time in the World Conservation Strategy of the International Union for the Conservation of Nature (1980). Later in the study, one of Hartwick's key assumptions is disentangled (technological growth) that has been consistent throughout time to see how it affects the model's progress. The remainder of the paper is organized in the following manner. The literature review is discussed in Section 2. The theoretical background, data, and methods are all explained in Section 3. The findings, as well as their interpretation and robustness assessments, are discussed in Section 4. Finally, Section 5 shows the conclusion as well as the area of future research.

Literature Review

The relevance of comprehending diverse regulations involving environment, energy, and development has increased as a result of global warming and climate change, as well as increasing awareness of these issues. To elaborate on the relationships between the study's research topic and other parts, the literature review section is separated into four sub-sections. The first section discusses Weak Sustainability and its connection to Hartwick's Rule; the second section goes over the Solow-Hartwick model and its implications in the literature; the third section shows the derivation of the duo model for the purpose of analysis; and the fourth section reviwes some of the earlier studies on natural resources and Hartwick's rule.

Hartwick's rule and Weak Sustainability

After the founding of the World Commission on Environment and Development, the term "sustainable development" became highly popular, especially after the Brundtland Commission's statement that "environment and development are inextricably intertwined" was released. Nonetheless, environmentalists are concerned about the overuse of nonrenewable resources. According to studies, the combustion of fossil fuels is the single cause of global warming since it increases the amount of carbon dioxide in the atmosphere (Lee, et al., 2021; Zuo et al., 2021). A significant distinction between non-renewable and renewable resources is that, while all countries on the planet can use renewable resources to some extent, because non-renewable resources have economic value due to their finite nature, only countries with abundant non-renewable resources are able to make the most use of them. Not only that, but these nonrenewable non-resources are well-known for being utilized as a potent weapon by some countries, which has aided them in achieving diplomatic wins. As a result, for the past 70 years, we've heard a lot about phrases like "energy security" and "political instability" in resource-rich countries. As a result, policy analysts, ecologists, and environmentalists have been conducting extensive study to help them make the transition from non-renewable to renewable resources (Lee, et al., 2021; Zuo et al., 2021). Mostly because renewable resources are regarded as a beneficial instrument that may be swapped for non-renewable resources in the majority of circumstances in order to reduce the overall cost of the energy issue (Zuo et al., 2021). The following are the three most essential reasons for contemplating this shift in resource usage: Nonrenewable resources generate energy shortages and, in some cases, peace disruption; they are finite in nature, so we may run out of energy in the future decades; and, last but not least, the combustion of nonrenewable energy is extremely harmful to the environment because it emits CO2. These environmental issues have already prompted a global movement to prevent climate change (Zuo et al., 2021), and there is still a lot more study to come in the near future to tackle it.

Solow-Hartwick Duo Rule

John Hartwick demonstrated an intriguing thesis under assumptions that are fully standard in the theory of growth with exhaustible resources in a series of articles produced immediately after the first oil shock (Solow, 1986). We know that non-declining consumption is conceivable as long as the stock of capital does not shrink over time, according to the famous thesis. This rule is often abbreviated as "Invest Resource Rents" because it emphasizes that if governments invest all rents from exhaustible resources in reproducible capital, the diminishing stocks of exhaustible resources will be exactly compensated (Hartwick, 1977; Solow, 1986).

Furthermore, Solow (1974) demonstrated that natural and created capital are interchangeable in the sense that rapid accumulation of capital leads to sustained consumption or an unchanging flow of utility, thereby countering the depletion of non-renewable resources. Because the aggregate production function for consumption products is a Cobb-Douglas one, as the amount remaining of the non-renewable resource falls to zero, its average product grows to infinity, the natural resource does not operate as a growth limitation (Hartwick, 1977; Solow, 1986). This situation clearly refers to the "Weak Sustainability" scenario, in which natural and manufactured capital are assumed to be interchangeable in terms of productivity. Similarly, "real savings" refers to the difference between total investment in created capital and total disinvestment in natural capital (Hamilton & Hartwick, 2005; Hamilton et al., 2006). However, resource-rich countries are frequently accused of being unable to maintain sustainable growth by failing to meet the goal true saving rate (Hamilton et al., 2006; Zuo et al., 2021). According to Hartwick's rule, countries should have developed economically if they had been substituting one form of capital for another. However, data shows that most resource-rich countries are still lagging behind their resource-poor counterparts in terms of GDP after 1977, when Hartwick's rule was formulated (Hamilton et al., 2006).

