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Governing Jevons' Paradox: Policies and Systemic Alternatives to Avoid the Rebound Effect

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Abstract

In this article we lay the foundations for a new approach for Jevons Paradox and rebound effects, based on how it is triggered (origin) and how it expands (expansion), and from it, explore the potential of different ways to minimize or offset rebounds from resources productivity and conservation. We conceptualize different key aspects to understand and reframe rebound effects. On the "origin" side, we introduce the key concept of "resourceefficient paths", to show how productivity is a changing and complex issue, affected by the interaction of all other resources that produce goods or services, as well as behavior. This is a necessary, but not sufficient condition for the existence of rebound effects. On the "expansion" side we introduce the notion of systemic insatiability as key in the expansion and consolidation of rebounds through socioeconomic systems, and sufficient condition for the existence of rebound effects. Moreover, we analyze how inequality can exacerbate insatiability. With this framework in mind, we examine two main positions to find solutions: In the first, under our current socioeconomic, cultural, and institutional structures, we analyze different means of public policy intervention: resources pricing, cap-and-trade systems, regulation, and voluntary actions. The second position implies tackling systemic changes. Here we explore different post-growth systemic alternatives: steady-state, degrowth, agrowth, and post-development intellectual currents in relation to rebounds and Jevons Paradox.

Keywords

Rebound effect, Jevons Paradox, resource productivity, satiation, post-growth, policies.

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1. Introduction

Over the past four decades, many studies have emerged on Jevons Paradox, or more generally speaking rebound effects. Under these terms we can encompass, in general terms, all the unexpected and undesirable secondary effects of resources productivity and behaviors such as conservation on the effective and final use of resources. Most of these studies have been attempts to empirically prove the existence, and quantify the size of rebounds, using different perspectives and methodological approaches. Jevons Paradox is an extreme but feasible case of rebound, which arises when resources use end up increasing (rebound effects of over 100%) [1,2]. This case is also known as "backfire" in literature. Remarkable literature reviews of evidence can be found in [3,4,5,6,7]. Most are focused on energy resources, with some exceptions such as [8,9], which covers water.

William Stanley Jevons stated in 1865 that, contrary to common intuition, an increase in the efficiency of energy use increases energy consumption [10]. Since then, and despite many studies and efforts, it is still difficult to find satisfactory responses to one of the main questions related to rebounds, and specially Jevons Paradox: Is it really obstructing efforts in achieving sustainability?² According to [12], since 1970, global use of materials has increased by a factor of 3.74, from 26.7 billion tons/year to 100 billion tons/year in 2019. Of these, 50.8 Gt are minerals, 10.1 Gt are ores, 15.1 Gt are fossil fuels, and 24.6 Gt are biomass. Many factors have triggered this situation, but during this period many efforts have been implemented to reverse this situation, with apparently no success, at least on a global level. It would have been worse without these efforts, or were some of these efforts backfiring?

Rebounds are associated with not only secondary effects but also tertiary and beyond. Rather the physical or technical sciences, specialists in social and behavioral sciences, are well primed to address this issue [13]. The uncertainty of these effects is high because economic, social, and behavioural forces are implied in the process. This is why it is so difficult to track all the consequences of specific actions. However, there are some key aspects that need to be accounted for to refine and enrich its understanding and reframe this uncertainty in a way that we can articulate more effective responses.

² We consider a broad definition of sustainability like the one provided in the 1987 Brundtland Report: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [11].

The aim of this conceptual/perspective article is to lay the foundations for a new framework for rebound effects and Jevons Paradox, involving social and behavioral sciences, and based on this perspective, to propose potential solutions. It is based on how it is triggered ("origin") and how it expands ("expansion"). We do not present a review of literature, but rather, we set up this framework by conceptually introducing its key aspects, giving new insights to widener the field, and engaging with other literatures. This article traces the development of two core aspects to reframe the understanding of the nature of rebound effects: resourceefficient paths (from the "origin" side) and the role of satiation (from the "expansion" side). Both elements are fundamental, being necessary and sufficient condition, respectively, for the existence of rebounds and Jevons Paradox. As Galvin and Gubernat [14] noticed, conceptual theorizing as to how rebound effects happen, in relation to the human consumers who seem to cause it, is relatively limited. York and McGee [15], from a sociological perspective, demonstrate that, at a variety of levels, a positive correlation between efficiency and resource consumption is common, suggesting that there is something to be explained. We introduce some novel ideas, which can help setting new frameworks or reframe current conceptualizations.

All resources are likely to improve their productivity, while simultaneously they are likely to see their use increased as a consequence of other resources' productivity improvements or behavioral actions thereon.³ However, this is not novel in rebound literature, see for instance [16,9]. In this article, we extend the traditional focus on energy services to all goods and services because they use other resources in their productions, amenable to experiment productivity improvements or behavioral changes. Rebound effect studies started and consolidated in energy resources for the importance and characteristics of energy in socioeconomic systems [4]. It is also key in climate change discussions because societies have been, and are, highly dependent on fossil fuels. However, the emergence of two key aspects increases the importance of including other resources in rebound discussions: 1) the unstoppable global increase of total resources consumption and 2) the gradual increase of the share of renewables in total energy use and the current debate on abandoning fossil fuels in the coming decades. The last point may mean transitioning from an intensive use of some resources (fossil fuels) to other types of resources (some renewable and some nonrenewable), creating other kinds of environmental problems (i.e., resources exhaustion) and not avoiding current ones in some cases.

