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Rebound Effects Caused by Artificial Intelligence and Automation in Private Life and Industry

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Abstract: Many tasks in a modern household are done by machines like e.g. a dishwasher or a vacuum cleaner and in the near future most household tasks can be done by smart service robots. This relieves the residents who in turn can enjoy their free time. This newly gained free time turns out to cause the so called spare time rebound effect due to more resource consumption [1,2]. We roughly quantify this rebound effect and propose a CO_2-budget model to reduce or even avoid it. In modern industry, automation and AI take over work from humans, leading to higher productivity of the company as a whole. This is the main reason for economic growth which leads to environmental problems due to higher consumption of natural resources. We show that, even though the effects of automation at home and in the industry are different (free time versus higher productivity) in the end they both lead to more resource consumption and environmental pollution. We discuss possible solutions to this problem such as carbon taxes, emissions trading systems and a carbon budget.

Keywords: rebound effect; artificial intelligence; automation; economic growth; service robot; free time; productivity; carbon tax; emissions trading system; carbon budget; economy for the common good

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1. Introduction

Autonomous driving, service robots, smart homes and many other new services will increasingly simplify our life in the coming years. Computers and robots use AI techniques for solving difficult tasks such as diagnosis in medicine, determining the optimal route in road traffic, creating images or writing texts in every day business. Along with these achievements that increase labour productivity come some challenges. Among other things, various rebound effects lead to an increased consumption of resources in contrary to an expected efficiency gain.

Already in 1865, the British economist W. S. Jevons observed that technological innovations, which improved the efficiency of machines fuelled by coal, ultimately lead to a higher consumption of energy. Although the machines burned less coal for the same amount of work the burning of coal overall did not decrease but increase. This effect was called the Jevons Paradox and is nowadays better known as rebound effect [3]. Whenever the expected gain due to an improvement of efficiency of a certain technology is reduced by other effects such as e.g. higher consumption, this is called *rebound effect*.

A descriptive example for a rebound effect is the private use of cars. The energy efficiency of cars is constantly improving, which theoretically should lead to less fuel consumption and lower costs, if the car´s size and mileage stays the same. But due to the lower costs, people tend to use their car more often, drive faster or buy a bigger car or they do all of it at the same time, which ends in higher energy consumption. According to [1] this would be a direct financial rebound effect. Mostly, the rebound effect refers to an improvement of energy efficiency and it´s consequences. There are many instances for this since the beginning of the industrialisation in the eighteenth century.

Formally the rebound effect is quantified as the ratio of the additionally spent energy caused by the rebound effect to the gain caused by the efficiency enhancement. Hence, if a more energy efficient car only burns 4 liters of fuel instead of 5 liters per 100 kilometres, there will be an efficiency

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enhancement of 20%. If the driver uses his or her new car 10% more than before, there will be a rebound effect of $10\%/20\% = 0.5 = 50\%$. Apparently, the rebound effect can be bigger than 100%. This is called *backfire*.

It is often not energy, which is saved by using machines, automation or Artificial Intelligence but human labour time. Here, higher demand for energy yields a productivity gain for the factor labour, which is called *material cross factor rebound effect* [1]. Take the example of a cordless screwdriver: Instead of a conventional screwdriver a portable electric drill is used which replaces labour time by consumption of resources for production, energy for operation and resources for disposal. This rebound effect becomes greater the more expensive human labour is in contrast to energy.

2. Service Robots as a Typical Example of a New AI Application

Service robots can be used for household chores such as vacuum cleaning, ironing, tidying up, filling and emptying the dish washer and many others. In the near future these intelligent robots with learning abilities will be sold for less than 10.000 Euro in our local electronics store and many people will probably purchase one of these little helpers because it simplyfies daily life and increases labour productivity which leads to more spare time. Especially in rich countries with high salaries these robots will be an interesting purchase for many consumers.

The increase in labour productivity is typical for many technological innovations. Therefore service robotics is a useful example for a new technology and it is irrelevant, whether the use of these robots will actually spread. In the following, two with this example connected rebound effects will be discussed. The biggest contribution is caused by the so-called spare time rebound effect, i.e. the gain of spare time for the user due to the robot's household work. When people do the housework themselves, they are less likely to expend a lot of energy on other activities at the same time. But, once the robot takes over the duties, humans have additional time for activities such as consuming, travelling, social media use, sports etc., all activities with a poor ecological balance. This is a really paradox situation. The robots are made to do our work while we can spend our time for other activities. But exactly these activities in the newly gained spare time cause extra harm to the environment. We will show that this spare time rebound effect is much bigger than that caused by the robot's energy consumption.

