Foreign direct investment, stock market capitalization and sustainable development: Relative impacts of domestic and foreign capital

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It is well acknowledged that achieving sustainable development goals without negatively impacting a country's economic activity is complicated. The question of whether foreign or domestic capital can be used to address the financial demands of the nations who lack the financial resources for a green transformation should now be resolved. Based on this, the main goal of this research is to analyze the impacts of domestic and foreign capital on carbon emissions for a heterogeneous panel of 42 countries for the period from 1990 to 2017. Aside from capital accumulation, the environmental impact of elements such as economic growth, urbanization, trade openness, and energy usage are also studied. The newly developed quantile via moment approach is utilized to isolate the impacts according to the countries' emission levels. Finally, the impact of these variables on the recently constructed sustainable development index is investigated in order to ensure its robustness. The findings of the study reveal that the environmental efficiency of domestic capital accumulation in countries with low emission levels is higher than in countries with high emission levels. Foreign capital, on the other hand, has no substantial effect on emission levels in all quantiles.

Keywords: Stock market capitalization; foreign direct investment; carbon emissions, sustainable development

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ABSTRACT

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1. Introduction

Although the period of the industrial revolution is widely accepted as the origin of climate change and global temperature anomalies, when global average temperature values are evaluated in a baseline for the period 1850-2019, it is clear that the period after 1990 is when the temperature increase accelerated significantly (Morice et al. 2012). The fact that this increase occurred primarily as a result of a rise in cumulative carbon emissions demanded adopting actions to reduce carbon emissions, particularly in the context of climate change mitigation. In this approach, particularly in the recent several decades, international efforts to find a solution to the problem of climate change have been made, first with the Kyoto Protocol and later with the Paris Climate Agreement. In actuality, the Paris Climate Agreement's primary goal is to keep global average temperature rises below 2 degrees Celsius relative to pre-industrial levels; additionally, the goal has been set at 1.5 degrees Celsius (UNFCCC, 2015). However, even when carbon emissions are separated from population-sourced emissions, an increase is evident in the post-Kyoto Protocol period, which might be considered the predecessor to worldwide efforts. Carbon emissions per capita grew from 4.49 tonnes in 2005 to 4.72 tonnes in 2019 (Ritchie and Roser, 2020).

The inability to combat climate change is attributed to a number of issues, including: i) developed countries do not provide enough financial assistance to developing countries for the transformation in question, ii) developing countries do not invest the funds required for transformation in productive areas, and iii) developing countries prioritize economic expansion over environmental protection. In order to address potential finance challenges for developing countries, the Paris Climate Agreement prioritizes the goal of stabilizing financial flows on the road to low-emission and climate-resistant development (UNFCC, 2015). Countries, on the other hand, should encourage local capital and foreign direct investments to tackle climate change and mitigate the danger of worldwide financial instability. In fact, without international financing, it is impossible to achieve an environmentally sustainable change without causing economic harm to the country. On the other hand, the promise of low environmental regulation by developing countries' economies, whose economic development strategies are based on foreign capital inflows, to pollution-inducing industries that adhere to strict environmental policies in developed countries makes combating global climate change even more difficult.

Aside from the notion that a developed and stable financial system could harm the environment (Tamazian et al. 2009; Tamazian and Rao, 2010; Boutabba, 2014; Omri et al. 2015; Charfeddine and Khediri, 2016; Javid and Sharif, 2016; Shahbaz et al. 2016; Haseeb et al. 2018; Hafeez et al. 2018; Moghadam and Dehbashi, 2018; Shahbaz et al. 2018; Phong, 2019; Zakaria and Bib, 2019; Le and Ozturk 2020; Bui, 2020; Tahir et al. 2020; Kayani et al. 2020; Destek and Manga, 2021), it is well known that studies have found that financial development plays a critical role in the fight against climate change, thanks to the efficient use of financial resources for access to and development of renewable and environmentally friendly technologies (Jalil and Feridun (2011); Shahbaz et al. (2013); Shahbaz et al. (2013); Chang (2015); Destek (2015); Salahuddin et al. (2015); Lee et al. (2015); Rizwan Nazir et al. (2018); Olowu et al. (2018); Zaidi et al.