³ As we will see, not just productivity, but also behaviors can trigger rebound effects.

As we offer a broader perspective than traditional approaches, we explore traditional, but also alternative potential solutions to minimize or even avoid Jevons Paradox and rebounds. These actions have been classified into two main groups. The first comprises policy instruments within our current socioeconomic, institutional and power structures; the second implies adopting systemic alternatives. In section 2, we analyze 'the origin', by defining the behavioral nature of efficiency and resources productivity through what we call "resourceefficient paths"; in section 3, we analyze the 'expansion', by pointing out the importance of insatiability in expanding and dimensioning rebound effects and the role of inequality. Section 4 includes an analysis of potential policy instruments to offset rebound effects. In section 5, we go deeper on different systemic alternatives existing in literature that would potentially avoid Jevons Paradox minimizing rebounds, but which may entail deep changes in current socioeconomic and cultural systems. Section 6 offers the main conclusions of this article.

2. The Origin: Resource-efficient paths

From a microeconomic perspective-as is usually adopted in rebound literature-we can start from Becker's households' production framework [17] to derive the direct rebound effect. In this context, households use energy, capital, labor, land, and other intermediate inputs to produce energy services such as transportation, cooking, thermal comfort, or lighting. Households are treated similarly to productive sectors but aim at maximizing their utility rather than profits, like firms do in standard theory of production. Firms also use primary and intermediate inputs to provide energy services. However, we can extend this framework to all goods and services produced by households, firms, governments, and the rest of the world because all of them require some kind of energy to be produced. Although the energy services concept is useful at household level when framing the direct rebound effect, we need to talk about all services and goods at a systemic level. Both market and nonmarket production is provided by the combination of labor, capital, materials, and some form of energy to satisfy a human need. More resource-efficient devices (capital) provide better⁴ or cheaper goods or services. This framework works for different economic agents, leading to direct rebound effects at the first instance and finally impacting on the overall socioeconomic system through the complex relationships among economic agents.

⁴ This is usually referred to as "attributes" in literature [4].

Conservation of energy or of other resources can also trigger rebound effects, but with slightly different consequences at different levels [18].

However, part of productivity also has a behavioral and mobile nature. It is factors of production that can change to embrace energy or other resources efficiency improvements. For instance, to provide an energy service such as transportation, one may need two main production factors, capital (the car) and labor (the driver), besides energy. Both can change to improve energy efficiency: Each generation of car engines is more efficient, but drivers (labor) can also change the way they drive to perform an "efficient driving." For other (nonenergy) goods and services provided by any economic agent, we can use the same logic. Let us assume that cookies production, for instance, only needs two production factors: labor and capital. Both production factors can improve the way they use energy, leading to productivity improvements and potential rebound effects. All services provided by households require some kind of energy (following a broad definition of energy) and have potential to improve its efficiency through capital or labor. Labor can mainly improve the use of capital in a way that improves energy efficiency. Human capital has a similar but cumulative effect. Household cleaning, for instance, can be a service subject to energy efficiency improvements through the use of better vacuum cleaners but also through changes in the way they are used and through the accumulated experience of cleaning. Thus, each technological change incorporated in capital allows a potential productivity improvement that depends on labor behavior and resources use to different extents. Each technology allows access to different energy efficiency potentials in combination with energy, labor, materials, and time. Figure 1 is a simplification of different resource efficiency potentials under different hypothetical technologies. The axis of abscissas represents quality rather than quantity. The efficiency of some technologies may also be independent from the use of other factors (see technology 2).



Fig. 1. Resource-efficient paths under different technologies.

From an applied and policy perspective, the difficulty lies in knowing the resource efficiency change along space, time, agents, and technologies. A "resource-efficient path" can be defined as the different efficiency levels that can be achieved in the use of a resource with a specific technology, in combination with other resources and factors along time. Not only are there different resource-efficient paths for each technology, but each technology is also embedded in capital in many forms: potentially one curve per variety (or even brand and model) of product and service. Some technologies such as artificial intelligence and, to a lesser extent, computing may also be able to evolve their own efficiency paths. Besides, each economic agent using labor, in combination with energy and materials, can be at different points of the efficiency curve.

In this sense, for each technology, efficiency paths may adopt diverse functional forms and can depend upon similar factors as those in production functions from standard economic theory. Each technology delivers an average efficiency path in each area, period, and location. This perspective visualizes the fact that productivity may ultimately come from behavior.