3. The Material Cross Factor Rebound Effect

The material cross factor rebound effect leads among other things to an increased consumption of resources (e.g. electricity) and to environmental pollution due to production and recycling of robots. In absence of accessible life cycle assessment there is no quantitative estimate possible. Hence, we will disregard this fraction of the rebound effect in the following. Furthermore, the robot constantly consumes about 100 watt of electricity 24 hours per day. Assuming that the use of robots will increase strongly in the years coming, we would probably have around one billion service robots (with a world population of eight billion people). With an average power of 100 watt per robot this would amount in a worldwide demand of 100 gigawatt. A medium-sized nuclear power plant produces about one gigawatt leading to about 100 additional nuclear power plants in addition to the currently about 411 operational reactors [4]. Alternatively, we could install 50,000 big wind power plants with two megawatt gain and about 250 metres height each. Or a photovoltaic power plant with a surface of approximately 5000 km^2, which is more than three times the size of London, the nine million inhabitants capital of Great Britain.

The gain in comfort humanity will experience in the near future caused by many universal machines has to be purchased at the expense of much higher consumption of energy and resources. The above mentioned service robot would use $100\text{ W} \cdot 8760\text{ h} = 876\text{ kWh}$ of electricity per year. This amounts to 22% of the average electricity consumed by a German four person household.[1] In order to

[1] Please note that production and recycling of the robot are not considered.

quantify the rebound effect, we have to investigate the efficiency enhancement by the use of the robot. Since it is an increase in labour productivity and not directly an energy efficiency measure, one can not simply calculate the ratio between the robots energy consumption and increased labour productivity. As a remedy, we try to convert the increase in labour efficiency into the saved energy of the respective person. In order to do so, we assume that the service robot is used in a 4-person-household and takes over one hour of labour every day from each household member.

According to [5] an average human can perform the continuous mechanical power of approximately 60 watt.[2] The service robot saves four hours of human labour per day, equivalent to approximately 240 Wh. Since the efficiency of human muscles is about 30% [6], to perform 240 watt humans must consume about 800 watt-hours of energy in the form of food. The robot, in contrast, uses 100 W · 24 h = 2400 Wh of electricity per day. Thus we calculate the

$$\begin{aligned}\text{cross factor rebound effect} &= \frac{\text{energy consumption by robot/day}}{\text{saved energy from human labour/day}}\\ &= \frac{2400\text{Wh}}{800\text{Wh}} = 3 = 300\%.\end{aligned}$$

Under the assumptions we have made, the robot consumes 3 times as much energy as a human for the same amount of labour. This is quite plausible, since the first robot generations will work much slower and less efficient than humans.

4. The Spare Time Rebound Effect

What will the owners of the robot do in their newly gained free time? They could, for example, spend this time for meditation, relaxing or sleeping (at home) and would consequently not use any energy or resources in addition to their basal metabolic rate. However, they could instead spend this time for activities such as exercising, travelling or consuming, leading to the so called spare time rebound effect. These activities are all bound to additional consumption of energy and resources. Let us investigate the following two scenarios for the 4-person-household with its service robot and assume like before that the robot takes over one hour of labour per day from each household member.

4.1. Meditation

If the four persons decide to meditate instead of doing household chores, no spare time rebound effect will occur, since no additional energy is consumed. [3] Thus, we calculate

$$\begin{aligned}\text{spare time rebound effect} &= \frac{\text{energy consumed by human in spare time/day}}{\text{saved energy from human labour/day}}\\ &= \frac{0}{800\text{Wh}} = 0.\end{aligned}$$

Surely, this scenario seems to be unrealistic in contrast to the following.

4.2. Business as Usual

To keep it simple, we assume that a person during the newly gained free time behaves as usual during free time. According to the CO_2-Calculator of the German Federal Environmental Agency,[4] the overall CO_2-emissions of an average German person per year of 11.61 tons can be divided into 4.87

[2] A person can permanently provide about 60 watts of mechanical power during work. The basal metabolic rate of approximately 80 watts for all body functions such as brain activity or metabolism does not play a role here.

[3] Nevertheless, implicitly the energy consumption for public infrastructure, food, heating and electricity still accumulates, but this amount will be as high as in the following scenario.

