Joint Discussion Paper Series in Economics

by the Universities of

Aachen · Gießen · Göttingen
Kassel · Marburg · Siegen

ISSN 1867-3678

No. 38-2015

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International Trade in Second-hand Electronic Goods and the Resulting Global Rebound Effect

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Abstract

This paper analyzes the consequences of innovations in the electronic goods sector for global energy consumption and identifies a global rebound effect with respect to trade in second-hand electronic consumption goods. With the help of 2SLS-regressions, the positive influence of trade in second-hand electronics on the respective penetration rates in developing countries and the consequences for worldwide energy consumption are estimated.

JEL classification: F14, F63, Q49

Keywords: Second-hand trade, global rebound effect, energy consumption

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†Acknowledgment: This paper was written as part of a research studying rebound effects in North-Rhine Westphalia (NRW) funded by the Ministry of Innovation, Science and Research (MIWF) with project management by Energie, Technologie und Nachhaltigkeit (ETN) (Grant No. 313-005-2013-W029-MIWF).

1 Introduction

In a world of ever faster innovations in the electronic consumption goods sector, a TV, bought a few years ago, is already outdated. The quest for a new mobile phone is a persistent companion and the energy efficiency rate of a new refrigerator beats the energy consumption of the one in place by far. Innovations in electronic goods motivate people to substitute their possessions despite the remaining full functional capability. The acquisition of a new electronic device is usually accompanied with lower energy consumption. Simultaneously, consumers adapt their consumption behavior to lower costs resulting from more energy efficient devices by increasing their consumption pattern. For example, a new refrigerator or TV might be larger than the one that is being replaced. This change in consumer behavior offsets part of the potential energy savings from improved energy efficiency. This shortcoming to the potential energy savings has been first detected by William Stanley Jevons in 1865 and is widely known as rebound effect (Sorrell, 2009; Alcott, 2005). In a vast literature, the direct as well as indirect rebound effect have been analyzed and quantified showing that the adoption of more energy-efficient technologies does not decrease total energy consumption by the expected amount.[1] This rebound effect is even more pronounced in developing countries due to a larger distance to the saturation point in the consumption of electronic goods.[2] Only recently, Wei (2010) recognized that a national view on energy consumption is too short-sighted and developed a general equilibrium model to analyze the global rebound effect. Adding to this consideration, I take a closer look at the consequences of substituting used electronic goods for new, more efficient ones in industrialized countries for worldwide energy consumption. I suggest that following the substitution of used electronic goods for new devices in industrialized countries, the old goods are not necessarily scrapped. Instead, second-hand electronics can be exported to developing countries where the demand for used electronic goods at a cheaper price is comparably high. I hypothesize that, on a global scale, the export of second-hand goods therewith causes an expansion of the consumer group. That is, in developing countries, imported electronics serve as primary purchases for the population. Hence, next to enabling an access to technologies from industrialized countries in the developing world, energy consumption worldwide increases. On a global level, this export reduces energy savings gained by installing more energy efficient devices in the industrialized countries. Consequently, a global rebound effect occurs.

[1] See Sorrell et al. (2009) for a thorough review.

[2] Sorrell (2007); Roy (2000); Ouyang et al. (2010); Li and Yonglei (2012)

Given its relative importance, energy consumption of private households in developing countries appears to be worth further investigation. In Germany, for example, private households account for around 27% of national energy consumption (Cook et al., 2011); this figure accumulates to even higher 39% for residential buildings in the US (Kavousian et al., 2013). Consumer electronics make up for 22% of this residential electricity consumption, refrigeration causes an additional 28% (De Almeida et al., 2011). Wolfram et al. (2012) demonstrate that the expected increase in world energy demand in the period of 2007 - 2035 will be mainly driven by developing countries. The primary purchases of domestically used electronic goods resulting from the increasing income will play a major role. The authors refer to Dubin and McFadden (1984), who identified energy intensive consumption goods, such as refrigerators and vehicles, as the main drivers of domestic energy demand. Chugh et al. (2011) point out that vehicle sales in India have increased by the threefold between 2002 and 2008. According to Auffhammer (2014), the consumption of air-conditioning has also experienced an explosive growth. Wolfram et al. (2012) view this as general evidence for an overall trend in augmented primary purchases of energy intensive goods in developing countries.

This rise in primary purchases of energy intensive goods causes an increase in the respective penetration rates in these countries. In order to analyze the international diffusion of electronic goods and consequently a possible global rebound effect, the theories on global technology diffusion serve as a stepping stone. Barro and Sala-i Martin (1997) have introduced the innovator-imitator model as explanation for the diffusion of new technologies. Data provided by the industrial commodity production statistics database of the United Nations Statistic Division show that production of electronic consumption goods in developing countries, mainly in Africa, is limited at best. Considering the often lacking producers of electronic devices, the imitation process does not seem to work in all developing countries. Instead of focusing on the imitation of electronic devices by producers in developing countries, I take a closer look at the access to these devices for consumers through international trade. Grossman and Helpman (1995), as well as Holmes and Schmitz (2001) and, in an empirical study, Comin and Hobijn (2004), analyze the effect of international trade and "trade openness" on the diffusion of technologies and find a positive impact. Furthermore, Helpman and Trajtenberg (1996) look into the diffusion of general purpose technologies, while Acemoglu et al. (2007) investigate upon the impact of different factor endowments on technology diffusion. In analogy to the results of Caselli and Coleman (2001) and Lee (2000), Comin and Hobijn (2004) find that next to GDP per capita, trade openness as well as human capital, political institutions, the level of accumulated technologies, infrastructure of a country and the effectiveness of legislature have a positive influence on the technological development of a country. Despite identifying economic prosperity (GDP p.c.) with 23% as main explanatory factor for the differences in technological diffusion between countries, Comin and Hobijn (2004) agree with Basu and Weil (1998), Acemoglu et al. (2007) and Caselli and Coleman (2001) that economic prosperity is not the unique explanatory factor for these differences.

Building upon these findings, I seek to explain the differences in penetration rates of electronic devices between countries based on the trade effect identified by Grossman and Helpman (1995) and Holmes and Schmitz (2001). Thereby, I focus on the impact of trade in second-hand goods on the respective penetration rates. Due to data limitations, I analyze the diffusion of computers, televisions, refrigerators and radios as representative examples for electronic goods in general. Finally, I estimate the resulting increase in energy consumption in order to quantify the global rebound effect. I start by introducing the dataset on which I base the analysis. Next, trade with second-hand electronic goods is identified. Afterwards, I apply a cross-sectional regression analysis to provide support for the hypothesis of an increasing consumer group caused by trade in second-hand goods. Here, the impact of trade on penetration rates is estimated. Finally, the consequences for energy consumption are quantified. Before summing up the results and giving an overall interpretation of the significance for the global rebound effect in the conclusion, possible shortcomings of this analysis are exposed and justified to the best of my knowledge.

2 Data

I construct two datasets based on the availability of penetration rates of electronic devices in developing countries. The database "Cross-country Historical Adoption of Technology (CHAT)" by Comin and Hobijn (2009) provides information on the number of electronic devices used in a country, such as computers, televisions and telephones. The widest, and most recent coverage of data is available for the year 2002, with records for the number of computers in 129 countries worldwide. Due to the low coverage with respect to televisions and the rather modest energy consumption of telephones, this regression analysis only considers computers from this database. Dividing the number of electronic devices in a country by its population size yields the number of computers per inhabitant - the penetration rate.[3] The Demo-

[3]In their dataset, Comin and Hobijn (2009) define the relevant variable as the"number of self-contained computers designed for use by one person".