3. The Expansion: Systemic Insatiability and Inequality

From a global perspective, rebound effect is an issue related to systemic boundaries. Productivity advances or resources conservation relieves limits that constrain the physical dimensions of economies [19]. This is inherent to capitalist economic systems. However, within current capitalist modes of production, sociocultural and psychological behaviors have a key role in exploiting these new potentials. In this framework, we can conceptualize "systemic insatiability." Despite its importance, especially in natural resource economics, satiation is not a particularly popular concept among economists [20]. Jackson [21] states that within the economic perspective is the assumption that human wants are essentially infinite, and the desire for commodities in general is taken to be insatiable. Jackson et al. [22] point out that the assumption of insatiability at the heart of economics is counter to certain classical conceptions of human wellbeing. Jackson [21,p.24] states: "Pleonexia, the insatiable desire for more, was regarded in Aristotle's day as a human failing, an obstacle to achieving the "good life." In the modern consumer society, it is encoded in both the ideological foundation and the institutional structure of the market economy." Satiation is a highly complex concept and is not just an economic or physiological issue [23,24]. As regions increase their welfare, satiation also becomes a psychological and anthropological issue. Social values shape the way individuals and societies interact with the environment while helping define their material needs. If fluctuating and subjective material satiation levels are not reached, productivity gains will ultimately rebound unexpectedly somewhere in the system. It is unclear whether policies oriented to correct market failures can partially or totally tackle this paradox.

If satiation is never reached, the system will generate rebounds in the absence of imposing adequate limits. However, these limitations need to be global. Because socioeconomic systems are globally linked through economic specialization, trade, the financial system, and even institutional structure, spillovers may hinder avoiding rebounds in different areas, regions, and/or periods inevitable if there is no a global strategy. Despite that it is a complex issue, a societal consensus of sorts may arise on basic material needs—defining physiological satiation levels—that quantifies some set of objective parameters: a quantity of daily ingested calories per person, a dwelling, and so on. However, at some point or threshold, the importance of psychological satiation grows, despite basic material needs being met. Different factors may drive this kind of satiation. The role of capital accumulation, and capitalism's resultant growth imperative [25,26], can ultimately drive systemic insatiability. It is not clear, however, if the systemic need of continuous economic growth is the ultimate cause of lack of psychological satiation or the other way around; that is, the never-ending

satiation drives continuous economic growth. Thus, to reframe Jevons Paradox and rebounds as a global systemic problem, we refer to the notion of systemic insatiability, rather than individual insatiability.

One important trigger at systemic level, but not the only one, as this is an effect of markets as such, is financial mechanisms seeking niches of potential growth and reallocating freed resources to the system. If we assume that resource efficiency exists but the direct rebound effect is contained—thanks to policies, morality, or any other limitation—then monetary savings and other behavioral responses result (i.e., other kinds of moral issues) expand rebounds in different ways, but newly freed resources do not remain vacant without some type of physical or psychological limitation. Additional resources or incomes can be spent to satiate other needs through the consumption of other goods or services or can be saved. A financial system allocates savings to current or future investments or consumption if current or future satiation has not been reached at all levels. This is known as the re-spending mechanism in indirect rebound effect literature [27,28,29]. This concept can be partly proved empirically and should be generalized to wider levels than just those allowed by current macroeconomic frameworks.

Satiation can adopt different perspectives and nuances. Mainstream consumer theory in economics uses indifference curves to generate demand curves. Non-satiation is one of the basic assumptions of these curves, meaning that marginal utility for goods and services is always positive. However, economic theory does not go deeper on the concept and potential consequences for natural resources and the environment. Some mainstream economic literature approaches the concept [30]. Witt stated that "the 'explanation' for the sustained growth of per capita consumption relies on a non-satiation axiom of some kind and the continuous relaxation of the budget constraint as a side condition" [31, p.24]. This author, from an evolutionary economics perspective, related non-satiation with the increasing variety of consumption items offered in the markets and the increasing specialization of consumers in their demand activities. In relation to the environment, [20] showed that satiation in consumption is not only sufficient to find an environmental Kuznets curve (EKC)⁵ but that a tendency to satiation is even necessary if we assume a standard functional form for the

⁵ An EKC is a hypothesized relationship between environmental quality and economic growth or development, showing an inverted U curve. That is, environmental degradation grows first but then decreases as economic growth advances (for a literature review see [32]).

pollution function. Regarding the rebound effect or Jevons Paradox literature, no specific studies exist on the nature and importance of the global role of satiation. However, some authors remark its importance at microeconomic level, most of them recognizing that rebound effects might be higher in developing countries because they are further from their satiation levels for specific energy services than are industrialized countries [4]. This is an issue that needs more research because it may be key in reaching global sustainability in resources use by controlling or minimizing rebounds and elude Jevons Paradox.

Another related issue, linked with systemic insatiability and receiving insufficient attention in rebound and Jevons literature is inequality, in both ways: how rebound effects shape inequality and vice versa. No theoretical or empirical studies specifically address both issues. Regarding the first, we know that at microeconomic level, poor households can afford higher levels of the services affected by productivity improvements, which they could not before. A short-term microeconomic perspective shows that direct rebound effects improve lives in the poorest households or regions. However, we struggle to discern the effects on inequality from a long-term macroeconomic perspective.