(2019); Destek (2019); Umar et al. (2020); Godil et al. (2020); Samreen and Majeed (2020); Baloch et al. (2021). Domestic credits are frequently utilized as a measure of financial development in these researches, indicating that the environmental consequences of domestic capital vary by country. Although there is a substantial literature on the consequences of foreign capital on the environment, there is no consensus at this time. The "pollution haven hypothesis" refers to the argument that developing countries are seen as a pollution haven, and that foreign investors will shift their investments to these countries to take advantage of the loose environmental regulations in these countries, causing an increase in foreign direct investment inflows to accelerate environmental degradation. On the other hand, the "pollution halo hypothesis" states that firms that transfer current high technology to rich countries with inflows of foreign capital help developing countries create environmentally friendly technology. According to this evidence, the environmental impact of foreign capital varies by country.

The previous findings that the comparative environmental impacts of domestic and foreign capital differ for countries with similar development levels provide a foundation for determining whether these differences are due to the countries' current production structures, or, in other words, their current emission levels, rather than the countries' development level. In this vein, the goal of this research is to compare the environmental implications of domestic and foreign capital in 42 countries with varying levels of pollution (low, medium, high emission level) using with quantile-based approaches for the period of 1990-2017. It is possible to distinguish and observe the environmental impact of various capital accumulations for countries with varying emission levels in this way. In addition, the effects of domestic and foreign capital on a country's sustainable development are evaluated for robustness check.

The study makes a five-fold contribution to the literature. i) This is the first study to look at the effects of domestic and foreign capital on the environment for a heterogeneous panel ii) Unlike earlier researches, the methodology utilized in this one allows for discrimination based on the countries' emission levels rather than their development levels. As a result, policy recommendations will be differentiated based on the countries' emission levels, rather than their degree of development. iii) The impact of variables such as economic growth, urbanization, trade openness, and energy consumption are also separated according to the emission levels of the countries in the study, in addition to domestic and foreign capital accumulation. By include these variables in the empirical model, the omitted variable risk is reduced. iv) A second empirical model is evaluated in the study for robustness check, in which the recently established sustainable development index is utilized as the dependent variable instead of carbon emissions. v) This is also the first study to examine the role of domestic and foreign capital in sustainable development.

2. Literature Review

Although many studies have been done on the environmental implications of domestic and foreign capital, none have been done to compare these effects based on the countries' development or emission levels. When looking at the literature listed in Table 1, it is clear that the impact of domestic and foreign capital is either investigated for a panel of countries with

similar development levels or on a country-by-country basis. Once we separate the findings from prior studies according to the countries' emission levels, it is impossible to draw definitive conclusions, particularly on the consequences of foreign capital. For instance, Jun et al. (2018) discovered that foreign capital has a growing impact on China's carbon emissions while the emission-reducing effect of foreign capital for China has been established by Zhang and Zhou (2016) and Sung et al. (2018). Similarly, Sadorsky (2010), Paramati et al. (2016), and Sarkodie and Strezov (2019) found that foreign capital has a negative impact on the environment in emerging economies, while Destek and Okumus (2019) discovered that foreign capital has a contribution on the environment in a panel of similar countries. Salahuddin et al. (2017) found that foreign capital has a negative impact on the environment in Kuwait, whereas Al-Mulali and Tang (2013) found that foreign capital has a positive impact on the environment in the Gulf Cooperation Council, and Sbia et al. (2014) found that foreign capital has a positive impact on the environment in the United Arab Emirates. For Turkey, there is a comparable inconsistency. Foreign capital has an emission-increasing effect, according to Seker et al. (2015) and Kaya et al. (2017), but foreign direct investments have an emission-reducing effect, according to Ozturk and Oz (2016) and Mert and Caglar (2020).