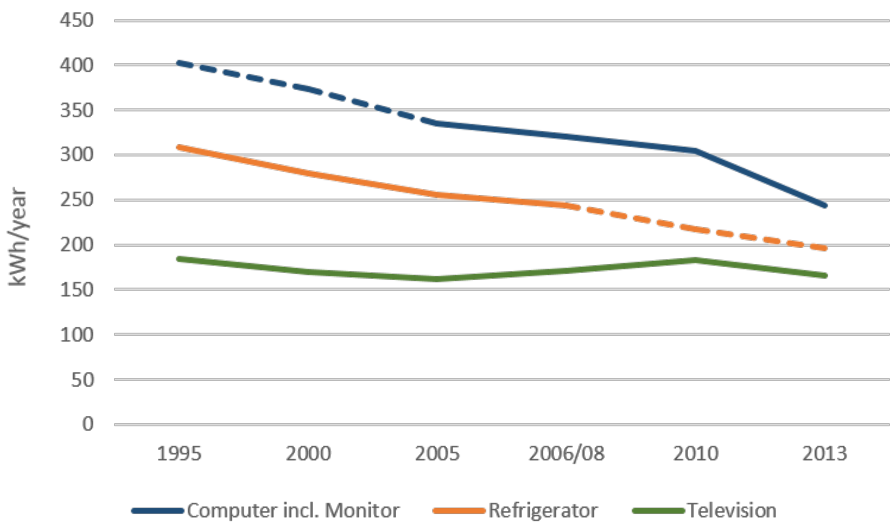
graphic and Health Surveys (DHS) conducted by USAID (2012) additionally provide data on penetration rates per household for radios, televisions, and refrigerators, i.e. the percentage of households owning the respective electronic device, over different survey years. The database comprises 71 developing or emerging countries with an average GDP per capita of 2,730 USD. More than half of the sample consists of African countries. The surveys were conducted between 1990 and 2012 in these countries. In most countries, however, the surveys were carried out only once during this time period. Even though some countries were covered multiple times, the sample of these countries is too small to analyze a change in penetration rates. In the case of multiple surveys, I always refer to the most recent survey data for the respective country. On average, the surveys were conducted in year 2005.

Hence, representing the electronic goods sector, this study analyzes the international diffusion of computers, televisions, radios and refrigerators. Data on the imported quantity of these electronics goods by the countries covered in both data sets is taken from the UN Comtrade Database (2014). The traded goods are defined according to SITC Rev.2 classifications given in Table A1 in the Appendix. However, a distinction between new and used goods is lacking from trade registers. A possible approach for the identification of trade in second-hand goods is explained in the next section. The values of total imports are recorded in million USD. Additionally, the aggregated weight and the number of imported units is added to the data set, if available. Trade data is collected for the corresponding survey year of the dependent variable, the penetration rates. In case of lacking data in the specific year, the trading volume of the previous available year up to three years prior to the survey year is included instead. Due to a high volatility in trading volumes between years, robustness checks are undertaken with five-year averages of trading volumes.

Additional controls are chosen in correspondence to Comin and Hobijn (2004) and Grossman and Helpman (1995): economic prosperity with GDP per capita, trade openness as the share of the sum of imports and exports to GDP, the population size of a country and education according to secondary schooling. Data on these controls is retrieved from the World Bank's World Development Indicators. A country's household number is documented in the DHS surveys. Geographical indicators applied in the construction of an instrumental variable are retrieved from the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) (Mayer and Zignago, 2011). All explanatory variables are included in the database in correspondence to the survey year of the dependent variable. Hence, I obtain one cross-sectional dataset for the year of 2002 with respect to computers for 129 countries, and one with varying years between 1990 and 2012 for televisions, refrigerators, and radios in 71 countries. The countries included as well as the income classifications applied in the analysis are listed in Table A2 in the Appendix.

Data on average yearly energy consumption of electronic devices used in households is available from different European and US American studies. A survey called REMODECE conducted by De Almeida et al. (2011) reports the average energy consumption of eight classes of electronic goods in kWh per year for households of twelve European countries. The study was conducted during the years 2006 to 2008 for 100 households in each country. Another European project (eepotential) envolving 27 EU countries reports yearly energy consumption for three electronic device categories per household in selected years between 2004 and 2012 (Energy Economics Group, 2009). The Fraunhofer USA Center for Sustainable Energy Systems (FhCSE) conducted surveys on the energy consumption of consumer electronics used in US households in 2007, 2010 and 2013 (Urban et al., 2014). Furthermore, the authors present an overview of previous studies on energy consumption of information and communication technology (ICT) devices. A report commissioned by the German Umweltbundesamt (Environmental Performance Agency, EPA) presents energy consumption rates for refrigerators, freezers and televisions in the years 1995, 2000, 2005 and 2008 (Cook et al., 2011). All studies portray the actual energy consumption of the electronic devices in place in the respective country of the survey. Hence, in addition to the state of the technology, the consumption behavior of European and American consumers is mirrored in these energy consumption rates. However, to my knowledge, consumption behavior and corresponding energy consumption rates per electronic device are not available for developing countries. Hence, I base the analysis on energy consumption data retrieved from indistrialized countries assuming that consumption patterns do not differ substantially between countries. When comparing the energy consumption rates across European countries no systematic differences with respect to climate areas or different income classes can be identified. Due to the repeated performance of the surveys conducted by the German EPA and the FhCSE, I apply the energy consumption rates reported in their studies. Also, these energy consumption rates reflect the lower boundary of the estimates presented in the various studies. Therewith, the energy impact quantified in this study is estimated with the needed caution. An overview of the energy consumption rates of the three electronic devices presented by the German EPA and the FhCSE is illustrated in Figure 1 and clearly shows a decrease in the energy consumption rates per electronic device over the last two decades. The values generated by linear interpolation (dashed line segments) are in line with the data reported by the eepotential project

(Energy Economics Group, 2009), as well as the general finding of over time decreasing consumption rates documented in the energy consumption literature.[4] Only for televisions the energy consumption rate has stayed rather constant. Here, the increase in screen sizes as well as the development from tube monitors to flat screens may have offset the improvements in energy efficiency. Data on yearly energy consumption of radios is only available from the REMODECE project with 46 kWh per year in 2006/2008.



Data on computers are retrieved from the FhCSE, values for 1995 and 2000 are linearly interpolated; Data on refrigerators are taken from the German EPA, values for 2010 and 2013 are linearly interpolated; Data for televisions are taken from the German EPA for the years 1995 through 2008, Data on 2010 and 2013 are taken from the FhCSE

Figure 1: Energy Consumption per Electronic Device

Based on these energy consumption rates, for the calculation of the global rebound effect, I will distinguish between three kinds of electronic goods: *new goods* currently used in the industrialized world, *second-hand goods* which are being sorted out in industrialized countries and *old goods* which are in place in the developing world. New goods are defined as the ones in place in industrialized countries and are assumed to perform according to the current energy consumption rates depicted in Figure 1 for 2013. Second-hand goods are assumed to have been in place around 2006 in the industrialized world and are replaced now and consequently exported to developing countries. Old goods have even lower standards in terms of energy efficiency, approximately equal to the energy consumption rates of products applied in 1995 in industrialized countries. These assumptions are in line with a German and

