Indirect Rebound and Reverse Rebound Effects in the ICT-sector and Emissions of CO_2

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Abstract *It has been suggested that the ICT sector has a large potential of reducing environmental impacts in society through enabling smarter and more efficient solutions. Some of this potential may however be offset by different types of rebound and other indirect effects. There are a number of different types of rebound and other indirect effects that can be relevant. Some of them may lead to positive environmental impacts; others may lead to negative impacts. In this paper we have analysed the indirect rebound effects for the ICT-sector and also what we here call the reverse rebound effect. We have used Environmentally Extended Input-Output Analysis with data for Sweden. The results in this paper indicate that rebound effects can be significant. If efficiency improvements occur in the production of the ICT equipment, there could be a strong rebound effect which would reduce the potential decrease of emissions that could occur without the rebound effect. If on the other hand, efficiency improvements concern the electricity used by the ICT equipment, the rebound effect is expected to be smaller, and real emission reductions could be expected. The total spending on ICT products have increased and this could lead to a reversed rebound effect when less is consumed of other products and services. The results here suggest that this reversed rebound effect could be significant and lead to overall reduced emissions.*

Keywords—indirect rebound; reveresed rebound; ICT; CO_2; environmentally extended input-output (EEIO) analysis

I. Introduction

As a result of efficiency improvements within the Information and Communication Technologies (ICT) sector, the prices on ICT products/services have fallen dramatically over time (e.g. [1], [2]). For example, computers have become less expensive, despite higher performance [3]. Another example is that consumers globally paid on average 18% less for ICT services in 2011 than they did in 2009. Also, the price for high-speed Internet connections dropped on average by 52% between 2008 and 2010 [4]. Hence the consumers have more money to spend on either more ICT or on other products and services.

In the same manner, efficiency improvements have led to that ICT products need less electricity when used and thus the consumers' expenditures for electricity have decreased. For example, an old bulky monitor use several times the power compared to a flat display [5]. Another example is that people use certain ICT services (such as e-mail) through cellphones and tablets instead through a desktop, where the latter use significantly more electricity than the former alternatives [6].

However, the decrease in prices will increase the demand and expenditure for other products and services that also require resources to provide [7]. The phenomena is known as indirect rebound effect, or the real income effect, since the lower prices leaves more income available to spend on other products and services. Reference [8] claims that indirect rebound effects will most likely not occur in the ICT sector, however he does not present any evidence for this claim. Reference [9] question this statement, and see no reason to why the extra money should not be used for consumption of other goods and services than ICT. The decreases in price could also lead to an increase of consumption of ICT products. This is known as the direct rebound effect, or the direct price effect [8]. There are clear indications of rebound and other indirect or second order effects in the ICT sector. For example, while the energy efficiency of ICT hardware has been dramatically improving and will continue to improve, the overall energy used for ICT is still increasing [10]. This is because the growing demand for ICT devices and services outpaces the efficiency gains of individual devices [10]. Also the CO_2-emissions from the ICT-sector are expected to increase [11].

In the economic literature direct and indirect rebound effects are analyzed on a microeconomic level. When direct and indirect rebound effects are analyzed together on a macroeconomic level, the rebound effects are called world-wide (even though the effects are often analyzed on country level) [12]. Reformulated to an ICT context, a world-wide rebound generates more growth and change resource consumption due to price and quantity readjustments throughout the economy as a result of both direct and indirect rebound responses to efficiency improvements within the sector [9].

In economic literature the direct and indirect rebound effect are derived from marginal changes in consumption as a result of a fall in prices (consumer demand theory). The direct rebound effect is relatively easy to analyse through quasi-experimental studies or through econometric analysis of secondary data [13], [14]. The indirect rebound effect and the world-wide rebound on the other hand involve general equilibrium adjustments on different markets that are difficult to analyse empirically [15].