Highly unequal societies may lead to higher systemic insatiability because they create material-intensive lifestyles in the part of the population that helps develop the desire for achieving those material standards among the rest of the society. This idea has been discussed by several authors, remarkably in defining Veblen's 'conspicuous consumption' [33] and Galbraith's 'Affluent Society' [34]. From an ecological economics perspective, some literature on degrowth argues that equality might be a precondition for limiting consumption collectively [35]. In this sense, equal societies may limit insatiability effects while simultaneously limiting rebounds. Some authors argue that global inequalities are growing [36]. Given the importance of systemic insatiability for expansion on rebounds, we can also formulate the problem of looking for the links among satiation, inequality, and rebound effects in a global economy context. In this framework it is not enough to achieve local equal societies; we need global ones because globalization would "export" the expansion of rebounds to other areas, periods, and regions through transboundary mechanisms such as the financial system, trade, specialization mechanisms, and technology (i.e., communication technologies), or in other words, a highly integrated global economy.



Fig. 2. Satiation and inequality. Source: own elaboration.

In the example shown in Figure 2, "Inequality A" is a less egalitarian society than "Inequality B". More equal societies would reach higher levels of satiation in relation to unequal societies. The horizontal line shows the threshold that separates physiological from psychological satiation.

As stated, empirical evidence of the direct rebound effect shows that direct rebound is higher in developing countries than in industrialized ones [4]. This is invariably associated with the fact that, at microeconomic level, developing countries are further apart from satiation and take advantage of efficiency improvements to increase their welfare, while more industrialized countries do not want or need a greater quantity of the specific resource that increased their efficiency. This effect may be related partly to physiological insatiability and partly to psychological insatiability, as exposed.

Under this framework we describe two main positions for imposing limits on rebounds: the first assumes it is possible to stop this effect by public policy intervention, while the second implies an assumption that the only way to avoid Jevons Paradox is to tackle systemic changes. Below, we dissect both possibilities under the premises exposed in this and previous chapters.

4. Policy Instruments to Tackle the Rebound Effect

One could consider the possibility that, without the need to encompass profound systemic changes, policy makers can set mechanisms to avoid rebound effects. The difficulty lies in knowing the feasibility and costs of carrying out the necessary actions successfully. It is not clear that implementing available policies successfully is less costly than systemic changes, considering the (ambitious) target.

From a public policy perspective, some instruments can be useful to counteract rebound. Generally speaking, the main policy tools are different forms of resource pricing, regulation, and individual voluntary actions.

4.1. Resource pricing

Resource pricing is considered one of the best measures to counteract the rebound effect [37,38,39]. If we focus on energy, under the consideration that energy rebound effects are driven by a drop in the effective cost of an energy service, energy pricing initiatives can try to compensate for this reduction by increasing energy prices. If we focus on other resources' productivity, pricing can be aimed at increasing costs of those resources. There are two main ways of implementing resource pricing: one focused on prices and the other one focused on quantities. The former includes different forms of resources taxation; the latter includes cap-and-trade systems.

There is no broad corpus of literature discussing the desirability of one instrument over the other in the specific context of limiting the rebound effect. The main discussions revolve around climate change mitigation, especially for cap-and-trade systems, which have been implemented to reduce CO₂ emissions.

Goulder and Schein [40] found that, to avoid environmental impacts (e.g., climate change), both instruments are equivalent along many dimensions, but pricing helps avoid both, problematic interactions with other climate policies and potential wealth transfers to oilexporting countries. A discussion on the pros and cons of each instrument can be found in [41]. Most of the problems can be managed with a proper design.

4.1.1. Resources rebound taxation

Resources taxation has proven an effective means of discouraging the use of specific resources. Environmental taxes have been broadly treated in the literature since [42]

developments. From an economic and policy perspective, it is one of the preferred forms of action by economists to correct market failures related to public goods provision and externalities. In this sense, fiscal instruments are recognized as a cost-effective policy instrument to achieve environmental targets [43]. We can show how resources pricing can work theoretically in quite a simple way, starting from a simple price equation of an energy service from [4] on the theoretical aspects of the rebound effect. However, we will generalize the analysis to all resources' productivity, rather than energy efficiency alone, and we will discuss goods and services provided by resources, rather than energy services, in the sense we argue in section 2.

The price of the commodity or service P_s is equal to the price of the resource P_R in relation to resource efficiency or productivity ε , measured in terms of the thermodynamic efficiency of a system providing a service:

$$P_s = P_R / \varepsilon \tag{1}$$

An increase in efficiency ($\Delta \varepsilon$) will drive down the price of the commodity or service.

$$P_S' = P_R / \varepsilon' \tag{2}$$

Where $\varepsilon' \ge \varepsilon$ and then, $P_S > P'_S$. To keep the price of the commodity or service constant, we can artificially increase the price of the resource or, alternatively, set a tax for the difference between P_S and P'_S .

$$P_S = (P_R + t)/\varepsilon' \tag{3}$$

The generalized cost of useful work (P_G) equals the sum of different components:

$$P_G = P_S + P_K + P_L + P_M \tag{4}$$

Where P_K , P_L , and P_M are the prices of capital, labor, and materials, respectively. From equations (3) and (4), we can obtain the next expression:

$$P_G = \left(\frac{P_R + t}{\varepsilon'}\right) + P_K + P_L + P_M \tag{5}$$

Rearranging terms, we can obtain the value of a theoretical optimal tax to counteract the direct rebound effect of efficiency:

$$t = (P_G - P_K - P_L - P_M)\varepsilon' - P_R \tag{6}$$

Assuming that t = 0 when $\varepsilon' = \varepsilon$, we have:

$$P_R = (P_G - P_K - P_L - P_M)\varepsilon$$
⁽⁷⁾

As noted, from an empirical perspective it is difficult to set an optimal taxation because of the difficulty of knowing the value of each cost component, especially efficiency, as shown in section 2. However, this framework is useful for understanding which components are important for tackling rebound effect from a pricing perspective.