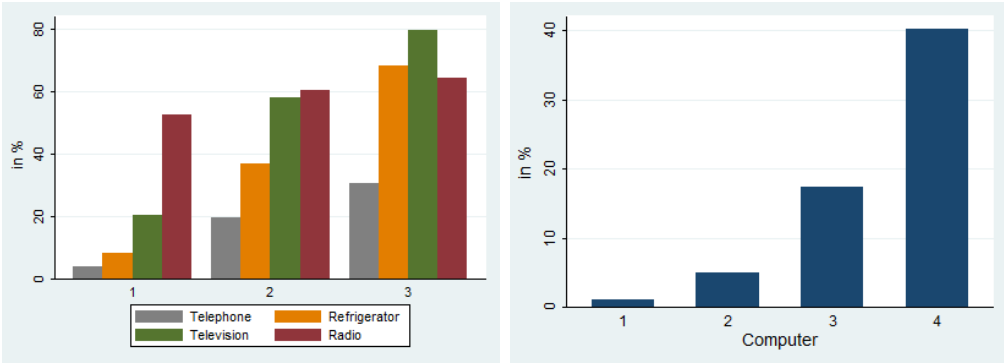
[4]See for example: IIIEE (nd), Ahmed (2012) and ZVEI (2012)

a British study, published by the German Statistisches Bundesamt (2013) (federal Statistical Office) and Cooper (1994), which classify refrigerators, telephones, computers and televisions as durable goods with a minimum usage time of five years but also often up to ten or twelve years. The lifespan of reused electronic items, i.e. second-hand goods, has been estimated to accumulate to an additional 3 years (Peralta and Fontanos, 2006). Accounting for the enormous repair activities in developing countries, the lifespan can however be extended considerably (Osibanjo and Nnorom, 2007).

3 Identification of Trade with Second-Hand Goods

Trade in second-hand electronics is not documented in international trade statistics. The identical commodity codes for new and second-hand electronics makes tracking of trade in used goods challenging. While academic research on trade with second-hand electronics is scarce, field studies, e.g. conducted by the Swiss e-Waste Programme, provide evidence for trade flows in used commodities between industrialized and developing countries. The share of second-hand goods in imported electronics lies around 70% in Ghana and Nigeria (Amoyaw-Osei et al., 2011; Ogungbuyi et al., 2012). The share of second-hand electronics in the imports of other African countries is estimated to be lower, but still amounts to between 15 and 50% (EMPA, 2009) of total trade volume. The focus in investigative journalism often lies on illegal trade with electronic waste and the detrimental environmental consequences. This study focuses on imports of functioning second-hand electronic goods. Due to practical reasons, this analysis is limited to the documented legal trade in electronics. Trade in electronic scrap is restricted by the Basel Convention and, moreover, prohibited for member countries of the European Union ruled by the EU-Guideline 2002/96/EG on Waste of Electrical and Electronic Equipment (WEEE). Hence, illegal and therefore non-documented waste exports, which are, however, partly repaired in developing countries and often continued to be used, are neglected from the analysis.

In order to identify trade with second-hand goods, I take a look at the two sides of the argument justifying second-hand trade between two regions of the world: demand and supply. On the one hand, there is demand for cheap electronic goods in developing countries. A possible saturation level for electronic devices seems far from being met. As can be seen in Figure 2, penetration levels are gradually increasing with the income level of countries. Except for radios, the penetration rates of electronic goods in developing countries have



(a) (b)

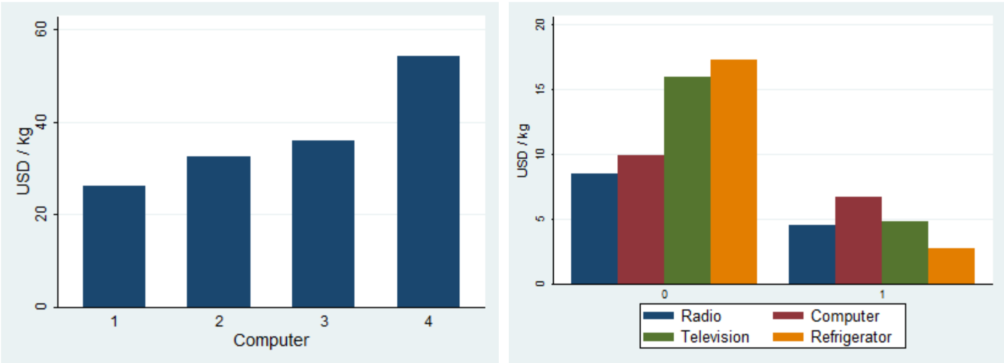
Own illustration based on DHS and CHAT databases.

Figure 2: Penetration Rates according to Income Classes

large potential to rise. Panel (a) of Figure 2 reflects the penetration rates in households of 71 developing and emerging countries classified in three income groups. Industrialized countries belonging to income class 4 are not covered in the DHS data set depicted in Panel (a). With increasing income, penetration rates with respect to all products increase. The penetration rates per head, generated from the CHAT Dataset and portrayed in Panel (b), also illustrate the dependence of penetration rates on income levels for computers. These illustrations are in line with the findings of Wolfram et al. (2012) who analyze the development of energy demand in developing countries and show that families emerging from poverty first acquire electronic household appliances such as televisions and refrigerators. Davis et al. (2014) also expect households from emerging countries to purchase electric appliances as income rises. The relatively lower penetration rates and the low income levels underline the hypothesis that there is demand for cheap electronic devices in developing countries. As data retrieved from the industrial commodity production statistics database from the UN Statistics Division[5] show, this demand can, however, not be met by domestic production. Hence, international products have to satisfy the demand for cheap electronics in developing countries.

However, on the other hand, data on the international supply of second-hand electronics to developing countries is missing. While trade in electronic appliances in general is documented in international trade statistics, the lacking distinction between new and used electronics asks for reasoning

[5] available under http://unstats.un.org/unsd/industry/commoditylist2.asp



(a) (b)

Own calculation and illustration based on data retrieved from the UN Comtrade database.

Figure 3: Mean Value of Imported Electronic Goods

and anecdotal evidence to underline the assumption of exports of second-hand electronics to developing countries. The challenge of lacking data on international trade with second-hand goods has been addressed in several studies. In these studies, second-hand goods have been identified by their comparably low value per kilogram exported of each product (Duan et al., 2014; Sander and Schilling, 2010). Based on this method, Duan et al. (2014) estimate an export volume of 870,000 used laptops for the United States in 2010. In 2011, US $1.5 billion worth of used electronic products have been exported by the US (U.S. International Trade Commssion, 2013). According to a field study, around 155,000 tonnes of used electronic goods have been exported from Germany in 2008 (Sander and Schilling, 2010). The lower value per kilogram of used goods in comparison to new goods from the same country of origin can be observed when comparing different groups of destination countries. Figure 3 demonstrates how richer countries import higher valued electronic goods. In Panel (a), the value per imported weight unit of a computer in USD per kilogram increases with the income level of the receiving country. A similar picture is painted in Panel (b). When distinguishing between destination countries in Africa (1) versus other emerging countries (0), a lower value per kilogram for all four electronic devices can be observed when exported to African countries.