Various Assumptions and formation of Model

The general assumptions underlying Hartwick's rule will be presented first. The economy is considered to be competitive, with a one-to-one substitution elasticity between natural and created capital. Along the way, a Cobb Douglas Production Function is assumed because we know that all inputs are required to generate a positive amount of good, and hence it is impossible to deplete one resource while maintaining constant consumption. Another key assumption is that natural resources are used in accordance with Hotelling's rule for intertemporally efficient extraction. In addition, the model assumes that the economy is closed, with no population or technical progress. It also concentrates on the environment as an input of production while ignoring its other uses.

The Cobb Douglas production function is: $X = K^{\alpha} Y^{\beta} L^{\gamma}$ (1)

Where,

X=Produced Commodity

K=Produced Capital

Y=Natural Capital

L=Population

Since population is constant thus L=1 and α+β=1. All of the variables are defined in per capita terms. The technology assumes to exhibit constant returns to scale and thus the production function is homogenous of degree one. The Hotelling's rule states that the rate of change in the marginal product of the exhaustible resource being equal to the rate of return on reproducible capital. Meaning:

DK=(f_y-a) Y(t)

$\frac{dlog(f_y - a)}{dt} = f_K$

Or, $f_{yy} D_y + f_{yk} D_k = f_k$ (f_y-a) (2)

Genuine Saving is given by:

GS= $\left|\text{DK-}f_y\text{y}\right|$ (3)

Whereas, national accounting gives,

X(t)=C(t)+DK+ aY(t) (4)

Hamilton and Hartwick (2005) show that consumption in this economy follows a path defined by:

$$DC = f_k GS - DGS \tag{5}$$

Thus, the consumption path depends on the amount of genuine savings.

These assumptions will be required when the constraint will need to be relaxed and total factor productivity or technological growth in the production function will be included.

An overview on earlier literature Reviews:

Several scholarships have looked at this well-known rule, with the goal of either making a strong link with the rule's fundamental subject or recommending changes (Dixit et al., 1980; Hamilton et al., 2006; Lee et al., 2021; Vincent et al., 1996; Zuo et al., 2021). Dixit et al. (1980) demonstrated that the generalized Hartwick rule is adequate to yield a constant utility maximin path when technical development and population increase are held constant (Dixit et al., 1980). On the contrary, according to Vincent et al. (1996), resource-rich countries will need to invest more than previously thought to maintain their consumption levels if natural resource prices continue their long-term historical decrease in small economies (Vincent et al., 1996).

Zuo et al. (2021) investigated the impact of natural resource rents, technological innovation, and financial development on the ecological footprint of some BRI economies. They discovered that natural resource rents have a significant negative impact on the environment, although technical improvements aid in the reduction of ecological footprint (Zuo et al., 2021), which contradicts Dixit et al 1980)'s findings. In opposition to Zuo et al. (2021), but more in line with Hartwick (1977), Lee et al. (2021) demonstrated that ecological footprints, industrial value-added, and population expansion are resource capital's negative factors. They discovered that continuing economic expansion aids in the conservation of natural resources for future generations (Lee et al., 2021).