The implementation of resources rebound taxation has three main problems: (1) difficulties in monitoring and quantifying the efficiency improvements effectively released to the users at different periods, places, economic agents, and areas. Because efficiency is embedded in devices (capital), not only purchases, but also their specific use, generate rebound effects. One possible solution is to estimate an average annual resource rebound tax considering efficiency improvements achieved during the previous year; (2) difficulties in setting a tax for the commodity or service, especially those nonmarket services such as those produced in households for self-consumption. Similarly to "energy services" in mainstream rebound literature, taxing goods or services-provided by resources-may be the best way to avoid rebound effects because taxing resources directly would imply discouraging the use of other services not affected by a specific efficiency improvement, thinking in efficiency as shown in section 2. One possibility would be taxing devices affected by efficiency improvements, but this creates two additional problems: it is not related to the use, and it could discourage innovation; (3) revenues from taxation need to be used wisely to avoid generating additional indirect rebound effects arising from the re-spending mechanism [27]. This is a key question, related to the interindustry links along the economic system, that dramatically increases the difficulty of avoiding rebound effects along said system. The real direct and, particularly, indirect use of resources is usually hidden and defies easy tracking. A tax policy like this

should include a well-designed spending policy of these revenues, taking into account all indirect effects. Proper public spending of revenues is needed to minimize rebound and, in the long term, changes in economic and trade structures [44].

4.1.2. Rebound cap-and-trade systems

Another way to control for rebound effects is setting global limits on resource use through cap-and-trade systems. Such a policy would avoid the rebound effect because there would be no legal way to use a higher quantity of the resource than the upper limit established by the regulator. From a theoretical perspective, we can reformulate the pricing problem by including quantities:

$$P_G Q_G = P_S Q_S + P_K Q_K + P_L Q_L + P_M Q_M \tag{8}$$

From [4], we know $Q_S = \varepsilon Q_R$. Using this expression and equation (8), we obtain:

$$P_G Q_G = P_S \varepsilon Q_R + P_K Q_K + P_L Q_L + P_M Q_M \tag{9}$$

Then we find the quantity of resource (Q_R) we want to keep constant:

$$Q_R = (P_G Q_G - P_K Q_K - P_L Q_L - P_M Q_M) / P_S \varepsilon$$
⁽¹⁰⁾

This identity shows how other factors change when the quantity of the specific resource changes. There is endogeneity between P_S and ε , in the sense that variations in efficiency change the cost of the good or service provided by the resource, or alternatively, other costs change. This endogeneity relationship involves the rebound effect that, under some circumstances, can be a proxy variable of the price elasticity [4]:

$$\eta_{\varepsilon}(R) = -\eta_{P_{\mathcal{S}}}(S) - 1 \tag{11}$$

$$\frac{\frac{dR}{R}}{\frac{d\varepsilon}{\varepsilon}} = -\frac{\frac{dS}{S}}{\frac{dP_S}{P_S}} - 1 \tag{12}$$

$$\frac{dP_S}{P_S} = \frac{\frac{dS}{S}}{\left(-\frac{dR}{S}-1\right)}$$
(13)

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Alternatively, it can be shown this way for an easier interpretation:

$$\%\Delta P_S = \frac{\%\Delta S}{\left(-\frac{\%\Delta R}{\%\Delta\varepsilon} - 1\right)} \tag{14}$$

This formulation shows that an increase in resources efficiency reduces the cost of the service, depending on elasticity values.

The main advantage of this instrument is that it avoids some of the difficulties derived from the uncertainty of taxation instruments, such as achieving the targeted policy. However, it does not avoid the need to obtain information on efficiency improvements and other data. However, once the target reduction of the resource use is known, setting a maximum and letting markets work under clear and specific rules should always lead to the objective. Other kinds of difficulties and costs are typically associated with this instrument,⁶ but if the target is minimizing rebound effect, there is no better instrument because there is no possibility of rebound effect theoretically: if there is an increase in resource efficiency, the cap must be set in a way that rebound effect is equal to zero. This does not mean that other effects can be important or render the measure unfeasible in economic or social terms.

4.2. Other policies: Regulation, voluntary actions, and changing lifestyles

Other policies are mainly related to regulation and voluntary actions. Regulation, in the context of the rebound effect, can basically be implemented by imposing direct bans of or limits to resources' use. Theoretically, if a global ban is imposed on the use of a specific resource, its use cannot possibly increase. This means total effectivity in achieving the goal if it is correctly defined. This absolute effectiveness may not occur in practice because of regulation limitations. The option of banning or limiting the increase in the use of resources based on the rebound effect shares most of the difficulties of implementing resource pricing and adds some more. For instance, regulation may need more controls and monitoring than pricing to be effective. A discussion on this can be found in [46].