Even though trade with second-hand electronics cannot be uniquely determined, I present strong evidence confirming the assumption that the share of second-hand electronics imported by developing countries is relatively high compared to the used goods' share in imports of industrialized nations.[6] Moreover, African countries can especially be identified as recipient countries of used goods. In fact, a number of African countries belongs to the main importers of second-hand goods. Coming back to the argument of the imported goods value per kilogram, Panel (a) of Figure 4 shows, exemplary for the case of used computers, that almost half of those countries importing computers with a value below 15 USD per kg are located on the African continent. In Panel (b) of Figure 4, African countries as well as the average of all countries that import computers valued less than 20 USD per kg are depicted. Nigeria, Ghana, Cameroon, Tanzania and Sudan can be identified as the main importing hubs of second-hand imports with low levels of value per imported kilogram but comparatively large imported quantities. The average second-hand importing country represents all countries importing computers with a value below 20 USD per kg.[7] Confirming this finding, Ghana and Nigeria have repeatedly been identified as main hubs of used electronic goods and electronic scrap in other studies (Sander and Schilling, 2010).

4 Results

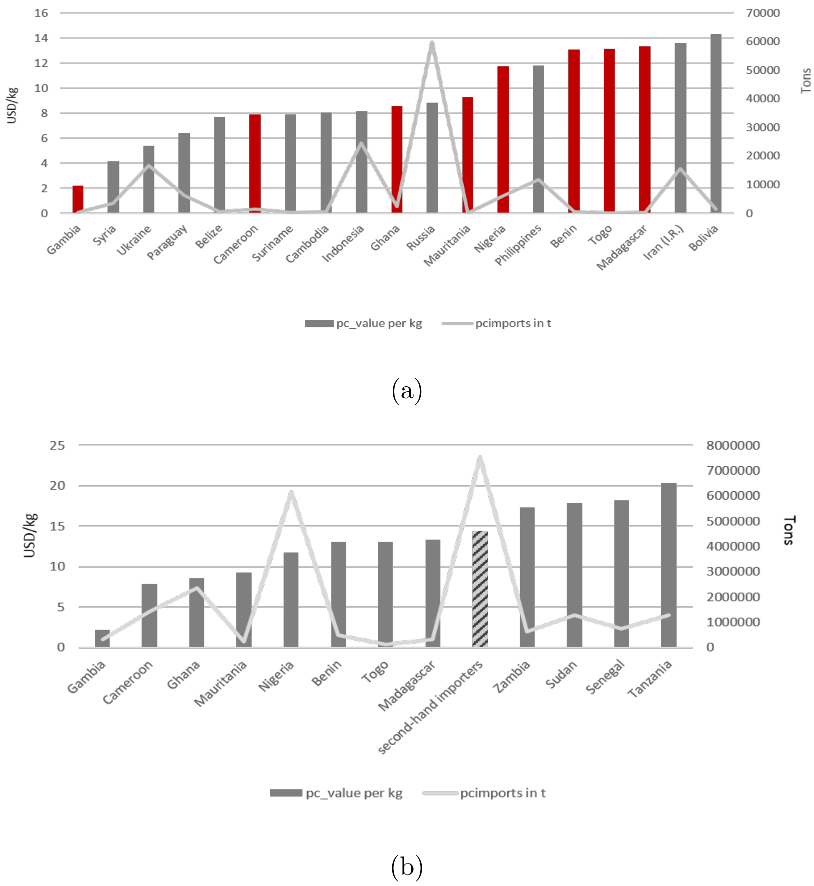
Having argued that developing countries, and specifically, African countries import to a large share second-hand electronic devices, the question remains on what the consequences of trade in second-hand electronics for developing countries are: Does this kind of trade enable more consumers to have access to technologies from industrialized nations or are the imported goods only enabling consumers to exchange their products for newer devices? And, in a second step, what are the consequences for energy consumption in developing countries?

With the help of a cross-sectional ordinary least squares (OLS-) regression, the effect of trade on the penetration rate ρ of good n in the importing country i is identified and quantified. With a multivariate model this effect is separated from other factors influencing the diffusion of technology. The parsimonious model per good n is defined as:

$$\rho_i = \beta_0 + \beta_1 IM_i + \beta_2 GDPpc_i + \beta_3 openness_i + \beta_4 Africa + \epsilon, \qquad (1)$$

[6] I acknowledge however the fact that the difference in value per kilogram can also mirror a different quality of the imported good. As argued, anecdotal evidence convinces me to continue with the assumption that developing countries import a larger share of second-hand goods.

[7] The three largest importing countries of low-valued goods, namely Russia, Indonesia and Ukraine, are responsible for the high average volume of imported computers for the average country.



Own illustration based on imported values and weights retrieved from the UN Comtrade database.
Panel (a) shows all importers of electronic goods below 15 USD/kg;
Panel (b) presents all African importers of electronic goods below 20 USD/kg.

Figure 4: Import Values and Quantities of Computers

with IM_i giving the imported value of country i of electronic device n in million USD. In analogy to Comin and Hobijn (2004), GDP p.c. and trade openness in general prove to be relevant factors positively affecting the level of technology adoption in a country. A dummy for African countries is chosen as additional control accounting for the continent specifics. Other continent dummies were found to be insignificant and irrelevant for the results. An indicator for the democratic constitution of a country, the polity2 index, was also insignificant and therefore dropped from the parsimonious model. Similarly, including education drastically reduces the sample size without allowing further insights and is therefore also omitted from the model presented here. Table 1 displays the regression outcomes on the respective penetration rates of the four electronic devices. The total volume imported of each electronic good, given in million USD, represents the explanatory variables of main interest.[8] The coefficients and corresponding p-values depicted in the table show the relevance of trade in electronic goods for explaining cross-country variation in the respective penetration rates. All else being equal, the diffusion of refrigerators, radios and computers is positively and significantly correlated with imports of these products. Importing televisions has no significant effect on the respective penetration rate.

	(1) television	(2) refrigerator	(3) radio	(4) computer
GDP_pc	0.00617*** (0.000)	0.00594*** (0.000)	0.000204 (0.859)	0.00131*** (0.000)
TradeOpenness	0.153** (0.016)	0.180** (0.020)	0.109 (0.108)	0.0377** (0.021)
Africa	-39.51*** (0.000)	-27.93*** (0.000)	11.04** (0.013)	-2.292 (0.182)
tv_imports	0.00851 (0.145)			
fridge_imports		0.184*** (0.006)		
radio_imports			0.305*** (0.001)	
pc_imports				0.00035** (0.028)
N	59	59	59	118
Countries				
Adj.R2	0.747	0.626	0.195	0.812

The dependent variables are the respective penetration rates; p-values are depicted in parentheses. Significance levels are marked by: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1: OLS - Regressions on Penetration Rates

In addition to the findings on the trade effect on penetration rates of electronic goods and in analogy to the suggestion from the descriptive part in Section 3, it is shown that higher penetration rates of electronic devices come along with higher per capita income in a country. However, the coverage of radios in a country is independent of GDP per capita. This finding originates in the fact that radios classify to a lesser degree as high-technology

[8]Data on the traded volume in monetary units covers the largest sample compared to imports documented in units or weights. Moreover, for existing data, correlation between imported units and values is highly positive and significant with correlation coefficients ranging between 0.5 and 0.98 depending on the electronic device. Therefore, the analysis is based on imports documented in million USD.

goods.[9] A high level of trade openness in a country, measured as the share of overall exports and imports to GDP, facilitates the diffusion of technology in addition to the imports in the specific product category. The positive effect of trade openness indicates the importance of globalization and international connectedness of a country. Last, the Africa-dummy controls for the continent specifics such as the generally lower level of penetration with respect to all high-technology goods. Again, radios are the exception. Interestingly, when controlling for other factors, such as per capita income, more African households possess a radio whereas this good has, apparently, been substituted by modern media on other continents.

