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## Simple Myths and Basic Maths about Greening Irrigation

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## Simple Myths and Basic Maths about Greening Irrigation

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### Summary

Greening the economy is mostly about improving water governance and not only about putting the existing resource saving technical alternatives into practice. Focusing on the second and forgetting the first risks finishing with a highly efficient use of water services at the level of each individual user but with an unsustainable amount of water use for the entire economy. This might be happening already in many places with the modernization of irrigated agriculture, the world's largest water user and the one offering the most promising water saving opportunities. In spite of high expectations, modern irrigation techniques seem not to be contributing to reduce water scarcity and increase drought resiliency. In fact, according to the little evidence available, in some areas they are resulting in higher water use. Building on basic economic principles this study aims to show the conditions under which this apparently paradoxical outcome, known as the Jevons' Paradox, might appear. This basic model is expected to serve as guidance for assessing the actual outcomes of increasing irrigation efficiency and to discuss the changes in water governance that would be required for this to make a real contribution to sustainable water management.

**Keywords:** Jevons' Paradox, Rebound Effect, Agricultural Economics, Water Economics, Irrigation Efficiency

**JEL Classification:** Q15, Q18, Q25, Q51, Q58

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Abstract: Greening the economy is mostly about improving water governance and not only about putting the existing resource saving technical alternatives into practice. Focusing on the second and forgetting the first risks finishing with a highly efficient use of water services at the level of each individual user but with an unsustainable amount of water use for the entire economy. This might be happening already in many places with the modernization of irrigated agriculture, the world's largest water user and the one offering the most promising water saving opportunities. In spite of high expectations, modern irrigation techniques seem not to be contributing to reduce water scarcity and increase drought resiliency. In fact, according to the little evidence available, in some areas they are resulting in higher water use. Building on basic economic principles this study aims to show the conditions under which this apparently paradoxical outcome, known as the *Jevons' Paradox*, might appear. This basic model is expected to serve as guidance for assessing the actual outcomes of increasing irrigation efficiency and to discuss the changes in water governance that would be required for this to make a real contribution to sustainable water management.

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## 1. Introduction

Climate change, water supply limits, continued population growth and the improvement of living standards brought about by development are making water scarcity one of the most pressing environmental problems worldwide. Among all the competing uses, agriculture is the world's largest water user and is often believed to be wasteful. Consequently, policy makers have recently called for measures to save water in this sector. Among these measures, subsidies to increase irrigation efficiency (or technical efficiency, i.e., the effectiveness with which water is used at a plot level to produce agricultural goods) have rapidly become widespread (OECD, 2008)<sup>1</sup>. It is widely believed that more efficient irrigation technologies save water, making it available for other productive uses and also for the environment. However, technical options to reduce water use and withdrawals<sup>2</sup> are but a social opportunity that might be wasted if no other measures necessary to improve water governance are set (e.g., enforcing property rights, water pricing and metering, etc.). In fact, recent empirical work shows that even when the desired technical shift is successfully implemented, it might end up reinforcing the already unsustainable trends in water use (Pfeiffer and Lin, 2012, 2010; Rodríguez-Díaz et al., 2012). There are two arguments that help to explain this apparently paradoxical outcome: i) the *hydrological paradox*, based on the hydrological assessment of irrigation efficiency increases; and ii) the *Jevons' Paradox*, grounded on economic theory and on which the present work focuses.

The *hydrological paradox argument* comes from the hydrological study of the water balance<sup>3</sup> within a basin. Take for example a traditional irrigation system. Due to its low technical efficiency, a large share of the water used does not effectively contribute to satisfy evapotranspiration (i.e., the consumptive use of water or water consumption) and is therefore "lost". But much of this water is later on recaptured and returned to the watercourse, and is still available for alternative uses<sup>4</sup>. However, after an increase in the irrigation efficiency, although water use may actually fall, water availability for other uses may decrease through increased consumptive use, reduced return flows and lost aquifer seepage. This *hydrological paradox* can be found for example in Jensen (2007), Rodríguez-Díaz et al. (2012), Scheierling et al. (2006) and Ward and Pulido-Velazquez (2008).

The *Jevons' Paradox argument* comes from basic economic principles: without any complementary policy, an increase in irrigation efficiency makes water a more productive

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<sup>1</sup> Government subsidies for irrigation modernization are common across OECD countries, covering the totality or part of the irrigation modernization costs. This is the case for example of Australia, Austria, Mexico, the Netherlands, Portugal or Spain (OECD, 2008).

<sup>2</sup> Water withdrawal is water removed from its source for a specific use, while water use refers to the effective demand by users. The two flows are not the same because of leaks. In this paper we assume that there is no change in the transportation and delivery efficiency and we will refer directly to the technical efficiency of water use.

<sup>3</sup> In hydrology, a water balance equation can be used to describe the flow of water in and out of a system. A general water balance equation is:

$$P = Q + E + \Delta S$$

Where  $P$  is precipitation,  $Q$  is runoff,  $E$  is evapotranspiration and  $\Delta S$  is the change in water storage (in soil or the bedrock).