As well as productivity, resources conservation can also generate rebound effects. Alcott [47] wrote about the limitations of voluntary individual actions, or even actions conducted by a

⁶ See, for instance, [45].

nation or a region, in decreasing overall resources use. Although these actions are not policy themselves, they can be fostered by governments as a policy strategy. Van den Bergh [18] argued that governments foster voluntary actions because they seem a cheap solution to environmental problems; however, they can generate rebounds without physical and price constraints on behavior, but could they counteract rebounds if properly driven? The short answer is yes. In the same way that some actions can lead to or increase rebounds, other economic voluntary actions can reduce them. The difficulty lies in knowing which individual actions are the most adequate. "In industrialized countries private and public decision-makers are largely unaware of rebound effects of their decisions. One is even tempted to say that energy conservation is more driven by good intention than by good oversight of all its consequences" [18: p.45]. The empirical analysis of ways to tackle rebounds through incentivizing specific production, distribution, and consumption voluntary actions that differ from the traditional approaches is not adequately addressed in literature. What we know is that some of the typically recommended measures by policy makers to achieve sustainability generate rebound effects (see, for instance, [48]).

In this context, the concept "resource sufficiency," similar to conservation, involves reducing consumption of resources to minimize the associated environmental impacts [47,49]. As [49, p.11] found in a recent literature review of energy sufficiency actions and rebound effect: "The results strongly suggest that environmental values and self-reported energy sufficiency actions have a very limited influence on both direct and total energy use and emissions." The main reasons they pointed to were as follows: respondents exaggerate their adoption of energy sufficiency actions, they prioritize actions with limited impact, there is a re-spending effect of their monetary savings, and they think they deserve a "moral license" to engage in other actions that damage the environment. Seebauer [50] stated that social norms may backfire, as they legitimize additional consumption. Resources productivity, conservation, and sufficiency can lead to the same consequence: expansion of production and consumption capabilities. This creates more availability of space, time, and resources, with the intersection of cultural constructions and psychological factors.

"Downshifting" is another kind of voluntary action consisting of voluntary reductions in working time and income. The effect of these reductions will depend on how the additional free time is spent. Changes in the pattern of time use (i.e., time-use rebounds) could offset resources savings from lower consumption, so the balance between the two is unclear [49]. Besides, beyond this balance, and from a wider perspective, this could be not considering that under an insatiability premise discussed in section 3 (and no physical or psychological limitations) firms may hire other workers to maintain global production levels and/or switch their processes to satisfy other new consumption needs (for instance, more oriented to leisure), with no real reductions in global resources use.

However, engaging with other related strands of literature, changing lifestyles beyond specific individual voluntary actions can be a powerful means of achieving sustainable societies and avoid Jevons Paradox. Nonmaterial (or less material) factors can provide a meaningful, prosperous, and happy life [51,52]. This, however, necessitates a profound change in cultural values, which current democratic systems should be able to create [53]. This position could be linked with adopting deep global systemic changes, as we analyze in the next section. In this context, also the discussion of whether current democratic systems are realistically able to create a profound change in cultural values becomes relevant.

5. Systemic Alternatives for Strong Sustainability Under rebound effects

Some of the arguments covered in section 3 could entail that capitalism systemic functioning leads inevitably to Jevons Paradox. Non-systemic solutions discussed in section 4 may be impossible to apply in practice to reduce resources use, even globally implemented (which would avoid transboundary effects). Resource-efficient paths show complexities involved in the origin of rebounds, key to implement these measures. Besides, technological progress encouraged by insatiability could deviate demands toward other resources [54,55], making impossible or ineffective the practical implementation of these mechanisms.

Beyond the traditional focus on individuals or agents from the economic theory embedded in non-systemic solutions, social structural constraints tend to lock individuals into certain behaviors that are difficult to change if these constraints do not [56]. Systemic insatiability may be deeply rooted in current social structures. In this context, systemic alternatives arise as pertinent solutions.

Despite all the remarkable technological advances that have improved resources' productivity throughout the history of capitalism, the hypothesis of decoupling economic growth and environmental pressures has been refuted in recent reviews [57,58]. Focusing on resources use, the hypothesis of "dematerialization," which states that resources use grows more slowly than GDP, has only held true in industrialized countries because of their

outsourcing of productive processes to developing countries. They relocate most of them to reduce labor costs and avoid (environmental) regulations [51,59,60,61]. In five decades, the global economy has gone from using 26.7 billion tons/year of materials to 100 billion tons/year [11]. According to the International Resource Panel [62], the total amount of resources used by 2050 will be between 170 and 184 billion tons.

Introducing more complexity into the discussion brings further difficulties in terms of understanding and tackling this problem, which some authors recognize. Ruzzenenti and Basosi [63], for instance, introduced an evolutionary perspective and stated that higher complexity, because of a greater energy density rate, counteracts the positive effects of energy efficiency. In this sense, post-growth views [64], which include the four major economic growth-critical currents, could embrace potential deep solutions to rebound effects because they go to the root of the problem, namely satiation and boundaries expansion. These approaches, which mainly derive from the ecological economics and political ecology fields, are steady-state economics, degrowth, agrowth, and post-development.