[INSERT TABLE I HERE]

It is feasible to draw a separate conclusion when the environmental consequences of domestic capital are compared according to the countries' development levels. Namely, Sadorsky (2010) identified the carbon emission-enhancing effect of domestic capital for 22 emerging countries and there are also some studies validating the emission increasing effect of domestic capital as follows: Zhang et al. (2011) for China, Abbasi and Riaz (2016) for Pakistan, Paramati et al. (2016) for 20 emerging market economies, and Zhang et al. (2019) for China. However, the contribution of indigenous capital to the environment was identified by Shahbaz et al. (2018) for France and Raghutla et al. (2021) for the top-10 investment countries. These researches suggest that when a country's development level rises, domestic capital begins to have a pollution-reducing effect. Indeed, Paramati et al. (2017) discovered that increasing domestic capital increased carbon emissions in developing countries while decreasing carbon emissions in developed countries. However, when prior researches are examined anew, it is impossible to establish that the environmental impact of domestic capital varies depending on the countries' emission levels.

When the previous researches are reviewed, it is clear that the environmental effects of domestic and foreign capital are often studied either on a country-by-country basis or for countries of a specific development level. Few studies have looked at the impact of domestic and foreign capital on carbon emissions in countries of various development levels. On the other hand, no research has been done on the environmental impact of domestic or foreign capital based on disparities in emission levels across countries rather than the countries' development levels. In addition, most of these studies focus on the efficiency of either domestic or foreign capital, with no comparison of the two variables' environmental efficiency. The fact that this study analyzes both variables' environmental activities and is based on a classification of countries based on their emission levels is significant in terms of filling a gap in the literature.

3. Empirical Strategy

3.1. Data

The study consists of 42 countries (Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Colombia, Egypt, Arab Rep., France, Germany, Greece, Hungary, India, Indonesia, Israel, Italy, Japan, Jordan, South Korea, Malaysia, Mauritius, Mexico, Morocco, Netherlands, New Zealand, Norway, Pakistan, Peru, Philippines, Poland, Portugal, Singapore, South Africa, Spain, Sri Lanka, Switzerland, Thailand, Tunisia, Turkey, United States) that are heterogeneous in terms of carbon emissions and sustainable development levels and covers the annual data from 1990 to 2017. To assess the environmental effectiveness of domestic and foreign capital at different emission levels, we considered carbon dioxide emissions as a function of economic growth, domestic capital, foreign capital, urbanization, trade openness and energy consumption following the studies of Paramati et al. (2017), Shahbaz et al. (2018) and Zhang et al. (2019). Here, we show carbon emissions (CO) in metric tons per capita to represent environmental pollution, real GDP per capita in US dollars to represent economic growth (GDP), market capitalization of listed companies as a percentage of GDP to represent domestic capital (DC), foreign direct investment inflows as a percentage of GDP representing foreign capital (FC), percentage share of urban population in total population representing urbanization (URB), percentage share of total exports and imports in GDP representing trade openness (TRA), and per capita energy consumption (EC) data in quad btu. In addition, the sustainable development index (SD) newly developed by Hickel (2020) is also used as a dependent variable in a second model for compare how carbon emissions and sustainable development index affected by different types of capital. Hickel (2020) defines the sustainable development index as the expanded version of the human development index with the ecological activities of the countries. In the process of collecting datasets, GDP, FC, URB and TRA data are obtained from the World Development Indicators database published by the World Bank. DC data were downloaded from the World Financial Development database of World Bank, CO data is sourced from OurWorldInData, EC data is collected from the Energy Information Administration database, and SD data is downloaded from the Sustainable Development Index database developed by Hickel (2020).

3.2. Methodology

To estimate our empirical models, we apply Quantile via Moment approach[2] developed by Machado and Silva (2019) due to several crucial reasons. First, our variables are highly heterogeneous across countries and over time. Any standard panel data –based techniques often fail to capture cross-sectional heterogeneity and variation over time.

The advantage of our approach is that it allows the use of methods that are only valid in the estimation of conditional means, such as differencing out cross sectional effects in panel data models, while providing information on how the regressors affect the entire conditional distribution. These informational gains are perhaps the most striking feature of quantile regression (see, e.g., Chamberlain, 1994, and Buchinsky, 1994) and were emphasized, for

[2] See Appendix A for detailed explanation of Quantile via Moment procedure.

example, in the surveys by Koenker and Hallock (2001), Cade and Noon (2003), and Bassett Jr and Koenker (2018). Besides, greatly facilitating the estimation of complex models, our approach also leads to estimates of the regression quantiles that validate a crucial requisite often ignored in empirical applications (see also He, 1997, and Chernozhukov et al., 2010).