This study, on the other hand, follows Hamilton et al.’s methodological approach (2006). Hamilton et al. (2006) produced two 'Hartwick Rule counterfactuals' based on a 30-year time series of resource rent data underlying the World Development Indicators (World Bank 2004) for 70 resource-rich countries: First, how wealthy would countries be in 2000 in terms of accumulated produced assets if they had invested resource rents according to the Hartwick Rule, and second, if genuine investments matched a specified positive constant amount from 1970? (Hamilton et al., 2006). The authors did not include an empirical test of whether a given saving rule leads to the expected route for consumption, which is a significant weakness of this research. Furthermore, because the study was only confined until 2000, it was unable to add major political and economic volatility that occurred after 2000 (9/11 incident, severe economic slump of 2007, Iraq and Afghanistan War, and so on). As a result, this study will investigate the same research topic by reducing the countries to only those with plentiful resources and capturing the years after 2000 to see if Hartwick's rule applies in this scenario. Even a modest investment effort, similar to the average investment effort of the world's poorest countries, might have significantly enhanced the wealth (in terms of created assets) of resource-dependent economies, according to Hamilton et al., Hartwick's rule counterfactual estimates (Hamilton et al., 2006). As a result, the current study concludes that productive investment is unavoidably vital for a country's long-term viability and has so included the network readiness index as a type of technical growth to analyze the link.

Methodology

Data

Initially, the study intended to look into the influence of Hartwick's rule on the top 40 countries with the world's largest oil reserves. Gross capital formation (current US $), natural resource rents (percent of GDP), GDP (current US $), and Network readiness index for the year 2019 as a proxy for technological development growth are the variables used in this study, and data for these variables is collected for a period of 24 years (1995-2019). Because data on Gross Capital Formation for most nations was not available before to 1995, 1995 was chosen as the study's starting point. 2019 has been chosen as the final year for a similar reason. Some oil-rich countries are currently in a war-torn state due to political instability, and data for them could not be found, so they were removed from the model. As a result of data shortages and mismatches, the analysis was limited to 29 oil-rich countries rather than 40. The World Bank's World Development Indicators (WDI) included the variables gross capital formation (current US dollars), natural resource rents (percent of GDP), and GDP (current US dollars) for 29 countries from 1995 to 2019. The data for the Network Readiness Index for 2019 was gathered from the Portulans Institute's website.

Estimation Techniques

The theoretical framework has been divided into two subsections: one without incorporating growth of technological progress and another with incorporating it. For the usefulness and convenience of the study, the calculation of variables and estimation techniques are also divided into 2 parts: One on MS excel and another on Stata Software.

Estimation with MS Excel. First, Excel is used to compute the created capital or gross capital formation for the year 2019 using the manual capital accumulation rule and the Gross Capital Formation of 1995 as a benchmark for each country over a period of 24 years (1995-

2019). The current gross capital formation, calculated using the conventional method aka baseline estimates of GCF (Gross Capital Formation), is then compared to the hypothetical gross capital formation for the year 2019, estimated using Hartwick's rule aka alternative estimates of GCF. However, because natural resource rents are expressed as a proportion of GDP, they were converted to natural resource rents in current US dollars and calculated in Excel. The percentage change between the two calculated gross capital formation is also calculated in MS excel.

Estimation with Stata. The network readiness index for 2019 is depicted in the diagram, and two econometric models have been built to investigate how it affects Hartwick's rule. The natural resource rents (current US $) for 2019 are regressed on the Gross Capital Formation data (current US $) for 2019. In the first econometric model, the natural resource rents (current US $) for 2019 are regressed on the Gross Capital Formation data (current US $) for 2019. Both the natural resource rents (current US $) and the network readiness index for 2019 have been regressed on Gross Capital Formation data (current US $) in the second econometric model. This modeling technique is used to determine the overall effectiveness of including the network readiness index into the model and whether this improves Hartwick's rule's overarching goal.

Methodological Approach

Formula Derivation: To estimate the capital stock, both a baseline and an alternative estimates of gross capital formation has been constructed for the year 2019 using data covering 1995–2019.

Baseline. The baseline capital stock for the year 2019 is derived by summing the Gross Capital Formation for the year 1995 with the summation of net Investment for 24 years. The Gross Capital Formation for all the years (1995-2019) were adjusted with a capital depreciation rate of 5% which is constant for all countries. The formula is as follows:

K_{2016}=K_{1995}+$\sum_{t=1995}^{2016} NI_t$ (6)

Where,

$$K_{1995} = \text{Gross Capital Formation}_{1995} - \text{Gross Capital Formation}_{1995} * \delta$$

$$= (1- \delta) *\text{Gross Capital Formation}_{1995}$$

$$= 0.95*\text{Gross Capital Formation}_{1995}$$

And,

$$NI_t = K_t - K_{t-1} \quad (7)$$

Expression (2) is trivially true for our estimated baseline capital stock series.