Within their different approaches and complexions, these four intellectual currents of postgrowth defend the hypothesis that traditional economic and policy targets in developed economies, through the use of indicators such as GDP, are not useful in terms of improving human well-being and ecological conditions. Furthermore, as they tackle the root of the problem, they can also deal with additional related "unexpected" problems, like the existence of cross-rebound effects, or how resource productivity improvements have effects on other resources' use [54,55].

5.1. Steady state economics, degrowth and agrowth

Steady-state economics promotes non-growing societies based on a stable material and energy throughput [65]. Herman Daly—the main proponent of this approach over the past four decades—has designed steady-state policies mainly targeted at industrialized countries (2012). Georgescu-Roegen, one of the main inspirations of the degrowth movement [66,67,68], criticized what he called the "growth mania" of mainstream economics. Some scholars argue that both approaches can be seen as complementary in many respects [69].

Degrowth proposes a deep change in socioeconomic systems toward not only a smaller but also a different societal metabolism, serving new functions [70], with an understanding of metabolism as the flow of materials and energy between nature and society, among societies, and within societies [71]. Equity should also be a central target for this new method of understanding economies, being also important the changes in social values, such as removing material accumulation as a central value. Leaving other considerations aside, steady state and degrowth postulates offer an effective way to reduce rebounds and avoid Jevons Paradox. As exposed in section 3, material needs come from many sources, but insatiability as a lifestyle comes from social values. Degrowth theories promote changes in the way we relate to the environment, leading to a disappearance of consumerism and material accumulation as a lifestyle. Rebounds under a system like this are expected to be extremely low or non-existent based on two main factors: (1) lower rates of productivity improvements, given that part of the incentives triggered by previous social values disappear. This would provoke, among other factors, lower rebounds throughout the system; and (2) productivity improvements used to reduce material metabolism due to strong moral and (in the long term) cultural limits. The possibility of low rebound effects is lower as a result of changes in the social perception of nature and personal material needs.

Both factors can be summarized in the fact that there is no insatiability that pushes system boundaries toward constantly increasing social metabolism. Beyond other considerations and potential difficulties in implementing a global degrowth system, it represents one effective way of dodging Jevons Paradox, especially in the sense described by [16]. This means avoiding multiple, irreversible changes in a context of evolutionary adaptative systems that affect economic, social, and technological structures at many levels. These are triggered by resources efficiency leading to an increase in resources use in unexpected dimensions. Great difficulties are involved in tracking these changes empirically. For instance, the disruption of a new general-purpose technology, such as the internet, not only triggers what we know as direct, indirect, and economy-wide rebound effects [4] but also gradually changes the way we see the world, with multiple consequences for how we relate to natural resources.

In this vein, [72] stated that steady-state and degrowth both agree with the idea that societies will not easily accept a sudden degrowth in terms of, for instance, GDP or energy and materials use. The option of (some) degrowth and then a mildly fluctuating steady state, avoiding rebound effects as technological efficiencies increase, would be socially more acceptable. Gunderson and Yun [73] analyzed South Korea's National Strategy for Green Growth (NSGG), pointing out that it would create rebound effects and concluding that a

degrowth strategy would more adequately allow the country to meet two goals of the NSGG: (1) mitigating climate change and achieving energy independence and (2) improving quality of life and enhancing international standing. Bliss [74] pleads to collective self-limitation, preferably democratically, to limit resources use.

The agrowth perspective, as an alternative to degrowth postulates, considers that economic growth should not be a primary societal objective. Welfare and sustainable targets should be central, and whether these targets require economic growth is irrelevant [75]. The rebound effect under the agrowth perspective could be avoided, depending on the new societal targets assumed. These targets should be fixed globally, oriented to the achievement of sustainably affixing clear boundaries to resources use. For instance, a strong global commitment to use only a pre-established quantity of resources would limit rebound effects to those resources' use. This could, however, affect economies by reducing GDP. Regional efforts would not be enough because leakage effects would export rebounds to other noncommitted regions. Thus, agrowth implies some changes in societal preferences and objectives, making people more likely to accept sacrifices but not going so deep as to change the social value of material welfare, as degrowthers propose. This perspective may be easier to implement from a public policy, and even from an international, perspective in the short/mid-term, and it could even be seen as transitionary toward a degrowth economy. Its efficacy in terms of avoiding the rebound effect should be accompanied by changes in some fundamental structures, specifically those related to satiation, as framed in section 3, to be viable socially and policywise. Because these changes do not seem as radical as those implied in degrowth perspectives, they could be more easily accepted than steady-state or degrowth visions. However, some kind of moral or psychological limit should arise in the mid/long term in order to contain insatiability not just with policies.

5.2. Post-development

Finally, post-development theory argues that the concept of "development" is a Western-Northern imposition over the other countries of the world to maintain influence and hegemony [76,77,78]. Following [64], we can identify three main post-development visions relevant to post-growth, which could also be relevant to rebounds: (1) culturally specific conceptions of the good life; (2) solidarity- or community-based economies [79]; and (3) post-extractivism, which calls for a societal change away from economies dependent on/guided by extractive industries [80].