In addition, we also used Driscoll-Kraay estimation technique of Driscoll and Kraay (1998) to check the robustness of the findings. The reasons of using that estimation technique are that using this technique both allows cross-sectional dependency among observed countries and our sample is suitable for DK estimation because we have the data which seems cross-sectional dimension is greater than time-period (N>T) condition.

4. Empirical Findings

The effects of domestic and foreign capital on both carbon emissions and the sustainable development index are explored for different quantiles using the quantile regression approach in the empirical procedure for two different empirical models. Table 2 shows the results of a quantile via moment analysis that looked at the impacts of economic growth, domestic capital, foreign capital, urbanization, trade openness, and energy consumption on carbon emissions for countries with various emission levels. Once it comes to economic growth, it's been determined that it raises carbon emissions for all quantiles. This finding is consistent with the studies of Malik et al. 2020; Bekun el al. 2021; Adedoyin et al. 2021; Bekun et al. 2022; Destek and Aydin, 2022; Caglar et al. 2022. When the positive coefficients for the Q70-Q90 quantiles are compared to the positive coefficients for the Q10-Q60 quantiles, it is clear that the positive coefficients for the Q70-Q90 quantiles are lower. This means that the negative environmental effects of economic growth are greater in countries with low emissions than in countries with high emissions. If it concerns to the environmental implications of urbanization, it is obvious that as the degree of urbanization rises, carbon emissions rise for all quantiles, whereas the environmental effects of urbanization do not differ significantly depending on the countries' emission levels. This finding is also validated by some previous studies as Zhang and Zhou, 2016; Behera and Dash, 2017; Solarin and Al-Mulali, 2018. Furthermore, increases in trade openness and energy use are found to raise emission levels for all quantiles. The negative impact of both elements on the environment are observed to be greater in countries with low emission levels. This result confirms the previous studies as follows: Tamazian and Rao 2010; Seker et al. 2015; Solarin et al. 2017; Zafar et al. 2019; Destek and Okumus, 2019; Khan et al. 2020; Xie et al. 2020.

In connection with the main purpose of the study, we observe the environmental effects of domestic and foreign capital at different emission levels and it is concluded that an increase in domestic capital decreases as found in Paramati et al. 2017; Shahbaz et al. 2018; Raghutla et al. 2021 emission levels for Q10-Q30 quantiles while increasing emission levels in line with some previous studies (Sadorsky, 2010; Paramati et al. 2016; Zhang et al. 2019) for Q50-Q90 quantiles. This suggests that, in comparison to countries with higher emission levels, domestic capital is steered towards more environmentally favorable investment areas in countries with

lower emission levels. On contrary, the environmental effects of increased foreign capital are statistically insignificant for all quantiles, and hence for all emission levels.

[INSERT TABLE II HERE]

Table 3 shows the findings of a quantile via moment analysis that looked at the effects of domestic and foreign capital on sustainable development, as well as the impact of economic growth, urbanization, trade openness, and energy consumption indicators for various quantiles. On the surface, domestic capital appears to reduce sustainable development in almost all quantiles, while foreign capital appears to have no statistically significant influence. Furthermore, economic growth and energy use are found to impair sustainable development in all quantiles. Similarly, it is observed that it has a negative impact on sustainable development in practically all trade openness quantiles. Once the results are divided into quantiles, the negative coefficient of economic growth in the Q10-Q60 quantiles is more noticeable than in the Q70-Q90 quantiles. This means that economic growth has a higher negative impact on sustainable development in countries with a low level of sustainable development than in countries with a high level of sustainable development. When looking at the effects of urbanization on sustainable development, the Q40-Q90 quantiles show a positive and substantial influence. The negative impact of increased urbanization on sustainable development, on the other hand, is determined in the Q10 quantile. While urbanization in countries with low levels of sustainable development undermines sustainable development, urbanization in countries with high levels of development is in line with sustainable development goals, according to this conclusion. The impact of trade openness on sustainable development, on the other hand, can be divided into three categories. In other words, the negative effect in the Q10-Q30 quantiles is smaller than in the Q40-Q60 quantiles. Surprisingly, in the Q70-Q90 quantiles, the negative effect was statistically insignificant. According to this study, the adverse effect of trade openness on sustainable development increases as the degree of development rises, and after reaching a particular level of development, the detrimental effect of trade openness decreases. In line with economic growth, the negative impact of energy consumption on sustainable development is inversely proportional to the development levels of countries.