Alternative Estimate. For the alternative estimate, we first try to get the formula for Capital stock at t period:

K_t = K_{t-1}+I_t-δK_{t-1} (8)

From the Genuine Saving rule, we know:

GS=I_t-δK_{t-1}-RR (Resource Rents)

Or, GS+RR=I_t-δK_{t-1}

Or, NI_t=I_t-δK_{t-1} [From (7) and (8)]

Or, NI_t= GS+RR (9)

From the later expression of the Net Investment, we calculate the alternative estimate of Capital stock for the year 2019 with the incorporation of genuine savings as follow:

K_{2019}=K_{1995}+$\sum_{t=1995}^{2019} NI_t$

= K_{1995}+ $\sum_{t=1995}^{2019} GS + RR$

This Capital Accumulation formula follows the conventional Hartwick rule, which asserts that Genuine Savings is zero, implying that investment in created capital exactly offsets disinvestment in natural capital, and therefore consumption remains constant from generation to generation. As a result, when GS=0, the sum of resource rents collected by extracting a country's natural resource over a period of years is added to the 1995 reference capital stock. Following Hartwick's rule, a country's Gross Capital Formation for the year 2019 is calculated.

Econometric Model Construction

Model 1. $Gross\ Capital\ Formation_{2019i}$=$\alpha_0$+ α_1 Natural Resource Rents $_{2019i}$ + μ_t

The alternative hypothesis test assumes that if countries had invested their resource rents in other assets, the value of those assets would have risen in lockstep with the value of those assets over time.

Model 2. $Gross\ Capital\ Formation_{2019i}$=$\beta_0$+ β_1 Natural Resource Rents $_{2019i}$ +β_2 Network Readiness Index $_{2019i}$ + ε_t

According to the alternative hypothesis, if countries had invested their resource rents in other assets while also adopting appropriate technology, the value of these assets would have grown faster over time than it would have grown without technology. This way, the study topic of whether observed consumption followed the projected pattern with the invention of technology would be effectively addressed.

Results and Discussion

General Results

Following the completion of all MS Excel computations, a table is created that includes all of the variables utilized in this study in their correct form Table 1. Total natural resource rents are made up of oil, natural gas, coal, mineral, and forest rents, with the difference between the price of a commodity and the average cost of producing it being used to compute natural resource rents. When we compare the Chart-1 of the top 20 countries that earn from natural resources in 2019 to table 1 of gross capital formation for countries in 2019, we can see that Azerbaijan, Congo, Oman, and Gabon are among the economies with very low levels of capital accumulation despite high rents. To put it another way, if we look at the top 20 countries with the highest GDP (in current US billions of dollars) for the year 2019 [Chart-2] instead of gross capital formation, we see that 18 of the top 20 countries (apart from Russia and Saudi Arabia) earn the highest rents from natural resource reserves. As a result, it is easy to conclude that most resource-rich countries have lower GDP than resource-poor countries.

Countries like Argentina, Indonesia, Brazil, and Malaysia, on the other hand, have low exhaustible resource rent shares but large levels of produced capital accumulated, as evidenced by the amount of gross capital creation attained in 2019. These are largely developing economies that will converge in the future years to become developed economies. A number of high-income countries, such as Norway and the United Kingdom, are included in this group. These countries have various forms of capital, such as human capital, which is translated into generated capital, and as a result, they are feeling the disparity.

Countries like the United States and Canada, on the other hand, have reduced the difference between the two levels of capital creation that can be seen in the table, while not using the whole produced capital if they had followed Hartwick's criterion. These countries are known as "Super Economies," and their GDP in current US dollars reflects this.