[4] https://uba.co2-rechner.de

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tons for public infrastructure, food, heating and electricity, even if a person is not active and 6.74 tons for mobility and other consumption. About 0.5 kg CO_2 per kWh of electricity were emitted for the German electricity mix of 2018.[5] Thus, 6.74 tons of CO_2 is equivalent to an electricity consumption of 13.500 kWh per year, or an average power of 1.54 kW per person. Thus, we can estimate the spare time rebound effect of a 4-person-household as follows:

$$\begin{aligned}\text{spare time rebound effect} &= \frac{\text{energy consumed by human in spare time/day}}{\text{saved energy from human labour/day}} \\ &= \frac{1540\text{W} \cdot 4h}{800\text{Wh}} \approx 8 = 800\%.\end{aligned}$$

4.3. Overall Balance

As a result, the purchase of a service robot for a 4-person household in the business as usual scenario leads to a rebound effect, which is the sum of both effects and has a value of 11. Energy consumption of the robot and the new leisure activities exceed the original energy consumption for the domestic work by a multiple. Surely, the factor 11 comes with a degree of uncertainty. But this should not be of big concern because what matters here is only the order of magnitude. It is interesting to note that the spare time rebound effect is about 2.5 times greater than the material cross factor rebound effect.

5. The Personal CO_2-Budget as a Problem Solution

While technological innovations are supposed to reduce energy, due to rebound effects overall energy consumption is still increasing [7]. In order to avoid or at least reduce climate change and other negative external costs, regulation is needed to ensure that we use energy sparingly. Taxing such scarce or critical resources is an effective way of persuading people to save. German CO_2 tax and the European carbon emissions trading are examples of this. The higher the tax, the more likely users of a technology will think about alternatives or forgo it. If one generalizes this concept of taxing external environmental costs to other areas such as human dignity, solidarity and transparency, that leads, for example, to the economy for the common good [8]. Based on the common good matrix the different values are quantified and after summing up transformed into a certain tax rate for every product or service.

However, taxing CO_2 emissions is not a truly sustainable solution because it is not equitable. While rich people can easily pay even a high CO_2 tax, it can be an existential problem for poorer people. Allowing the wealthy to cause environmental damage at the expense of future generations and poor people has little to do with climate justice.

A consistent and globally equitable approach to climate and environmental protection is to budget all critical resources. In the following, we will limit ourselves to CO_2 emissions. Science assumes that, in order to avoid a global climate catastrophe, on average less than one tonne of CO_2 may be emitted per person per year. So if each person is given, for example, a budget of one tonne of CO_2 per year[6], then that can be called climate justice. The practical implementation could be, for example, as follows: Each person (assuming a life expectancy of 90 years) receives a lifetime budget of 90 tons at birth. For each action, such as buying a product, refuel the passenger car or booking a trip, the amount of CO_2 emitted by that action is deducted from the budget. Anyone who consumes more than one tonne per year over a longer period of time must expect sanctions, in extreme cases prison with vegan diet. [7]

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[5] https://www.umweltbundesamt.de/themen/co2-emissionen-pro-kilowattstunde-strom-sinken
[6] For the sake of simplicity, we calculate with one ton. This value has to be discussed and fixed by policymakers.
[7] Vegan diet is not meant as a punishment here. On the contrary, it is healthy and, above all, very climate-friendly.

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So if our family of four now buys and uses a service robot, the operation of the robot leads to an additional energy consumption of 100 watt · 2/3 = 66.7 watt due to the rebound effect of 3.[8] Over a year, this adds up to 584 kWh which is equivalent to about 292 kg of CO_2. Each of the four people in the household accounts for 73 kg of this. By gaining one hour of free time per person per day, this adds up to about

$$1540\,\mathrm{W} \cdot 365\mathrm{h} = 562.1\mathrm{kWh}$$

of energy consumed. This is equivalent to about 281 kg CO_2. Because of the spare time rebound effect of 8, 7/8 of this, or about 246 kg, is additional. In sum, then, the robot results in an additional CO_2 footprint of 246 kg + 73 kg = 319 kg per person per year. This uses up almost a third of the total annual budget of one tonne per person. Presumably, under these conditions, most people would forego the robot in favor of other amenities.

6. Industrial Robots, Economic Growth and the Rebound Effect

AI systems will lead to disruptive changes in the labour market in the next ten to twenty years because they are being designed in particular to take work off our hands. And they are capable of doing so in a wide range of areas [9,10]. As shown above, the use of service robots in private households leads to a spare time rebound effect. However, if the service robot is now used commercially, for example in production or at a craftsman's, what happens to the human working time saved by the robot?