Environmentally extended input-output analysis (EEIO) is another approach for calculating rebound effects. EEIO is usually performed on a macro level [14], [16]. In this case the rebound effects are derived from emissions during the supply chain and the average consumption pattern, in other words a model that is static in its approach and does therefore not consider marginal price changes. The strengths with EEIO analysis are that the models are relatively easy to build, the method is flexible when it comes to investigating economic effects (and in the case of EEIO also environmental effects) of changes in the production and consumption chains and that a lot of data often is available through agencies such as Eurostat, and Statistics Sweden. The linear and static nature of EEIO analysis is however a drawback. Further, a general weakness is the often used assumption that household savings will be re-spent in proportion to current spending patterns [14]. For a summary of potential benefits and drawbacks with the economic approach (consumer demand theory) and the EEIO approach see [14]. It is not evident which approach that gives the most accurate answers. Most importantly, the importance of the difference between average and marginal spending is empirically unclear. Independent on approach used, in the current literature, the direct and indirect effects are estimated to be between a couple of percent to over hundred percent (so called back-fire) (See e.g [14] for a literature review.) Some attempts have been made to combine consumer demand theory with the EEIO in order to estimate rebound effects due to energy efficiency [14], [17]. Reference [18] presents a rebound effect of 5-15%, in terms of energy savings and CO_2-emissions, due to efficiency improvements that reduce household expenditures in either electricity, natural gas, or gasoline in the US. [17] finds similar numbers in terms of energy savings for residential and private energy efficiency improvements in Sweden.

Rebound effects occur at any efficiency improvement that leads to that less resources are needed as input when producing or consuming a product/service. Still, the existing literature focuses often on energy efficiency improvements and changes in energy consumption in the transport and heating sector. (See for example [14] for a current literature review.) The importance of rebounds effects in the ICT sector is under investigated [19].Within the existing literature that is focusing on ICT and empirical analysis of rebound effects several studies have dealt with direct rebound effects of decreased search costs due to e-commerce (e.g. [20], [21]) and [10] and [22] used system thinking and modelling instruments to include direct rebound in a study of effects of ICT on environmental sustainability. However, none of the above mentioned papers that are focusing on direct rebound and ICT presents actual numbers for the rebound effect in terms of energy savings or emissions. Also the literature on world-wide rebound effects and ICT is scare, and no general conclusions can be drawn. [9] One recent study by [23] shows that around 15% of the energy savings obtained from introducing a larger ICT sector will be lost due to rebound effects. This figure is considerably lower than those reported in many other studies that are analyzing world-wide rebound effects in terms of energy savings, where the rebound effect is often estimated to be above 50 percent (and in some cases above 100 percent). (See for example [24] for a literature review.)

In this paper we use EEIO analysis, data from the Swedish Environmental accounts, Swedish National accounts, and data from the Swedish Household Budget survey for investigating the links between consumption and environmental impacts. The aim with the paper is to investigate how changes in income, spending patterns, and efficiency improvements in the IT-sector affect CO_2-emissions. We will also present policy recommendations based on the results. The focus will be on rebound effects, however, to get input to our discussion and conclusions we also present how consumption and emission patterns has changed over time.

The paper is organized as follows. In Section 2, we present the EEIO method, the EEIO simulation model as well as the data that is used in the study. In Section 3 we present the results, and in Section 4, we discuss the results, and draw conclusions.

II. METHODS

2.1 EEIO, simulation model data bases, and rebound

IOA is a well-established analytical tool within economics and systems of national accounts [25], [26]. By using IO analysis, inter-industry relationships within an economy can be studied, i.e. how output from one industry sector becomes an input to another industry sector. IO analysis is based on the use and supply matrices and their inverse matrix. The inverse matrix describes the total amount of resources in the economy that is needed to generate a certain output of a particular demand category for final use. Researchers can apply IOA to include environmental impacts by adding emissions coefficients to the monetary input-output tables (e.g. [26], [27], [28]).

Input-Output Analysis has together with data form the Swedish Environmental Accounts been used in a number of studies to analyse impacts of Swedish consumption and impacts from specific sectors (e.g. [29], [30]). Statistics Sweden has built an EEIO simulation model that can be used for studying Swedish households' environmental contribution to emissions of CO_2. Based on assumptions regarding efficiency improvements, changes in income, and changes in spending patterns, changes in CO_2 emissions and rebound effects can be analyzed [31].