We can notice a clear distinction between resource abundant wealthy and resource abundant poor countries in the table. Despite having the same degree of natural capital, they have a significant level of economic inequality. Part of this can be explained by Hartwick's rule failing to incorporate technology advancements into the model. It is anticipated that if other resource-rich developing or poor countries incorporate technical advancements into their production systems, they will be able to achieve sustainable development and a consistent consumption level across generations. To observe how technological innovation affects Hartwick's rule and, as a result, aids countries in achieving sustainability, we must first let go of the premise that technical advancement is continuous. As a result, it is included in the production function (here network readiness index for the year 2019 in [Chart-3]).

If an economy has a steady population and positive technical advancement, the amount of investment in man-made capital required to maintain current-period per capita output is smaller than resource or Hotelling rents. Theoretically, because technological inclusion increases the efficiency of investing enterprises, the investment in created capital will be substantially lower than the revenue earned from resource extraction. As a result, a greater proportion of resource rents is invested in human capital and overseas financial assets, making it simpler for resource-rich countries to achieve financial growth (Hamilton et al., 2016). When the share of Resource rents is greater than the share of investment ($\alpha<\beta$), there must be a positive genuine saving, as shown by equation (3). As a result, we get a non-constant and unbounded consumption level, as shown by equation (5). On the other hand, the resource rich countries who are poor have a negative genuine saving because they are not able to use much technology to extract the natural resources and use them efficiently in produced capital. Therefore, they fail to hold a positive consumption overtime and also fails to attain sustainable development.

Furthermore, as shown in the table, nations with a smaller percentage disparity between produced capitals with and without the Hartwick criterion score higher on the Global Technology Index. The country's technological readiness is measured by the technology index. This score is based on factors such as company R&D spending, scientific community inventiveness, and personal computer and internet adoption rates. In addition, we can say that the technological index has a positive relationship with the GDP if we look at the trajectory of the GDP of the countries at the same time from the table.

Empirical Results

Similar results can be seen in terms of the empirical models which are shown in Table-2 and Table 3. First in model 1, a t-test is performed to learn about the significance of the impact of natural resource rents on gross capital formation which eventually can be translated as the sharp Hartwick's rule. The Breusch Pagan test for heteroskedasticity shows that there is no heteroskedasticity present in the model. Nonetheless, the model is not seen to be significant overall and also did not give a good fit. It produced a R^2 of 0.030, indicating that the model accounts for 3.0% of the variability observed in gross capital formation. The variable natural resource rents was not statistically significant and surprisingly surfaces a negative relationship between the natural resource rents and gross capital formation.

Then, for model 2, a t-test is performed when a new variable network readiness index has been incorporated. Upon finding a non-constant (heteroskedasticity) error variance, another t test has been performed using clustered standard error in the model, since error variance is group-based (in this case- country). The model is seen to be significant overall and also gave a comparatively way better fit than the previous model. It produced a R^2 of 0.263, indicating that the model accounts for 26.3% of the variability observed in gross capital formation in countries. The variable natural resource rents was still not statistically significant (though close to be significant at 11.3% confidence interval) and still surfaces a negative relationship with gross capital formation. The variable network readiness index was statistically significant (at 5% significance level) and indicates a positive relationship between with gross capital formation keeping the other variables constant. A simple regression shows that a 1 unit increase in network readiness index of a country is associated with a 4.568e+09 unit increase in the country's gross capital formation.

Conclusion and Future Scope of Research

The incorporation of technical advance growth boosts the overall importance and fitness of the model, as evidenced by the theoretical aspect and empirical outcomes found in the study. This variable also helps to explain the difference in ultimate gross capital formation seen between countries, regardless of how much money they make from their natural resource reserves, which was previously difficult to explain. Despite this, this research was unable to provide a full mathematical derivation of Hartwick's rule with the assumption of "technical development" relaxed due to data limits and other unavoidable constraints. Furthermore, this study cannot be considered a generic study because Hartwick's rule was not examined in all nations around the world. As a result, there may be a lot of room for making this research global by using data from all countries and applying robust statistical approaches. The goal of this work was to develop a generalization of the Hartwick Rule for sustainability, a rule that allows for unlimited consumption. This may be more appealing to policymakers than the constant consumption path that the traditional Hartwick Rule predicts. It was investigated if countries reliant on finite resources were indeed investing resource rents in manufactured assets. The Hartwick rule has never been adopted by a country with resource rents above 15% of GDP (Hamilton et al., 2006). Rather than 'showcase' initiatives with low returns, money should be diverted into productive investments that can underpin future welfare. Although studies claim that maintaining a constant positive level of genuine saving will result in a development path where consumption grows unabated even as finite resource stocks are depleted (Hartwick, 1977; Hamilton 1995), in practice, clinging to such theory is difficult given the abundance of natural, political, and man-made instability in our environment. Finally, shifting resources away from resource-rich industries/manufacturing sectors and effectively utilizing natural resource rents can result in a progressive and sustainable environment (Zuo et al., 2021).