In line with the main purpose of the study, the effects of domestic and foreign capital are analyzed for countries with various levels of sustainable development, and it is found that domestic capital has a negative and significant influence on all quantiles except Q10-Q50 quantiles. The negative effect in the Q20-Q40 quantiles is substantially higher than the negative effect in the Q60-Q90 quantiles, which is worth noting. As a result, the harm caused by domestic capital to sustainable development lessens as the level of sustainable development rises. On the other hand, it is established that the influence of foreign capital is statistically insignificant for all quantiles. This finding reveals that foreign capital inflows have not yet had a significant impact on the sustainable development of countries.

[INSERT TABLE III HERE]

5. Robustness Check

Additionally, we employ the Driscoll-Kraay (DK) robust estimator to determine the robustness of the empirical findings. The reason for choosing this estimator is that the number of countries in the study panel is greater than the number of periods in the study, and the DK estimator produces accurate results in this case. Before DK estimation, we check the possible cross-sectional dependency among countries for all variables and present the results in Table 4. Based on the findings, it is concluded that the null of cross-sectional independency is strongly rejected for all variables. This finding gives us a chance to use DK estimation technique.

[INSERT TABLE IV HERE]

According to the result shown In Table 5, economic growth and foreign capital have no statistically significant effect on carbon emissions when carbon emissions are employed as a dependent variable. Additionally, domestic capital accumulation results in a rise in carbon emissions. Similarly, urbanization, increased trade openness, and increased energy use all contribute to a rise in carbon emissions. The results of DK estimate are typically compatible with the Quantile via moment results presented in the preceding section.

[INSERT TABLE V HERE]

Table 6 shows the DK estimator results for the second model, which uses the sustainable development index as the dependent variable. Economic expansion, according to the findings, is detrimental to long-term development. This conclusion suggests that measures aimed at boosting economic growth come at the expense of social and environmental indices. Increases in domestic capital have a negative impact on sustainable development. This finding can be attributed to the fact that domestic investors make investments based only on economic considerations, with environmental concerns remaining in the background. Increased urbanization helps to promote sustainable development. As a result, it is clear that the examined countries' urbanization policies are either ecologically benign or that the benefits of urbanization in terms of social and economic indices outweigh the environmental costs of urbanization. Foreign capital, trade openness, and energy consumption, on the other hand, have statistically insignificant effects on sustainable development.

[INSERT TABLE VI HERE]

In general, our finding as economic growth increases emissions is compatible with the studies of Aliyu (2005); Tang (2009); Hitam and Borhan (2012) and Blanco et al. (2013). The finding that economic growth increases carbon emissions less in high-emission countries than in low-emission countries highlights the fact that environmental awareness has begun to rise in countries where environmental pollution has reached critical levels, and that the rate of emission increase is being attempted to be avoided. Furthermore, Solarin et al. (2017), Behera and Dash (2017), Zhang and Zhou (2016) and Destek (2021) all found that increasing urbanization increases carbon emissions, similar to our findings. Surprisingly, despite the environmental damage that urbanization generates, it appears that urbanization benefits to sustainable development in countries with high levels of sustainable development. This finding

demonstrates that urbanization and improved environmental quality can coexist, particularly in countries that prioritize sustainable urbanization.

When the findings are connected to trade flows, the finding that increasing trade openness increases emissions is consistent with the researches of Kaya et al. (2017); Xie et al. (2020); and Tamazian and Rao (2010). The fact that increased trade openness is more harmful to the environment, especially in low-emission countries, indicates that low-emission countries that produce products with high emission potential, and that as the trade volume of these products increases, so do the emissions of low-emission countries. The influence of energy consumption on carbon emissions has been determined, and this finding is compatible with Seker et al. (2015); Paramati et al. (2016); and Shahbaz et al. (2018). The fact that the negative environmental effects of energy consumption are stronger in low-emission countries, analogous to trade openness, suggests that fossil energy consumption-based production has begun in countries with relatively low emissions. The fact that pollution-intensive production has been shifted to low-emission countries to avoid the impediments of global agreements to reduce environmental damage suggests that pollution-intensive production has been shifted to low-emission countries to avoid the impediments of global agreements to reduce environmental damage.