<sup>4</sup> It should be noted, though, that after being withdrawn, water does not have the same quality nor follows the same pathway as before the withdrawal. This may have a relevant impact over economic activities downstream (Dolan et al., 2014; Wu et al., 2013).

input and may result in an increase, rather than a reduction, in water use<sup>5</sup>. The idea that under certain conditions an increase in the technical efficiency may lead to an increase in the use of a resource is well known in economics at least since the XIX<sup>th</sup> century and has received different names, such as the Khazzoom-Brookes Effect or the *Jevons' Paradox* (Alcott, 2008, 2005; Khazzoom, 1989). There is considerable interest in determining under what conditions this paradox appears, and much research is ongoing in fields such as energy or transportation (Brookes, 1990; Greene et al., 1999; Hong et al., 2006; Vringer et al., 2007). Surprisingly, its study in the field of water economics is relatively new and mostly based on *ex-post* empirical results (Ding and Peterson, 2006; Dumont et al., 2013; Gutierrez-Martin and Gomez, 2011; Lecina et al., 2010; Pfeiffer and Lin, 2012, 2010). There is no methodological framework that explains under what conditions an increase in the irrigation efficiency will result in a *Jevons' Paradox*. Therefore, it is difficult to predict *ex-ante* the impact that an increase in the irrigation efficiency will have on water use. This knowledge gap is shocking if we consider the prominent role that has been assigned to the modernization of irrigation devices in drought and water scarcity strategies worldwide, as well as the high costs of these projects in a time of financial crisis. This paper wants to help bridge this gap. In the following pages we present an analytical framework to discriminate the determinants of the emergence of the *Jevons' Paradox*. This study may serve as a methodological guidance for empirical papers analyzing the issue.

## 2. Analytical Framework

Conventional water policy has traditionally addressed water scarcity problems through the construction of major infrastructures to increase water supply (OECD, 2013). Eventually, though, the financial and environmental costs of developing these water works have begun to exceed the economic benefits in the least productive (marginal) uses of existing supplies in many basins (EEA, 2013; OECD, 2013; Randall, 1981). As a result, water authorities have started to consider alternative water management strategies, such as irrigation modernization. In this paper we want to assess theoretically the effect that a change in irrigation efficiency has on water use. We find that the change in water use following an increase in the irrigation efficiency depends on three opposing effects, namely, a *technical effect*, a *cost effect* and a *productivity effect*.

An increase in irrigation efficiency will reduce the amount of water required to obtain the same products as before (*technical effect*). Accordingly, water use could be reduced in the same percentage as the increase in irrigation efficiency, provided that the farmers choose the same crop portfolio and use water with the same intensity as before (Yilmaz et al., 2009). This over-simplistic scenario, where no other effects are considered, is the hidden assumption of many studies assessing the expected water savings from irrigation modernization plans (a good example of this can be found in the Spanish Irrigation Plan<sup>6</sup>). However, farmers are profit

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<sup>5</sup> There is a third possibility: neither an increase, nor a decrease, but rather *no change*. That is, the same amount of water is used as before; none is saved for (1) other uses or (2) the natural environment. For the purpose of rejecting irrigation efficiency increases as a water-saving measure it is enough to show that there is no change in water use, i.e. no savings.

<sup>6</sup> The Spanish Irrigation Plan (*Plan Nacional de Regadíos*, PNR) 2000-2008 was a large investment effort with the aim of reducing agricultural water use. This Plan was complemented with the Shock Plan 2006. Both plans invested 7,368 M EUR to modernize 2,244,570 ha of irrigated lands and forecasted a reduction in water use of 3 662 hm<sup>3</sup>/year (MAGRAMA, 2013). However, since the implementation of

maximizing agents that change their choices depending on conditions on revenues and costs, and water demand is derived from this choice (Gómez and Pérez-Blanco, 2012; Kampas et al., 2012; Rivers and Groves, 2013). Since the technical shift means also a change in the incentives in place, farmers will not normally continue taking the same decisions as before. Therefore, apart from this *technical effect*, two additional effects on water demand need to be considered: a *cost effect* and a *productivity effect*.

The *cost effect* stems from the higher water application costs associated to more efficient irrigation technologies and, similar to the *technical effect*, reduces water use. The increase in the water application costs is largely explained by the higher energy costs of the more sophisticated irrigation devices (e.g., drip irrigation) as compared to traditional devices (e.g., gravity irrigation) (Rodríguez-Díaz et al., 2012; Soto-García et al., 2013). For example, recent empirical work has found that the intense irrigation modernization in Spain has increased energy consumption in irrigated agriculture by 1,800% since 1950 (Corominas, 2010).

The third effect refers to the fact that more efficient irrigation systems make water more productive (*productivity effect*). Therefore, for a given amount of water use, the last drop generates a larger agricultural product than before and, for this reason, farmers would probably be willing to use more water than before. This productivity effect may have a large impact on water use and result in a *Jevons' Paradox*, though it has been traditionally ignored in the assessment of irrigation modernization plans.