The rebound effect is calculated using the formula:

Rebound effect (percent) = (1- ACE/PCE)*100

where PCE is potential decrease in emissions due to efficiency improvements, i.e. potential change in emissions without rebound, and ACE is actual change in emissions including rebound.

The data in the EEIO simulation model is from 2006. The data is from the Swedish Environmental accounts and Swedish National accounts, and is used to calculate the emissions of CO_2 through private consumption. This is done using the emissions by industry and final demand category presented in the Swedish Environmental Accounts, and the Input-Output tables presented in the Swedish National Accounts. By combining emissions in ton and expenditures in monetary units, emission intensities for products in private consumption are estimated. Swedish Household Expenditure Survey data is used to allocate emissions from private consumption over different household types. The absolute level of private consumption is taken from the Swedish National accounts as these are used to calculate the emission intensities.

Statistics Sweden [32] also presents time series (1993-2008) for private consumption, as well as CO_2-emissions that this consumption generates. The time series for consumption are based on Input-Output tables in the Swedish National Accounts, and the time series for CO_2-emissions are based on data for emissions by industry and final demand category that has been put together in the Swedish Environmental Accounts.

In the EEIO simulation model the consumers' expenditures are allocated to 45 product groups. This is an aggregate of the over 100 product groups in COICOP used in the official data from the Swedish National Accounts and the Swedish Environmental accounts. In the Swedish National accounts 146 product groups in COICOP are used. In the Swedish Environmental accounts these 146 product groups are aggregated into 107 product groups, which in turn are aggregated into 45 product groups in the EEIO-model.

The product group in the model that can be said to represent consumption from the IT-sector is the product group called "Information processing equipment". This product group includes data for the COICOP product groups CO913 Personal computers, CO914 Recording media, and CO915 Repair of audio-visual equipment, photographic equipment, and information processing equipment.

The households' contribution to CO_2-emissions is calculated directly through the use of fuel for running their vehicles, using technical equipment, and heating their homes, and indirectly through their purchase of products that generate emissions in production or transport/storage. In the model, a distinction is made between emissions generated in Sweden and emissions generated in Sweden plus emissions in other countries from the production of what is imported to Sweden. Imported products are consumed directly and also used as intermediary inputs in Swedish production. Calculations of emissions in other countries through imports are made using the replacement assumption, i.e. these emissions are calculated as if they were caused by the Swedish economy producing what is imported. In our analysis total CO_2-emissions due to households' consumptions will be studied, and hence both emissions generated in Sweden and in other countries will be taken into account.

In general, biofuels are considered as non-emitting CO_2. This is based on the assumption that the released carbon from biofuels will be reabsorbed by biomass regrowth (under balanced conditions). Hence, when investigating CO_2-emissions and rebound effects in this paper, emissions from As noted above EEIO models are linear and static. This means for example that if a given reduction in spending for a product group is inserted in the model, for example due to assumed efficiency improvements, it is given by the model that the efficiency improvements hold for all goods and services in the product group. More specifically, if the spending is reduced with 1 percent for a product group, then the reduction of emissions that the model will present will also be 1 percent (not including rebound effects). In the same manner, if it is inserted in the model that the consumption for a given product group will increase/decrease with 1 percent for any other reason, then will also the emissions from this product group increase/decrease with 1 percent.

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2.2 Rebound scenarios

Based on assumptions regarding different efficiency improvements within the ICT-sector, and changes in spending patterns, 4 different scenarios are presented. In all scenarios it is assumed that the consumers extra money due to efficiency improvements in the ICT-sector or increased income will be spent on immediate consumption, i.e. the households will not save the money for consumption in the future. Figure 1 presents the assumptions that are being used. By combining different assumption, a number of scenarios are constructed. Figure 2 presents the scenarios and the assumptions (As.) used in each scenario.

Assumption 1 Due to general efficiency improvements within the IT-sector the average household faces a 10 percent overall price reduction in the product group Information processing equipment. That is, a household can buy the same goods/services, but for less money.
Assumption 2 The extra money that a household gets due to an efficiency improvement will be spent in accordance with a household's general spending pattern in 2006.
Assumption 3 The extra money that a household gets due to an efficiency improvement will only be spent on the ICT-sector, i.e. on the product group Information processing equipment.
Assumption 4 Due to efficiency improvements within the IT-sector less electricity is needed in the user phase of ICT- services/goods. A 10 percent decrease in energy consumption is assumed, i.e. 10 percent of the money previously spent on electricity can be used for other consumption.