Domestic capital raises carbon emissions in countries with high levels of emissions, while it reduces carbon emissions in countries with low levels of emissions. This result is consistent with the findings of the Paramati et al. (2017), which indicated that domestic capital increases carbon emissions in developing nations with high emissions while decreasing carbon emissions in developed countries with low emissions. Considering that countries with greater levels of emissions place a larger priority on economic growth than environmental sensitivity, the panel found that these countries are hesitant to impose environmentally friendly laws on corporations listed on national stock exchanges. The rate of rise in carbon emissions is lower in countries with strong capital markets over the sample period. The conclusion is that the restrictions in place in these countries are effective, and that the growth in domestic company activity reduces emissions. When looking at the findings for foreign capital, it is found that an increase in foreign capital has no substantial impact on carbon emissions, regardless of whether the country has high or low emissions. This observation is in line with the findings of Shaari et al. (2014); Liobikiene and Butkus (2019); and Wang et al. (2021). The obtained result reveals that in countries hosting foreign investments, an effective policy in terms of environmental sensitivity of foreign investment is not followed.

6. Conclusions and Policy Recommendations

This study compares the contribution of domestic and foreign capital accumulation to the fight against environmental pollution in the 1990-2017 period for 42 countries that are heterogeneous in terms of environmental damage. In this direction, the effects of economic growth, stock market capitalization, foreign direct investments, energy consumption, urbanization and trade openness on carbon emissions are examined in this study. While doing this, the quantile via moment approach is used to observe whether the said effects change according to the emission

levels of the countries. Also, for robustness check, the effect of the same independent variables on the newly developed sustainable development index is also examined.

The results of the research can be summarized as follows: i) economic growth increases carbon emissions less in high-emission countries than in low-emission countries, ii) increasing urbanization increases carbon emissions and environmental effects of urbanization do not differ significantly depending on the countries' emission levels, iii) increases in trade openness increases carbon emissions and the environmental pollution increasing effect of trade openness is greater in low emission-countries. iv) raising energy consumption harms environmental quality and this harmful effect is greater in countries with low emission levels. v) domestic capital raises carbon emissions in countries with high levels of emissions, while it reduces carbon emissions in countries with low levels of emissions, vi) increase in foreign capital has no substantial impact on carbon emissions, regardless of whether the country has high or low emissions, vii) economic growth has a higher negative impact on sustainable development in countries with a low level of sustainable development than in countries with a high level of sustainable development. viii) urbanization in countries with low levels of sustainable development undermines sustainable development, ix) the adverse effect of trade openness on sustainable development increases as the degree of development rises, and after reaching a particular level of development, the detrimental effect of trade openness decreases, x) the harm caused by domestic capital to sustainable development lessens as the level of sustainable development rises, xi) foreign capital inflows have not yet had a significant impact on the sustainable development of countries.

In regard with policy implications, the following measures should be taken based on our findings: i) Intense environmental awareness-raising activities should be carried out in countries with low emissions, in other words, based on the unconscious destruction of the environment in countries where pollution does not reach critical levels. The fact that the environment is a more important goal than wealth should be imposed on these countries. ii) all observed country's policy makers are required to take measures to reduce the environmental damage of domestic capital accumulation. Various incentives and tax exemptions should be provided for domestic capital to fund or invest in projects developed in clean energy or energy efficiency areas. These tax revenues should be spent on the green transformation of these producers by imposing additional taxes on domestic producers who are responsible for relatively more emissions. iii) Instead of transferring foreign capital to countries with lax environmental regulations, governments should lead their green transformation.

The study has some limitations. i) Due to insufficient data, panel results are obtained, but country-specific coefficients are calculated and country comparisons cannot be made. In future studies, obtaining country-specific findings with the expansion of data sets will make policy recommendations more detailed. ii) In this study, the effect of foreign direct investments is found to be statistically insignificant. On the other hand, the interaction effects of possible factors that could make the impact of foreign capital on sustainable development significant are not taken into account. In future studies, the moderating effects of social, economic and political factors should be examined by including them in the empirical model.