References

Dixit, A., Hammond P. & Hoel M. (1980). On Hartwick's Rule for Regular Maximin Paths of Capital Accumulation and Resource Depletion. Review of Economic Studies, 47(3), 551–556.

Hamilton, K. & Hartwick J. M. (2005), Investing Exhaustible Resource Rents and the Path of Consumption. *Canadian Journal of Economics,* 38(2), 615–621.

Hamilton, K., Ruta G., & Tajibaeva, L. (2006). Capital Accumulation and Resource Depletion: Hartwick Rule Counterfactual. *Environmental and Resource Economics*, 34(4), 517-533

Hartwick, J. M. (1977). Intergenerational Equity and the Investing of Rents from Exhaustible Resources, *American Economic Review* 67(5), 972–974.

Lee, T. C., Anser,M. K., Nassani, A. A., Haffar, M., Zaman, K., Abro, M.M.Q. (2021). Managing Natural Resources through Sustainable Environmental Actions: A Cross-Sectional Study of 138 Countries. *Sustainability*,13, 12475.

Solow, R. (1974). Intergenerational Equity and Exhaustible Resources. *Review of Economic Studies*. Symposium on the Economics of Exhaustible Resources. 41, 29–45

Solow, R. (1986). On the Intergenerational Allocation of Natural Resources. *Scandinavian Journal of Economics.* 88(1), 141–149.

Vincent, J., Panayotou T. & Hartwick J. M. (1997). Resource Depletion and Sustainability in Small Open Economies. *Journal of Environmental Economics and Management*, 33(3), 274–286.

Zuo, S., Zhu, M., Xu, Z., Oláh J., 4, & Lakner, Z. (2021). The Dynamic Impact of Natural Resource Rents, Financial Development, and Technological Innovations on Environmental Quality: Empirical Evidence from BRI Economies. *International Journal of Environmental Research and Public Health*, 19(1), 130.

Appendix

Table 1: Table Showing General Relationships among Various Variables Used in the Study