Figure 1 Assumptions used in the scenarios

Scenario	Short description	As. 1	As. 2	As. 3	As. 4
1	A general efficiency improvement in the ICT-sector, and unchanged spending pattern	x	x		
2	A general efficiency improvement in the ICT-sector, and increased spending on ICT	x		x	
3	An efficiency improvement in the ICT-sector resulting in less electricity		x		x

	consumption, and unchanged spending pattern				
4	An efficiency improvement in the ICT-sector resulting in less electricity consumption, and increased spending on IT			x	x

Figure 2 Scenarios and assumptions

2.3 Reversed rebound scenario

The rebound scenarios described above, analyse a situation where spending on one product group is decreased. The reduction in spending in one product group leads to increased spending in other product groups, resulting in a rebound effect. We will here also analyse a situation which can be called a reversed rebound situation, i.e. a situation where spending on one product group is increased. This increased spending leads to decreased spending in other product groups, resulting in a reversed rebound effect. In the "traditional" rebound case, the rebound effect is a consequence of efficiency improvements. In the reversed rebound situation the rebound effect can be due to a number of things, such as changed preferences or changed incentives for consuming different goods/services.

A reversed rebound effect is defined as:

Reversed rebound (percent) = 1- ACE/PCE*100

where PCE is a change in emissions due to changed spending patterns, i.e. change without rebound. ACE is actual change in emissions including rebound.

In a reversed rebound scenario we will look at a case with an increased spending on ICT, i.e. on the product group Information processing equipment. The scenario is based on the assumption that the average household increases their spending on ICT with 1000 SEK due to for example changed preferences. That is, a household will buy less of other goods/services.

III. Results

3.1 Emissions and consumption from the ICT-sector over time

Figure 3 shows, looking at the time period 1993-2008, that the general trend is that consumption from the ICT-sector (represented by the product group Information processing equipment) has been increasing significantly over time. By taking a closer look at the more recent years (2006-2008), it can be seen that the consumption has been increasing with 76.1 % for the product group CO913 Personal computers, and with 13.5 % for the product group CO914 Recording media. The consumption for the product group CO915 Repair of audio-visual equipment has decreased with 1.2 %.

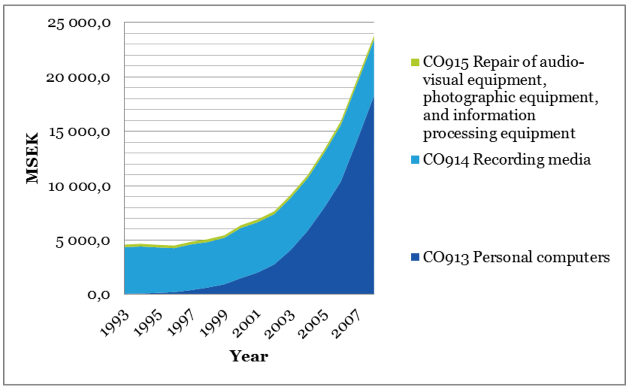

Figure 3 Consumption from the product group Information processing equipment (MSEK) between 1993-2008 (fixed prices, i.e. inflation has been taken into consideration). 1 MSEK equals approximately 0.1 MEuro (Feb 2015).

Figure 4 shows, looking at the time period 1993-2008, that the general trend is that CO_2-emissions per SEK from the IT-sector (represented by the product group Information processing equipment) has been decreasing significantly over time. By taking a closer look at the more recent years (2006-2008), it can be seen that CO_2-emissions have been decreasing during this period. This is especially true for the product group CO913 Personal computers (a decrease with 48.2 %). The corresponding numbers for CO914 Recording media and CO915 Repair of audio-visual equipment etc., are a decrease with 4.5% and 5.1 % respectively.