The simultaneous causality between supply and demand for technological goods strongly suggests a problem of endogeneity. Hence, a possible bias and inconsistency in the coefficients estimated with OLS is expected. To control for the possible endogeneity and to obtain a consistent estimator, I design an instrumental variable (IV). I adopt the approach from Romer and Frankel (1999), also employed in the context of trade with second-hand clothing by Frazer (2008), applying a gravity approach in the first stage of a Two-Stage Least Squares (2SLS) regression, to instrument for the import values. Specifically, the value of imported electronic goods of a country IM_i is predicted to be a function of geographic variables. The specification of the bilateral trade equation is

$$IM_i = \gamma_0 + \gamma_1 D_{ij} + \gamma_2 A_i + \gamma_3 A_j + \gamma_4 N_i + \gamma_5 N_j + \gamma_6 L_i + \gamma_7 L_j + \boldsymbol{\gamma x} + u_{ij}, \quad (2)$$

where D_{ij} is the distance between two trading partners. A, N, and L describe the trading partners' land area and population and whether the country is landlocked. The vector $\mathbf{x}$ accounts for the exogenous controls included in the second stage. The index i describes the importing country, while the country indexed by j is i's most important trading partner with respect to each commodity. On average the most important trading partner, for which the country characteristics are chosen in the gravity equation, accounts for around 50% of all imports in the respective good of a country. Romer and Frankel (1999) suggest that geographical factors serve well as instrument of trading volumes due to their strong correlation. Moreover, the combination of geographic attributes of the trading partners does not influence the dependent variable. To be more concrete, it is reasonable to assume that the orthogonality condition holds, i.e. that the error term ϵ is not affected by any of the instruments chosen.

[9] As a consequence, the adjusted R^2 is substantially lower in comparison to the explanatory power of the regressions of the other three electronic devices.

	(1) television	(2) refrigerator	(3) radio	(4) computer
GDP_pc	0.00620***	0.00566***	-0.000403	0.00122***
	(0.000)	(0.000)	(0.753)	(0.000)
TradeOpenness	0.150**	0.175**	0.138*	0.0451**
	(0.025)	(0.030)	(0.095)	(0.019)
Africa	-39.94***	-24.22***	13.67***	-2.174
	(0.000)	(0.000)	(0.002)	(0.237)
tv_imports	0.00467			
	(0.792)			
fridge_imports		0.285*		
		(0.057)		
radio_imports			0.436***	
			(0.003)	
pc_imports				0.0007
				(0.109)
N	57	56	57	111
Countries				
Adj.R2	0.738	0.593	0.164	0.807
Durbin	0.8067	0.4582	0.2358	0.3761

The dependent variables are the respective penetration rates; p-values are depicted in parentheses. Significance levels are marked by: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
The Durbin test presents the p-values against the null hypothesis of exogenous variables.

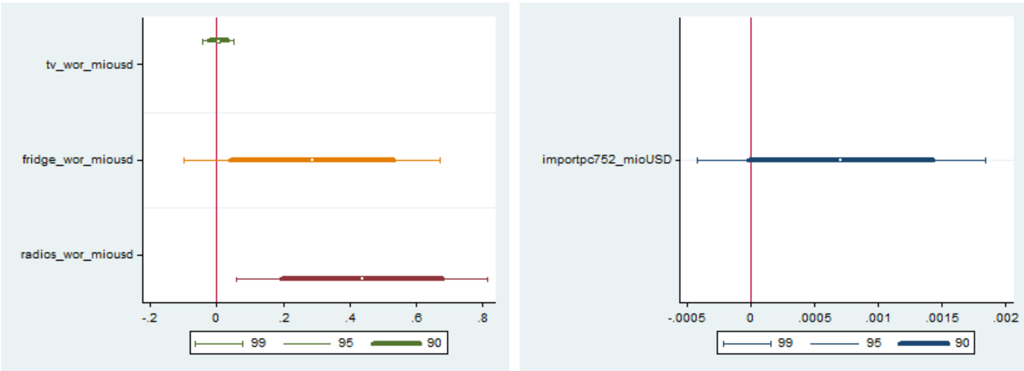
Table 2: 2SLS - Regressions on Penetration Rates

The results of the 2SLS regression are displayed in Table 2. The outcome supports the results found by applying OLS and emphasizes the previous findings. The sign and significance of the coefficients of all previously significant controls can be confirmed. Regarding the instrumented variable, the impact of trade in refrigerators and radios remains positive and significant. The impact of imported computers barely misses the margin of being significant at the 10% level. In terms of magnitude, the size of the coefficients increases for three out of four product categories. In economic terms, the results show that ceteris paribus, e.g., importing refrigerators worth one million USD increases the penetration rate on average by almost 0.285 percentage points. An increase in the consumer group resulting from importing second-hand electronics can be concluded. This effect is statistically significant for refrigerators and radios. The coefficient on the trade impact of computers and televisions also shows the expected positive sign, albeit being insignificantly different from zero. The insignificant coefficients indicate that, e.g., imported televisions do not reach new consumers but serve as substitutes for existing appliances. Statistically, the coefficients are equal to the OLS-estimates reported before. With p-values above at least 0.37 for all devices, the null hypothesis of equal coefficients cannot be rejected based on the Wald test. The results are also robust to different specifications. The regressions have been tested with 5-year averages to smooth trade volumes over a longer time period with similar results as presented here for OLS- and 2SLS-regressions. Similarly, conducting the OLS- as well as the 2SLS-regressions in log-log form supports the prior results. The outcome of the log-log 2SLS-regression is depicted in Table A3 in the Appendix. Here the dependent variable is the logarithm of the number of each electronic device applied in a country. For example, a 10% increase in imports of refrigerators, on average leads to additional 1.6% appliances of this electronic device in a country. Considering the 95%- confidence intervals increases this range by 0.1 to 3%.[10]

Testing the robustness of the instrumental variable approach, the Null-Hypothesis of weak instruments can be rejected for all four products. Nevertheless, the joint correlation of the instruments with the endogenous variable is rather low, such that a considerable efficiency loss has to be born in mind. While theory clearly marks a problem of endogeneity due to simultaneous causality between imported electronic goods and the penetration rates in a country, i.e. supply and demand, the Durbin test on exogenous explanatory variables conducted on the 2SLS-regressions, depcited in Table 2, does not confirm this theory. However, in the log-log regressions, displayed in Table A3, the null hypothesis of exogenous variables must be rejected for the cases of radios and computers providing some evidence for the theory of simultaneous causality. Additionaly, the Wu-Hausman test was conducted. The test statistics, while not being displayed in the tables, support the findings of the Durbin test in all regressions tested. Despite limited econometric support for the suspicion of endogeneity but due to the strong theoretical suggestion and the similarity in the quality of the results of OLS and 2SLS, I will continue with findings from the 2SLS approach.

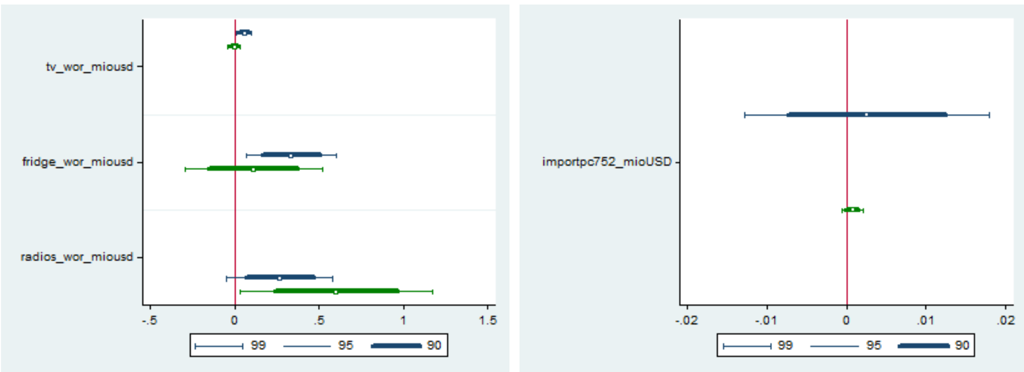
Figure 5 visualizes the trade effect per electronic device on a country's penetration rate, i.e. β_{1n}, as estimated by the 2SLS-regressions. Panel (a)

[10]Depicted in Figure A1 in the Appendix.