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Data availability: The datasets will be provided, if required

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Consent for publication: Not applicable

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Appendix A

$$Y = \alpha + X'\beta + \sigma(\delta + Z'\gamma)U \quad (1)$$

$$E(U) = 0 \; and \; E(|U|) = 1 \quad (2)$$

$$Q_y(\tau|X) = \alpha + X'\beta + \sigma(\delta + Z'\gamma)q(\tau) \quad (3)$$

where $q(\tau) = F_U^-(\tau)$, so $\Pr\big(U < q(\tau)\big) = r$

$$Q_y(\tau|X) = \alpha + \delta q(\tau) + X'(\beta + \gamma q(\tau)) \quad (4)$$

$$\beta_l(\tau, X) = \beta_l + q(\tau)D_{X_l}^{\sigma} \quad (5)$$

$$D_{X_l}^{\sigma} = \frac{\partial\sigma(\delta + Z'\gamma)}{\partial X'} \quad (6)$$

$$E[RX] = 0$$

$$E[R] = 0$$

$$E\big[(|R| - \sigma(\delta + Z'\gamma))D_{\gamma}^{\sigma}\big] = 0 \text{ a} \quad (7)$$

$$E[(|R| - \sigma(\delta + Z'\gamma))D_{\delta}^{\sigma}] = 0$$

$$E[I(R \leq q(\tau)\sigma(\delta + Z'\gamma)) - \tau] = 0$$

$$R = Y - (\alpha - X'\beta) = \sigma(\delta + Z'\gamma)U \quad (8)$$

$$D_{\gamma}^{\sigma} = \frac{\partial\sigma(\delta+Z'\gamma)}{\partial\gamma} \quad (9)$$

$$D_{\delta}^{\sigma} = \frac{\partial\sigma(\delta+Z'\sigma)}{\partial\delta} \quad (10)$$

$$E[UX] = 0$$

$$E[U] = 0$$

$$E\left[(|U|-1)D_{\gamma}^{\sigma}\right] = 0 \quad (11)$$

$$[(|U|-1)D_{\delta}^{\sigma}] = 0$$

$$E\left[I\left(U < q(\tau)\right) - \tau\right] = 0$$

$$U = \frac{Y-(\alpha+X'\beta)}{\sigma(\delta+Z'\gamma)} \quad (12)$$

$$Y = D'_{\beta_D} + C'_1\beta_1 + \sigma(D'\gamma_D + C'_1\gamma_1)U \quad (13)$$

$$D_l = \mathcal{D}_l(C_1, C_2, U^*) for\ l = 1, \dots k_D \quad (14)$$

where $\mathcal{D}_l(.): \mathbb{R}^{k_1+k_2+1} \to \mathbb{R}, \sigma(.)$

Let's have $X' = (D', C_1), C' = (C'_1,\ C'_2), \beta' = (\beta'_D, \beta'_1)\ and\ \gamma' = (\gamma'_D, \gamma'_l)$

$$Pr\{Y \le S_y(\tau|X)\} = Pr\{Y \le S_y(\tau|X)|C\} = \tau \quad (15)$$

$$S_y(\tau|C) = X'\beta + \sigma(X'\gamma)q(\tau) \quad (16)$$

$$\frac{1}{\sqrt{n}}\sum_1^n C_i\left(\frac{Y_i - X_i'\widehat{\beta}}{\sigma(X_i'\widehat{\gamma})}\right) = 0 \quad (17)$$

$$\frac{1}{\sqrt{n}}\sum_1^n C_i\left(\frac{|Y_i - X_i'\widehat{\beta}|}{\sigma(X_i'\widehat{\gamma})} - 1\right) = o_p \quad (18)$$

$$\frac{1}{\sqrt{n}}\sum_1^n \psi_i\left(\frac{|Y_i - X_i'\widehat{\beta}|}{\sigma(X_i'\widehat{\gamma})} - 1\right) = o_p(1) \quad (19)$$

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