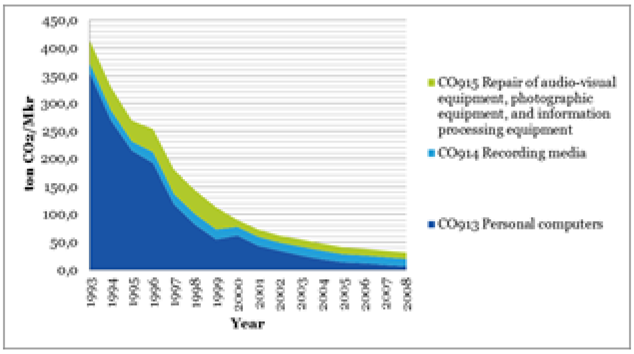

Figure 4 Ton CO_2-emissions per MSEK between 1993 and 2008 (fixed prices, i.e. inflation has been taken into consideration)

When the data in Figures 3 and 4 are combined, the results are the CO_2-emissions from the sector. Figure 5 shows, looking at the time period 1993-2008, that the general trend is that CO_2-emissions from the ICT-sector (represented by the product group Information processing equipment) has been increasing significantly over time. Still, by taking a closer look at the more recent years (2006-2008), it can be seen that the total CO_2-emissions has been decreasing during this period. This is especially true for the product groups CO913 Personal computers (a decrease with 8.7%), and CO914 Recording media (a decrease with 5.6%).

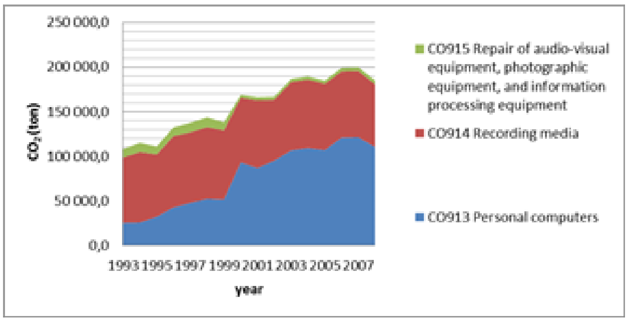

Figure 5 CO_2-(ton) emissions from the product group Information processing equipment between 1993-2008

3.2 *General patterns for consumption and CO_2-emissions*

In 2006 the average Swedish household spent 342 872 SEK on consumption. The total CO_2-emissions in 2006 were 8952.5 kg for the average household, including emissions due to consumption from both goods and services produced within and outside Sweden (import). This corresponds to 0.03 kg CO_2/SEK. 1.1 percent, or 3630 SEK, of the total spending was on the product group Information processing equipment. This consumption generated 0.5% of the total CO_2-emissions, or 48.8 kg. This corresponds to 0.01 kg CO_2/SEK. This can be compared to the product group Electricity. 3.8 percent, or 12939 SEK, of the total spending in 2006 was on this product group. This consumption generated 7.0% of the total CO_2-emissions, or 626.1 kg. This corresponds to 0.05 kg CO_2/SEK. In summary, both in absolute numbers SEK and kg CO_2, and in terms of CO_2-emissions per SEK spent, the product group Information processing equipment generates relatively little emissions, compared to other product groups, such as Electricity.

3.3 *Consumption and emissions depending on income group*

Table 1 presents each income group's (each income group corresponds to a percentile) consumption (in percent) compared to the average household. The table also presents (in percent) how the total CO_2-emissions for each income group differ from the average household. Finally, the table presents (in percent) how big part of the differences in CO_2-emissions between a given income group and the average household that is due to changed spending patterns (rather than to differences in income). That is, the table illustrates that if income changes in the society, such as that all people in the 7th percentile become as rich as the people in the 8th percentile, this will change spending patterns, and thereby also the amount of CO_2-emissions. The results presented in Table 1 show that the differences in emissions between different income groups can be rather large, however the main part of the differences in CO_2-emissions between different income groups are due to differences in income, i.e. not in spending patterns. For example, households in the 8th percentile generate 15.8 percent more CO_2 emission compared to the households in the 7th percentile, and only 3.7 percent of this difference can be explained by differences in spending patterns. (See Table 1)

Table 1 Differences in expenditures and CO_2-emissions depending on income group in 2006

a.