(a) (b)

Figure 5: Trade Effect on Penetration Rates



(a) (b)

The upper blue bar visualizes the trade effect coefficient for African countries.

Figure 6: Trade Effect on Penetration Rates: African vs. Other Countries

presents the trade effect coefficients including confidence intervals for televisions, refrigerators, and radios from the DHS dataset. Equally, the trade effect of computers is portrayed in Panel (b) based on the CHAT dataset. It can be seen that the effect of trade is positive and significant at the 10% level for trade with refrigerators, radios, and barely for computer. When distinguishing for different subsamples, the impression changes somewhat. Figure 6 illustrates the trade effect estimates for African versus other countries in the respective datasets. With the exception of the less technological good radios, African countries (depicted as the upper bar in blue) experience a greater increase in their penetration rates when importing electronic devices compared to other countries (the lower bar in green). While the impact of imported computers turns insignificant, the remaining imported electronic devices certainly increase penetration rates in African countries. In this subsample, importing television sets also has a significant positive impact on the penetration rate. The insignificant effect of imported computers suggests that these imported devices in Africa are rather used as substitutes for existing computers. The robustness checks conducted with log-log 2SLS-regressions and depicted in Figure A1 confirm this result. The limited sample size, however, gives reason to question the consistency of the estimators in the subsamples. Hence, I perform robustness checks by constructing interaction terms between the imported volume of good n and the African dummy and running 2SLS-regressions on the full sample with instruments applied to the imported volume and the interaction term. The results, presented in Table A4 in the Appendix, confirm the message conveyed in the graphical illustration and give additional insights. For non-African countries, the effect of trade on the respective penetration rate is only significant for radios. Performing the Wald test shows that the estimated coefficients of the imported volume and the interaction term are jointly significant for all electronic devices but computers. Hence, for African countries a positive and significant effect can be observed for trade with televisions, refrigerators and radios. The difference between African and non-African countries is however only significant for trade with televisions.

The rise in penetration rates implies that due to trade, the worldwide number of consumers of electronic goods increases since more electronic devices are used in developing countries. As a consequence, household energy consumption rises when developing countries gain access to consumer electronics. Based on the findings shown above, I continue by estimating the resulting increase in energy consumption. The absolute change in energy consumption per electronic device n in country i ($\triangle EC_{in}$) is calculated by

$$\triangle EC_{in} = \frac{\beta_n}{100} \times IM_{in} \times \#ofHH_i \times \overline{EC_n}, \tag{3}$$

where β_n gives the consistent point estimates displayed in Table 2 for the trade effect of good n, i.e. the increase in the penetration rate in percentage points per imported million USD of good n. IM_{in} gives each countries value of imports of good n in million USD. Dividing by a hundred and multiplying by the number of households transfers the rise in percentage points in the penetration rate to the absolute number of additional goods in a country.[11]

[11] The penetration rate of computers is given for the population instead of for households. Therefore the multiplication is conducted with the number of inhabitants for this product category.

Table A5 in the Appendix displays the last two decades' values of average yearly energy consumption per electronic device $\overline{EC_n}$ as depicted in Figure 1. For the application of second-hand goods the energy consumption rates from 2006/2008 are assumed.

In Table 3, the estimated average increase in energy consumption per electronic device and country resulting from international trade is depicted. A distinction is made with respect to the country group as well as two thought scenarios referring to the composition of electronic goods. For one, accounting for the differences between the country subsamples, the distinct changes in energy consumption per electronic device $\triangle EC_n$ can be calculated based on the respective import coefficients. Moreover, the differences in traded volumes across subsamples contribute further to differences in the energy consumption effect of trade. Putting the increase in energy consumption in the right perspective, a percentage increase with respect to the prior energy consumption of each good in a country is calculated. Hence, a closed economy without international trade is considered as counterfactual. And secondly, two scenarios are presented in Table 3. In scenario I, all goods imported are considered to be second-hand. Furthermore, the existing electronics in the importing country are assumed to have the same energy efficiency as the imported goods. Scenario II relaxes both of these assumptions. For one, relying on the findings of the case-studies conducted by EMPA (2009), the imported goods are assumed to be composed of fifty percent second-hand and fifty percent new electronic goods. And second, the existing goods are thought of as old goods with worse energy efficiency rates compared to second-hand imports. By assuming a rather long usage time of the durables in developing countries the second scenario can be considered as cautious estimates showing a lower boundary with respect to this concern. Since historical data on energy consumption for radios is lacking, only scenario I is displayed.

Scenario	I	II	I	II	I	I	II
	Refrigerator		TV		Radio	PC	
All countries	**26.09%**	**18.57%**	1.90%	1.74%	**10.14%**	**6.75%**	**4.73%**
Africa	**33.23%**	**23.64%**	**27.57%**	**25.24%**	**3.15%**	10.35%	7.26%
Other countries	9.12%	6.49%	-0.81%	-0.74%	**21.78%**	8.08%	5.67%

Bold digits present changes in energy consumption that are statistically significant, at least with 90%-confidence.

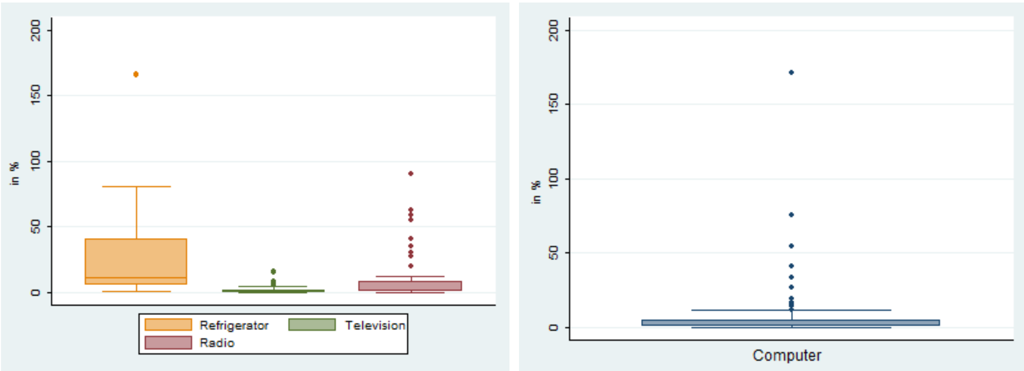
Table 3: Average Increase in Energy Consumption - per Electronic Device and Country Group

For the matter of completeness, the table presents the percentage changes for all four electronic devices in the whole sample as well as in both subsamples. Based on the results from the 2SLS-regressions, significant changes are presented in bold digits.