Schneider [81] stated that we should investigate different models of development, such as post-development, to work on the process of wealth transfer, which he linked to the rebound effect. He assumed that because of the rebound effect, we cannot limit goals to physical and economic degrowth. This is why, in his view, we need Economic Degrowth for Sustainability and Equity. As he stated, self-limitation by the West would give other societies room to explore their own political space and develop appropriate systems of production and social organization [82]. With the strong links between this intellectual approach and degrowth initiatives, Jevons Paradox would be restrained and rebounds minimized by imposing sociocultural constraints on the expansion of global use of resources and affluence.

Degrowth and post-development can also be seen as complementary parts of a plural set of systemic alternatives. As they are conceptualized in literature, degrowth and post-development may be the most effective systemic alternatives for avoiding rebounds, leaving other considerations aside such as the social, institutional, and economic viability of these approaches. This is an aspect left out of this article and is currently under discussion in literature.

6. Conclusions

In this article we introduced a new perspective to see Jevons Paradox and rebound effects, and discuss different means of dealing with them. Traditional frameworks of rebound effects highlight the relevance of energy services. Although these are useful at households' and firms' level, we showed the relevance of all sorts of goods and services, not just energy services, at a systemic level. All production (market or nonmarket) is susceptible to being seen to improve productivity in the use of different resources to produce them before triggering rebound effects.

There are two key aspects in this framework, the 'origin', or how rebounds are triggered, and the 'expansion', or why and how they expand. Related to the origin, resource-efficient paths, can be defined as the different resource efficiency levels a technology can adopt depending on the different potential combinations with other factors of production. Its conceptualization shows the complexity of efficiency as well as an additional difficulty when looking for solutions. Basically, there are no uniform changes in efficiency, and they depend on other factors forming part of that technology. The analysis of efficient paths also visualizes the fact that productivity may ultimately come from behavior in many cases. The second core concept in this framework is related to the 'expansion': insatiability. Productivity and other individual and collective behaviors relieve physical limits on socioeconomic systems. These new niches can potentially lead to more use of resources and then trigger rebound effects. Uncontrolled insatiability incentives take advantage of these potentials. Evidence shows that those areas closer to satiation levels experiment lower rebounds, while more industrialized, and consequently "satiated" countries, also have lower rebounds in relation to other countries. Resource-efficient paths stablish necessary conditions for the existence and expansion of rebound effects and Jevons' Paradox.

With these aspects in mind, we propose different ways to tackle rebounds. We explored two different paths: 1) policy instruments within current capitalist systems and 2) implementation of most prominent systemic post-growth alternatives. In the first option we analyzed resources taxation, cap-and-trade systems, regulation, voluntary actions, and changing lifestyles, while in the second we included different systemic alternatives considered as the main post-growth intellectual currents: steady-state economy, degrowth, agrowth, and post-development. We assessed these currents in relation to Jevons Paradox and rebounds in general, leaving aside their feasibility and other considerations currently being discussed in literature.

The first set of potential solutions assumes that governments need to design global and complex multifront resources policies; this changes some views on environmental policies and problems, but no systemic changes are needed. Efficiency improvements depend on the behavior of other production factors. Resource-efficient paths show this complexity. In any case, an adequate policy mix may be needed because there are no simple solutions. Jevons Paradox and rebound effect literature highlight the need to improve the design and implementation of resources conservation policies if they are to achieve the expected results. This implies designing complex multifactor policies with thorough socioeconomic and multidisciplinary assessments. Social scientists need to be closer to policy design and decision-making.

The second set of solutions assumes that there is no way to tackle this problem under current conditions, while systemic alternatives could. Their implementation means profound

changes in socioeconomic systems that, while potentially avoiding rebounds, may incur other problems related to their feasibility in socioeconomic, institutional, and cultural terms. Both sets of solutions may even be seen as different steps of the same process in this order: 1) implementing resource pricing, cap and trade, and changing lifestyles; 2) transitioning to agrowth; and 3) transitioning to steady-state and degrowth with post-development in developing countries. At the end of this transition, not policies, but rather a new set of social values and culture should limit systemic insatiability.

Another important consideration is that these measures could be only partially effective or even ineffective if they are not applied worldwide (see however [47]), depending on the target of the policy. These measures, only applied regionally, are effective for specific problems such as local impacts or consumption of resources with local markets (e.g. aggregates), but are not so effective with global environmental problems such as climate change or global resource depletion. Besides, rebounds can present in other areas, regions, and periods owing to transboundary effects. As this is a conceptual study, there are some limitations related with the research design. Further research should deepen on its underlying ontological and epistemological considerations, analyze its degree of complexity and abstraction, and show the strengths and limitations that result from the proposed framework and the novel concepts described in this article.⁷

Avenues for further research include obtaining evidence on the different alternatives proposed in this article for tackling rebounds and avoiding Jevons Paradox. The empirical analysis of ways to tackle rebounds through incentivizing specific production, distribution, and consumption, as well as voluntary actions different from the traditional ones, is something not adequately addressed in literature. Moreover, empirical studies are overly focused on energy. It is important to understand the effects of changing how we use other resources, which broadens the picture. This would give the issue more relevance in sustainability terms. Future research should go further, theoretically and empirically, to assess all possibilities shown in this research, with the aim of clarifying which are the best options and in which contexts.

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⁷ See the Special Issue on the Problems of Methods in Climate and Energy Research, to know more about potential problems on research design, edited in Energy Research & Social Science [83].

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