	Income group (percentile)				
	1	2	3	4	5
Expenditure compared to average household (ref. 100%) (%)	58.49	62.27	72.79	78.98	88.57
Difference in CO_2-emissions compared to average household (%)	-49.41	-49.23	-36.02	-28.14	-15.54
Difference in CO_2-emissions due to differences in spending patterns (%)	-13.51	-18.46	-12.10	-9.02	-4.64

b.

	Income group (percentile)				
	6	7	8	9	10
Expenditure compared to average household (ref. 100%) (%)	95.83	109.67	120.63	138.20	160.70
Difference in CO_2-emissions compared to average household (%)	-1.12	13.66	29.49	48.57	71.08
Difference in CO_2-emissions due to differences in spending patterns (%)	3.14	3.64	7.34	7.51	6.46

3.4 *Rebound scenarios*

For each Scenario 1-4, Table 2 presents changes in CO_2-emissions (in kg, and kg/SEK), with (actual change in emissions, ACE) and without rebound effect (potential decrease in emissions due to efficiency improvements, PDE), due the assumptions made in each scenario, as well as the rebound effect (in percent). Scenario 1.a, 2, 3, 4, present results for an average household in the whole population, Scenario 1.b, and 1.c, present results for an average household in the 7th and 8th income percentile, respectively.

Table 2. The scenarios effects on CO_2-emissions in 2006 per average household with and without rebound effect (kg), and rebound effect (%)

Scenario	PDE (kg; kg/SEK)	ACE (kg; kg/SEK)	Rebound effect (%)
1.a	-4.88;-0.013	+4.60;+0.013	194.36
1.b	-5.01/-0.013	+5.08/+0.013	201.43
1.c	-6.43/-0.013	+6.99/+0.015	208.71
2	-4.88;-0.013	0	100.00
3	-62.61;-0.048	-28.93;-0.022	53.79
4	-62.61;-0.048	-45.22;-0.035	27.78

Table 2 presents three major results. First, whether efficiency improvements in the IT sector are targeting the production phase in general, i.e. the product group Information processing equipment, or only the need for electricity in the user phase, i.e. the product group Electricity, has a major impact on both CO_2-emissions, and the rebound effect. In general, efficiency improvements in the product group Electricity give much higher effects on the decrease of CO_2-emissions (both with and without rebound), compared to efficiency improvements in the product group Information processing. The opposite holds for the rebound effect, i.e. the rebound effect is much higher for Information processing equipment, compared to Electricity. For example, if rebound is included in the analyses, the CO_2-emissions, in terms of kg CO_2 per extra SEK for consumption due to efficiency improvements is + 0.01 kg/SEK for Scenario 1a, and – 0.04 kg/SEK for Scenario 4. On the other hand the rebound effect is 194.4 percent for Scenario 1a, and only 53.8 percent for Scenario 3.

Secondly, whether the extra money for consumption, due to efficiency improvements, is spent in the same manner as before the efficiency improvement or not has a major impact on the rebound effect. For example, if the efficiency improvement is in the product group Electricity, and if the spending pattern is unchanged (Scenario 3) the rebound effect will be 53.8 percent, and if the extra money is spent only on the product group Information processing equipment the rebound effect will be 27.8 percent (Scenario 4). In the same manner the rebound effect is 194.4 percent in Scenario 1, but only 100.0 percent in Scenario 2.

Thirdly, consumption patterns do not differ that much between different income groups that are close to each other (See Table 1), it follows that the difference in rebound effect between two income groups will not be that big. This is illustrated by Scenario 1b, and Scenario 1c in Table 2. Scenario 1a, 1b, and 1c, are the same with the only difference that Scenario 1a represent an average household of the whole population, Scenario 1b a household with an income in the 7th percentile, and Scenario 1c a household with an income in the 8th percentile. As shown in Table 2 the rebound is 201.4 percent and 208.7 percent for Scenario 1b, and 1c, respectively. However, the rebound effect for the average household in the whole population is 194.4 percent (Scenario 1a). The rather large difference in rebound effects between Scenario 1a, and 1c illustrates that if large income changes in the society will occur, there will be major impacts not only on the total CO_2-emissions due to increased income, but also on the rebound effects due to changed spending patterns.