In general, a substantial increase in energy consumption caused by trade can be observed. Since Scenario II presents more cautious estimates, these estimates will be discussed below. Across the full country sample, the average increase per country and per electronic good mounts up to 18%. The impact is largest, and mostly significant, in the subsample of African countries. Only for radios, as the exception from the advanced technologies, the increase in energy consumption resulting from trade in African countries is lower than in the rest of the world. In African countries, international trade with second-hand electronics causes an increase in device specific energy consumption of up to 25%. The driving force for the larger impact among African countries can be identified as the trade effect, displayed in Figure 6. I.e, despite the lower volume of trade directed to African countries, energy consumption increases most in this subsample. Overall, trade with second-hand goods raises the penetration rates of poorer countries and therewith enlarges the number of consumers worldwide. Imports in other parts of the world seem to be used to a larger extent as substitutes for existing devices. The rather large point estimates are however put into the right perspective when considering the 95%- confidence-intervals of the increase in energy consumption for the full country sample, as presented for Scenario I in Figure 7 showing the large variety in the impact on energy consumption estimated. Despite the already large confidence intervals, there are some remarkable positive outliers for which the impact on energy consumption is extraordinarily high. With respect to computers, these remarkable positive outliers are namely China, and below 100% India and Mexico. With respect to refrigerators, the outlier is Nigeria. Concerning radios, five countries in transition experience an increase in energy consumption of above 50%: Indonesia, Columbia, Brazil, South Africa and Turkey.

In absolute numbers, and accounting for a mixture of second-hand and new imports with more efficient energy consumption rates in comparison to the old devices in place, the documented international trade in refrigerators, televisions and radios causes, on average, a significant increase of 178,469 kWh, 186,715 kWh and 18,831 kWh respectively in African countries. Aggregated over the 34 African countries included in the DHS dataset, trade with these three[12] electronic goods leads to an increase in energy consumption of 13.1 GWh. Taking the full sample results and aggregating over all countries covered in my datasets, the worldwide increase of energy consumption accumulates to nearly 62 TWh.

[12]Computers are excluded from the aggregation due to the insignifcant results.



(a) (b)

Figure 7: Confidence Intervals of the Increase in Energy Consumption

5 Conclusion

Innovations which lead to the application of new, more energy efficient electronic devices are supposed to decrease energy consumption. The adaption in consumption behavior and the resulting rebound effect, however, diminish possible energy savings. On a global level, energy savings suffer further losses since the old, substituted goods are often continued to be used in other parts of the world. By distinguishing second-hand imports from new goods by their lower value per kilogram, I provide evidence for the hypothesis that a large share of exported electronic devices, specifically televisions, radios, refrigerators, and computers consists of second-hand goods when the destination country lies in the developing world. Especially, some African countries have been identified as importing hubs of used goods. In a second step, I analyzed the impact of these imports on the penetration rates of the respective goods in a country. A special focus was set on developing countries in order to investigate upon the effect of second-hand imports. Applying 2SLS regressions in order to correct for possible endogeneity in the explanatory variable, a positive impact of imports of electronic devices on the penetration rates in developing countries is found, while the effect is largest in African countries. In fact, this rise in penetration rates provides support for the hypothesis of an increase in the consumer group for electronic goods resulting from trade with second-hand electronics. That is, the paper shows that substituting used electronics for more energy efficient ones and subsequently exporting the second-hand electronics to developing countries leads to an increase in the number of electronic appliances in use worldwide. Consequently and when taking a world without trade as counterfactual, the increase in the penetration rates leads to a a rise in energy consumption for these countries. Quantifying this rise in energy consumption, in African countries an increase up to 25% in energy consumption per electronic device is estimated. Trade with refrigerators and televisions causes the largest relative increase. Summing up over all African countries, an estimated additional 13.1 GWh are consumed. Including trade with new goods and extending the view to non-African countries leads to an estimated increase in energy consumption of 62 TWh.

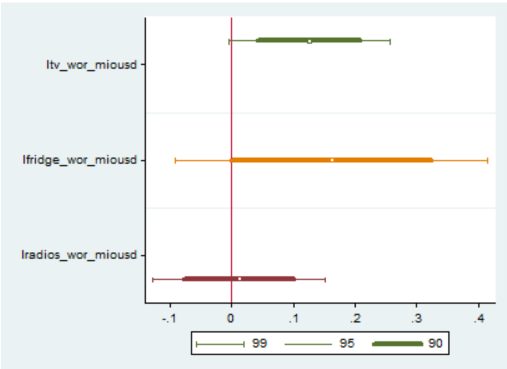
The findings presented here are a first step towards the analysis of trade in second-hand electronics in the context of rebound effects. This paper aims to provide support for a global energy consumption effect resulting from innovations in energy consuming goods. The limitations of available data require, however, a cautious interpretation of the findings presented here. On the one hand, only four electronic goods have been analyzed. Further electronic consumption goods such as washing machines, freezers, and other ICT devices, to name but a few, are omitted from the analysis here due to lacking data. Therewith, the total size of the global rebound effect concerning all electronic devices is underestimated. On the other hand, identification of trade in second-hand electronic consumption goods is complicated due to limited data. Additional research in trade with second-hand goods is required for the future. Lacking data prevents a clear distinction between imports of second-hand goods and new goods. Therefore, this study places a major focus on African countries where the share of second-hand imports has been highest. The increase in energy consumption based on a mixture of second-hand and new electronic imports compared to even less energy efficient old electronics in place in African countries can only be considered as a rough first estimate of the here defined global rebound effect. Moreover, the absolute number of second-hand goods shipped to developing countries cannot be identified. Hence, a possible substitution of outdated electronic goods in addition to the identified increase in the consumer group cannot be quantified. If substitution is large, the estimated increase in energy consumption due to trade should be scaled down. Furthermore, the energy needed in the production of new, more energy efficient electronic goods is neglected. In fact, continuing the use of electronic goods may be energy saving when accounting for the energy expenditure in electronic goods production. Finally, the widely discussed negative impact of trade in electronic second-hand goods and waste on the environment due to insufficient recycling technologies is not part of this analysis.

Despite the obvious limitations of the analysis conducted here, it can doubtlessly be concluded, that estimations concerning the rebound effect after the introduction of new energy efficient technologies should not be limited to a national view. When introducing improved energy consuming goods the worldwide consequences on energy consumption need to be recognized. Despite this conclusion, the potential increase in welfare and enabling of further development through the distribution of advanced technologies due to trade in second-hand goods should not be forgotten.

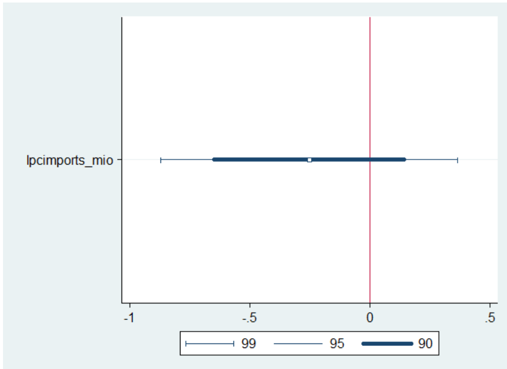
A Appendix

Product Classifications	SITC Rev. 2	Description
Computers	752	Automatic data processing machines and units thereof; magnetic or optical readers, machines for transcribing data onto data media in coded form and machines for processing such data, n.e.s.
Televisions	761	Television receivers (including receivers incorporating radio-broadcast receivers or sound recorders or reproducers)
Radios	762	Radio-broadcast receivers, (including receivers incorporating sound recorders or reproducers)
Refrigerators	7752	Refrigerators of household type (electrical and other)