Country Name	Gross Capital Formation in 1995 [Current US $]	Total Net Investment in 2019[Capital accumulation]	Gross Capital Formation 2019[Current US $]	Total Natural Resource Rents in 2019 [Current US $]	Gross Capital formation in 2019 (Hartwick's Rule) [Current US $]	% change followed Hartwick Rule
Algeria	12263232362	59331900322	71595132684	9.14313E+12	9.1554E+12	12687.74%
Argentina	45350086350	32253052378	77603138728	2.97429E+12	3.0196E+12	3791.08%
Australia	90866498366	2.16911E+11	3.07777E+11	2.32553E+13	2.3346E+13	7485.36%
Azerbaijan	689558965.1	8503591035	9193150000	3.65091E+12	3.6516E+12	39620.88%
Botswana	1283421110	4912069109	6195490219	4.81418E+12	4.8155E+12	77625.89%
Brazil	1.26379E+11	1.37761E+11	2.6414E+11	1.34808E+12	1.4745E+12	458.23%
Brunei Darussalam	1648793566	3300393138	4949186703	9.11824E+11	9.1347E+11	18356.97%
Canada	1.11565E+11	2.62959E+11	3.74524E+11	9.79745E+12	9.909E+12	2545.76%
China	2.71018E+11	-2.71018E+11	0.000488281	5.84001E+13	5.8671E+13	##########
Colombia	22672429790	45939005760	68611435550	4.60173E+12	4.6244E+12	6639.98%
Congo, Rep.	735184641.5	1196577983	1931762624	1.70388E+12	1.7046E+12	88140.66%
Ecuador	4601573787	20868335663	25469909450	2.26667E+12	2.2713E+12	8817.58%
Egypt, Arab Rep.	11514302566	-11514302566	0	5.97167E+11	6.0868E+11	#DIV/0!
Gabon	1097789718	2449884142	3547673860	1.66147E+13	1.6616E+13	468263.23
Indonesia	58432974765	3.00573E+11	3.59006E+11	1.18008E+13	1.1859E+13	3203.29%
Iran, Islamic Rep.	27644513638	-27644513638	0	#VALUE!	#VALUE!	#VALUE!
Kazakhstan	4513580695	41665481836	46179062530	1.0167E+13	1.0172E+13	21927.30%
Kenya	1875192398	13913002817	15788195215	4.30209E+11	4.3208E+11	2636.73%
Malaysia	36775378788	35712501428	72487880216	7.6103E+12	7.6471E+12	10449.49%
Mexico	71718002344	1.8416E+11	2.55878E+11	1.01967E+13	1.0268E+13	3912.85%
Nigeria	15588279751	-15588279751	0	1.26275E+13	1.2643E+13	#DIV/0!
Norway	34813139285	76281372078	1.11095E+11	9.31941E+12	9.3542E+12	8320.04%
Oman	1964239272	-1964239272	1.90735E-06	6.3446E+12	6.3466E+12	##########
Russian Federation	95589212537	2.77551E+11	3.7314E+11	6.73327E+13	6.7428E+13	17970.43%

Saudi Arabia	27624841025	1.78156E+11	2.05781E+11	6.29637E+13	6.2991E+13	30510.71%
Uganda	678693022.2	7967534198	8646227220	8.95025E+11	8.957E+11	10259.43%
United Kingdom	2.36406E+11	2.30764E+11	4.6717E+11	5.10772E+12	5.3441E+12	1043.93%
United States	1.54392E+12	-1.54392E+12	0	3.72477E+13	3.8792E+13	#DIV/0!
Venezuela, RB	12890062104	1.00801E+11	1.13691E+11	#VALUE!	#VALUE!	#VALUE!