3.5 Reversed rebound scenario

An increased consumption of the product group Information processing equipment with 1000 SEK would generate 13.4 kg CO_2 (PCE), this while a spending in accordance with a household's general spending pattern in 2006 would generate 26.1 kg CO_2. Instead of increased emissions, the reversed rebound effect will therefore instead lead to decreased emissions by 12.7 kg CO_2. That is: Reversed rebound= 1-(-12.7/13.4)=194.8 %.

Put it another way, the changed spending patterns would decrease the CO_2-emissions with almost 200%.

IV. DISCUSSION AND CONCLUSIONS

It has been suggested that the ICT sector has a large potential of reducing environmental impacts through enabling smarter and more efficient solutions (e.g. [33], [34]). Some of this potential may however be offset by different types of rebound and other indirect effects [22]. There are a number of different types of rebound and other indirect effects that can be relevant [35], [36] also for the ICT sector [9], [19]. Some of them may lead to positive environmental impacts; others may lead to negative impacts. It is often difficult to analyse rebound and other indirect effects and there is a need for studies looking into this area [9]. In this paper we have analysed the indirect rebound effects and also what we here call the reverse rebound effect.

Our results show that the product group Information processing equipment, which is the product group most closely linked to the production phase in the ICT-sector, generates relatively little CO_2-emissions/SEK, compared to the production and use phases of many other product groups. This means that the magnitude of CO_2-emissions and the rebound effects are very dependent on spending patterns.

The results in this paper indicate that rebound effects can be significant. If efficiency improvements occur in the production of the ICT equipment, there could be a strong rebound effect which would reduce the potential decrease of emissions that could occur without the rebound effect. If on the other hand, efficiency improvements concern the electricity used by the ICT equipment, the rebound effect is expected to be smaller, and real emission reductions could be expected. That increases in energy efficiency will lead to decreased CO_2-emissions is in accordance with existing literature [37].

The total spending on ICT products have increased. Although the increased spending on ICT products lead to increased emissions from the ICT sector, this could lead to a reversed rebound effect when less is consumed of other products and services. This could be seen as an economy-wide substitution where more ICT products are bought replacing other products and services with higher emission intensities. The results here suggest that this reversed rebound effect could be significant and lead to overall reduced emissions. This analysis is however simplified since it does not take into account the electricity use when the ICT equipment is used. Further analysis in this area would therefore be of interest.

Further, our results show that the spending patterns differ depending on income. The richer people become the higher will the rebound effect be. This result is in contrast to results generated by other approaches [38].

Figure 4 shows that CO_2-emissions per consumed SEK from ICT have decreased significantly and this trend has probably continued. This means that CO_2-emissions/SEK today is lower than those presented in this paper. This could suggest that the differences in rebound effects depending on the spending patterns assumed could be even larger today.

A significant limitation of the present study is the assumption that production in other countries occurs as if in Sweden. A large part of the production occurs in other countries and data for example about electricity mixes in different countries can have significant impacts on results for the ICT sector [11]. A further development of the present study would therefore be to use multi-regional input-output analysis which includes input-output tables and emission intensities for several regions [39].

It should be noted that rebound effects can occur for all kinds of resources and emissions, i.e. not only for CO_2. The existing literature on rebound effects is to a major extent only focusing on CO_2 [9]. Rebound effects for other resources are an area that needs to be further investigated.

The ICT-sector's importance in our society will most likely continue to increase, and the sector will most likely continue to have efficiency improvements and thereby experience price falls. (e.g. [2]) Policy makers must be aware of the rebound effects that this will create, and if desired, try to steer people's extra consumption, due to the efficiency improvements or increased income for other reasons, to sectors with relatively low CO_2-emissions/SEK (such as the ICT-sector). Increasing CO_2- or energy taxes could be one policy measure for using the rebound effects as a lever for decreasing emissions.

Since rebound and other indirect effects can have significant impacts it is important that it is considered in policy appraisal and other impact assessments [36]. In order to do that, methods for assessing these effects need to be developed. The approach used here can capture some of the indirect effects, but not all [9]. It is therefore important that different types of methodology is developed and tested in order to get comprehensive assessments.

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