The robot is only used in the company if it increases labour productivity, i.e., if it produces more than the people previously employed for the same amount of capital. Productivity thus increases and human labour could be freed up. Unemployment for the workers concerned cannot be the solution. Instead, all people should step by step reduce their working hours. Similar to the service robot in the household, the work performed by the robot would lead to more free time for all people. Both above described rebound effects occur here in the same way. The calculations can be taken over accordingly.

The current capitalist economic system however argues and acts as follows: To prevent unemployment, the economy must grow. New products must be created together with new markets. The redundant workers will find other work elsewhere in a process of structural change. Instead of the spare time rebound effect, the robots' work leads to economic growth. However, this is not acceptable in times of climate change either. As a remedy we again suggest the above proposed CO_2-budget. It would solve this problem, because the budget does not allow for economic growth.[9]

In the free time we have gained, due to our CO_2 budget of one tonne per year, we will neither go shopping more than before, nor will we undertake more climate-damaging trips. Rather, we will learn to live a full life with less consumption (sufficiency), more time for our families, personal interests and a fulfilling sustainable circular economy (subsistence) [11,12]. This transformation should be supported by a structural change in the working world away from stress and pressure to perform and towards more creativity, enjoyment of work and self-realization[13].

Policymakers are challenged to put the boundary conditions for such a climate-just future into legal form. This is certainly not easy, but it is necessary, because it is about a livable future for the species Homo Sapiens.

7. Conclusions

AI as one of the most important driving forces of technological progress takes over more and more labout intensive tasks in the private household as well as in industry now and in the near future.

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8 With a rebound effect of 3, 2/3 of the 100 watts consumption is additional compared to the baseline without robot.

9 The budget is applied only to consumers, but it stops economic growth immediately, because people will significantly reduce their consumption. More than that, it will lead to degrowth of the economy.

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The service robot as an example eases our lives but at the same time leads via the rebound effect to more consumption of resources, environmental damage and possibly negative effects on lifestyle and society. We have shown that the gain of free time generated by robots represents the major part of the rebound effect. Damages are not so much caused by using AI but by doing harm to environment and society during our newly gained free time. Similar effects are caused by many other AI applications such as for example diagnostic systems in medicine, or large language models generating texts, images or videos within seconds.

It is the task of society as a whole to push politicians to change our capitalist economic system so that these rebound effects disappear, while at the same time improving our quality of life through stress reduction, better health, social balance and self-efficacy. The proposed personal CO_2-budget is just one particularly equitable solution.

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References

1. Santarius, T. Der Rebound-Effekt: über die unerwünschten Folgen der erwünschten Energieeffizienz. Technical report, Impulse zur WachstumsWende, 2012.
2. Ertel, W. Artificial Intelligence, the Spare Time Rebound Effect and how the ECG would avoid it. International Conference: Economy for the Common Good (ECGPW-2019); , 2019.
3. Alcott, B.; Giampietro, M.; Mayumi, K.; Polimeni, J. *The Jevons paradox and the myth of resource efficiency improvements*; Routledge, 2012.
4. Nuclear Power Reactors in the World. International Atomic Energy Agency, Vienna, Austria, 2015.
5. Dittmann, A. *Energiewirtschaft*; Springer-Verlag, 1998.
6. Böning, D.; Maassen, N.; Steinach, M. The efficiency of muscular exercise. *Deutsche Zeitung für Sportmedizin* **2017**, *68*, 203–214.
7. Lippelt, J.; Sindram, M. Global energy consumption. *CESifo Forum 1/2011* **2019**, pp. 80–82.
8. Felber, C. *Change everything: Creating an economy for the common good*; Zed Books Ltd., 2019.
9. Frey, C.B.; Osborne, M.A. The future of employment: How susceptible are jobs to computerisation? *Technological forecasting and social change* **2017**, *114*, 254–280.
10. Deranty, J.P.; Corbin, T. Artificial intelligence and work: a critical review of recent research from the social sciences. *AI & SOCIETY* **2024**, *39*, 675–691.
11. Fromm, E. *To have or to be?*; Harper & Row, New York, 1976.
12. Hickel, J. *Less is more: How degrowth will save the world*; Random House, 2020.
13. Jackson, T. *Prosperity without Growth: Foundations for the Economy of Tomorrow*; Routledge, 2016.