Chart-1: Natural Resource Rents for top 20 Countries

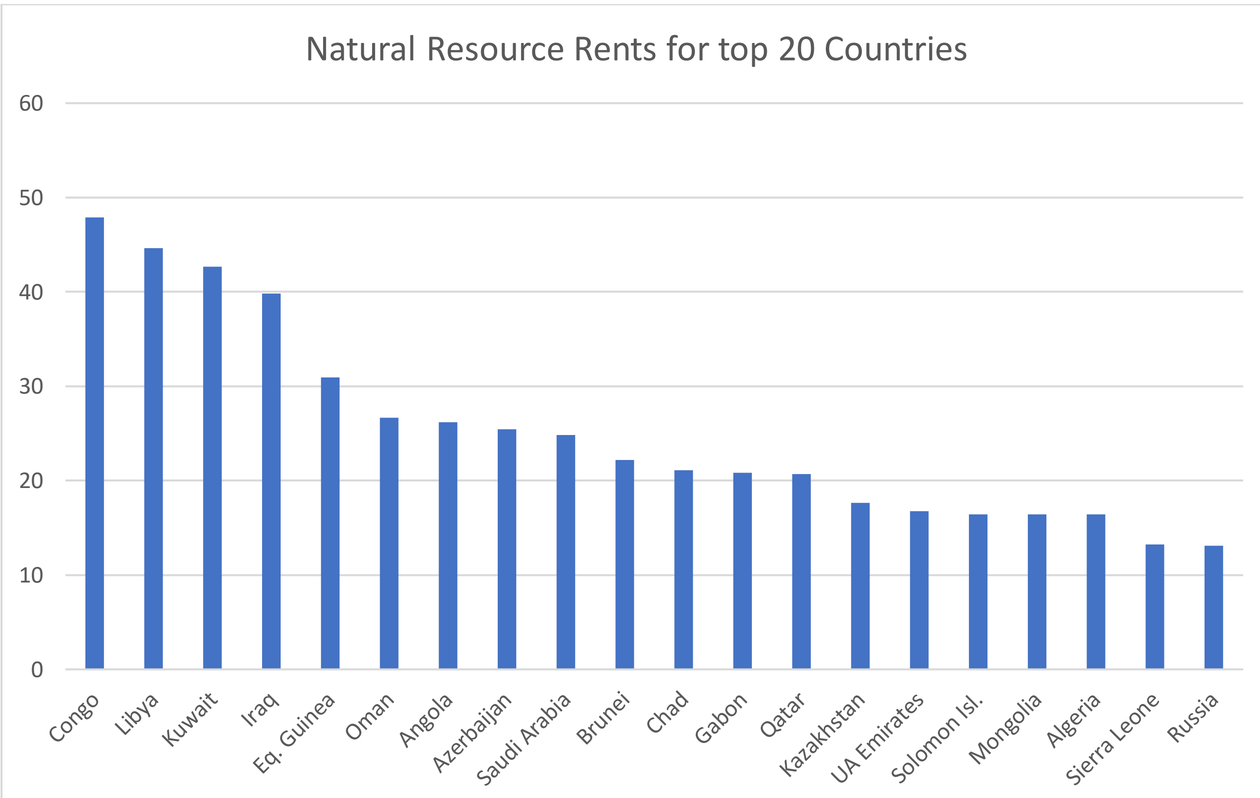

Chart-2: GDP (Current US Billion $) for top 20 Countries

Country Name	GDP (Current US Billion $)
USA	21433.22
China	14279.94
Euro area	13413.57
Japan	5148.78
Germany	3888.33
UK	2878.67

India	2870.5
France	2728.87
Italy	2009.38
Brazil	1877.82
Canada	1742.02
Russia	1687.45
South Korea	1651.42
Spain	1393.05
Australia	1391.95
Mexico	1269.43
Indonesia	1119.09
Netherlands	910.19
Saudi Arabia	792.97
Turkey	761

Chart-3: Network Readiness Index 2019 for the countries used in this study

Country Name	Network_Readiness_Index_2019
Algeria	35.3
Argentina	51.27
Australia	74.8
Azerbaijan	47.74
Botswana	34.85
Brazil	51.07
Brunei Darussalam	
Canada	74.72
China	57.63
Colombia	48.77
Congo, Rep.	
Ecuador	41.98
Egypt, Arab Rep.	38.58
Gabon	
Indonesia	46.15
Iran, Islamic Rep.	43.66
Kazakhstan	50.68
Kenya	38.19

Malaysia	63.76
Mexico	51.44
Nigeria	28.22
Norway	81.3
Oman	52.87
Russian Federation	54.98
Saudi Arabia	52.47
Uganda	29.7
United Kingdom	77.73
United States	80.32
Venezuela, RB	34.14

Table-2: Regression Analysis for Model-1

gross	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
natural	-.005	.006	-0.91	.369	-.018	.007	
Constant	1.177e+11	2.925e+10	4.02	0	5.769e+10	1.777e+11	***

Mean dependent var	107912498145.138	SD dependent var	146134860509.732
R-squared	0.030	Number of obs	29
F-test	0.835	Prob > F	0.369
Akaike crit. (AIC)	1575.449	Bayesian crit. (BIC)	1578.184

*** $p<.01$, ** $p<.05$, * $p<.1$

Table 3: Regression Analysis for Model-2

gross	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
natural	-.004	.002	-1.64	.113	-.008	.001	
network	4.568e+09	2.007e+09	2.28	.032	4.356e+08	8.701e+09	**
Constant	-1.085e+11	9.454e+10	-1.15	.262	-3.032e+11	8.619e+10	

Mean dependent var	119962839347.000	SD dependent var	149859971122.465

R-squared	0.263	Number of obs	26
F-test	6.341	Prob > F	0.006
Akaike crit. (AIC)	1408.938	Bayesian crit. (BIC)	1412.713

**** p<.01, ** p<.05, * p<.1*