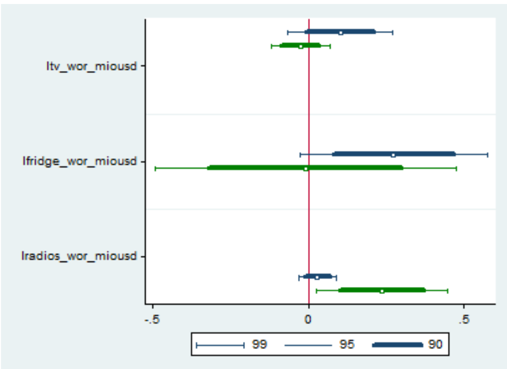
Table A1: Product Classifications



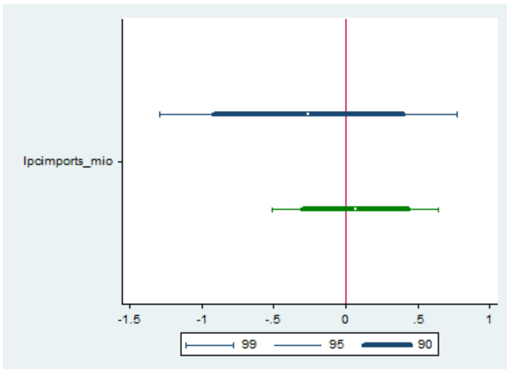
(a)



(b)



(c)



(d)

Panels (a) and (b): trade effect coefficients for the full sample;
Panels (c) and (d): trade effect coefficients for African countries (upper blue bar) vs. rest of the sample (lower green bar).

Figure A1: Confidence intervals of the Trade-Effect Elasticities

Continent	DHS - dataset	CHAT - dataset
Africa	Burkina Faso, Burundi, Central African Republic, Cameroon, Chad, Comoros, Democratic Republic of the Congo, Egypt, Eritrea, Ethiopia, Gabon, Ghana, Guinea, Ivory Coast, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Morocco, Mozambique, Namibia, Niger, Nigeria, Republic of the Congo, Rwanda, Sao Tome and Principe, Senegal, Sierra Leone, South Africa, Sudan, Swaziland, Togo, Uganda, United Republic of Tanzania, Zambia, Zimbabwe	Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Democratic Republic of the Congo, Egypt, Eritrea, Equatorial Guinea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Ivory Coast, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Republic of the Congo, Rwanda, Sierra Leone, Senegal, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe
Asia	Azerbaijan, Bangladesh, Cambodia, India, Indonesia, Jordan, Kazakhstan, Kyrgyzstan, Maldives, Nepal, Pakistan, Philippines, Turkmenistan, Uzbekistan, Vietnam, Yemen	Azerbaijan, Afghanistan, Bangladesh, Cambodia, China, Hong Kong, India, Indonesia, Iran, Iraq, Israel, Japan, Jordan, Kazakhstan, Kuwait, Kyrgyzstan, Laos, Lebanon, Malaysia, Mongolia, Nepal, Oman, Pakistan, Philippines, Russia, Saudi Arabia, Singapore, South Korea, Sri Lanka, Syria, Tajikistan, Thailand, Turkmenistan, United Arab Emirates, Uzbekistan, Vietnam
Australia		Australia, New Zealand, Papua New Guinea
Europe	Albania, Armenia, Turkey, Ukraine	Albania, Armenia, Austria, Belarus, Belgium, Bosnia-Herzegovina, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Macedonia, Moldova, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom
North America	Dominican Republic, Guatemala, Haiti, Honduras, Nicaragua	Belize, Canada, Costa Rica, Cuba, Dominican Republic, El Salvador, Georgia, Guatemala, Haiti, Honduras, Mexico, Nicaragua, Panama, United States
South America	Bolivia, Brazil, Colombia, Guyana, Peru	Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana Paraguay, Peru, Suriname, Uruguay, Venezuela

For the analysis, the countries are grouped into four income classes which are defined according to the worldbank classifications; for classification, GNI data from the respective year of the penetration rate data is taken, borderlines of income classes are set according to the guidelines of 2012, given below.

Income Classes:	GNI per capita in current USD
1	< 1035
2	1036 - 4085
3	4086 - 12615
4	> 12616

Table A2: Countries

	(1) log(television_number)	(2) log(refrigerator_number)	(3) log(radio_number)	(4) log(computer_number)
log(GDPpc)	0.381***	0.642***	0.066	1.251***
	(0.000)	(0.000)	(0.355)	(0.000)
log(trade_openness)	-0.0103	0.314**	0.001	0.559**
	(0.029)	(0.051)	(0.937)	(0.025)
Africa	-0.923***	-0.862***	0.278***	-0.291
	(0.000)	(0.000)	(0.009)	(0.119)
log(Household)	0.822***	0.621***	1.012***	1.299***
	(0.000)	(0.000)	(0.000)	(0.000)
log(tv_imports)	0.126**			
	(0.013)			
log(fridge_imports)		0.162*		
		(0.099)		
log(radio_imports)			0.012	
			(0.824)	
log(pc_imports)				-0.253
				(0.292)
N	57	56	57	111
Countries				
Adj.R2	0.853	0.808	0.761	0.901
Durbin	0.3087	0.3255	0.0052	0.0058

The dependent variables are the logs of the total number of electronic devices in a country; log(Households) controls for the size of the country; p-values are depicted in parentheses. Significance levels are marked by: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
The Durbin test presents the p-values against the null hypothesis of exogenous variables.

Table A3: 2SLS- log-log Regressions on the Number of Electronic Devices

	(1) television	(2) refrigerator	(3) radio	(4) computer
GDP_pc	0.00683***	0.00607***	-0.000303	0.00123***
	(0.000)	(0.000)	(0.798)	(0.000)
TradeOpenness	0.103	0.154**	0.135*	0.0440**
	(0.117)	(0.039)	(0.074)	(0.020)
Africa	-50.53***	-30.33***	14.94***	-2.507
	(0.000)	(0.000)	(0.004)	(0.245)
tv_imports	-0.0151			
	(0.327)			
importtv_Africa	0.0689***			
	(0.007)			
fridge_imports		0.149		
		(0.251)		
importfridge_Africa		0.186		
		(0.334)		
radio_imports			0.442***	
			(0.001)	
importradio_Africa			-0.115	
			(0.568)	
pc_imports				0.000651
				(0.122)
importpc_Africa				0.00668
				(0.781)
N	57	56	57	111
Countries				
Adj.R2	0.746	0.630	0.172	0.8096
Wald	0.0164	0.0376	0.0017	0.2934

The dependent variables are the respective penetration rates; *p*-values are depicted in parentheses. Significance levels are marked by: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Interaction terms are formed between the instrumented imports and the Africa-dummy. The Wald test statistic gives the p-value for joint significance of the import variable and the interaction term.

Table A4: 2SLS-Regression with Interaction Terms

	[kWh/year] 2013	[kWh/year] 2010	[kWh/year] 2008/2006	[kWh/year] 2005	[kWh/year] 2000	[kWh/year] 1995
Refrigerator	195.7	217.5	244	256	279	309
Desktop PC incl. Monitor	244	304	320	335	373	401.9
Television	166	183	171	162	170	184
Hi-Fi			46			

Data on computers are retrieved from the FhCSE, values for 1995 and 2000 are linearly interpolated; Data on refrigerators are taken from the German EPA, values for 2010 and 2013 are linearly interpolated; Data for televisions are taken from the German EPA for the years 1995 through 2008, Data on 2010 and 2013 are taken from the FhCSE; Data on Hi-Fi devices is retrieved from the REMODECE study.

Table A5: Average Yearly Energy Consumption

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