In order to assess the combined effect of the technical shift on water use, we develop a methodology in two stages: in the first one we obtain water demand as a function of irrigation efficiency; in the second one, we assess the impact of an increase in the irrigation efficiency on water use, identifying the determinants of the incidence of each of the three effects above.

## 2.1. The water demand function

Water used by farmers ( $W$ ) is bought at a unitary price,  $P$ , (for example, per cubic meter of water used) and applied to the crops incurring in a unitary water application cost,  $c(E)$ . Therefore, the marginal cost of water use ( $MC(W)$ ) is equal to:

$$MC(W) = P + c(E) \quad [1]$$

Where  $c(E)$  is an increasing function of the technical efficiency  $E$  ( $E \in [0, 1]$ ) of the irrigation devices in place<sup>7</sup>, since more sophisticated techniques are costlier ( $\frac{\partial c(E)}{\partial E} > 0$ ) (Corominas, 2010; Soto-García et al., 2013).

The amount of water that effectively satisfies the agronomic water needs of the crops, or water consumption ( $EW$ ), is only a fraction  $E$  of the total water use ( $W$ ). Therefore, to

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the PNR, water use from agriculture in these areas are far from decreasing (Gutierrez-Martin and Gomez, 2011; Rodríguez-Díaz et al., 2012).

<sup>7</sup>  $E$  measures the technical efficiency of the irrigation technology in place with, for example, typical values of 0.5 for traditional gravity, 0.7 for sprinklers and 0.9 for drip devices.

consume one unit of water, farmers use  $\frac{1}{E}$  units of water. Accordingly, the marginal cost of the water consumed ( $MC(EW)$ ) is equal to:

$$MC(EW) = \frac{P+c(E)}{E} \quad [2]$$

Water consumption serves to produce crops. We use a generic function ( $Y$ ) that represents the maximum production value at a farm level that can be achieved for every amount of water consumed ( $EW$ ), considering the remaining inputs (land, labor, etc.) constant. Although this function may change from one farm to another depending on their characteristics, it is reasonable to assume that the production value increases at a decreasing rate with the amount of water consumed<sup>8</sup>.

$$Y = F(EW), \text{ with } \frac{\partial F(EW)}{\partial (EW)} > 0 \text{ and } \frac{\partial^2 F(EW)}{\partial (EW)^2} < 0 \quad [3]$$

Farmers will demand water up to the point where the marginal productivity of the water consumed ( $\frac{\partial F(EW)}{\partial (EW)}$ ) equals its marginal cost ( $MC(EW)$ ):

$$\frac{\partial F(EW)}{\partial (EW)} = \frac{P+c(E)}{E} \quad [4]$$

Accordingly, the inverse demand function for water can be expressed as:

$$P = \frac{\partial F(EW)}{\partial (EW)} E - c(E) \quad [5]$$

## 2.2. What happens with water use after an increase in the irrigation efficiency?

The answer to this question lies formally on the response of water use ( $W$ ) to an increase in the irrigation efficiency ( $E$ ), that is to say, on the sign of the derivative  $\frac{\partial W}{\partial E}$ . A positive sign (i.e.,  $\frac{\partial W}{\partial E} > 0$ ) means that more water is used after an increase in the irrigation efficiency, and thus *Jevons' Paradox* occurs.

Provided that following the irrigation efficiency increase there is no complementary pricing policy and thus water prices remain constant ( $\Delta P = 0$ )<sup>9</sup>, the effect of an increase in the irrigation efficiency on water use can be obtained from the inverse demand function [5] as follows:

<sup>8</sup> We also assume that this function is continuous. Non continuous functions may be of relevance for further empirical research, but it is out of the scope of this analytical paper.

<sup>9</sup> This is the case in most of the irrigation modernization plans, such as those of Spain, Portugal, Mexico or Australia, where bulk water supply is controlled by a supplier that decides on the prices. (OECD, 2008). However, this price-taking assumption is not valid if farmers are directly pumping water from an aquifer, where drawdown would influence costs and provide a counterbalancing impact on the rebound effect (Dumont et al., 2013).

$$\frac{\partial P}{\partial W} dW + \frac{\partial P}{\partial E} dE = 0 \Rightarrow \frac{dW}{dE} = -\frac{\frac{\partial P}{\partial E}}{\frac{\partial P}{\partial W}} \quad [6]$$

That is to say:

$$\frac{dW}{dE} = -\left( \frac{W}{E} + \frac{\frac{\partial F(EW)}{\partial(EW)}}{\frac{\partial^2 F(EW)}{\partial(EW)^2} E^2} - \frac{\frac{\partial c(E)}{\partial E}}{\frac{\partial^2 F(EW)}{\partial(EW)^2} E^2} \right) \quad [7]$$

Which, after multiplying both sides by  $\frac{E}{W}$ , can be transformed into the efficiency elasticity of water use ( $\epsilon_{W,E}$ ) (this step is detailed in Appendix I):

$$\epsilon_{W,E} = -1 - \frac{1}{\frac{\epsilon_{\partial F(EW)}_{\partial(EW)} E}{\frac{\partial^2 F(EW)}{\partial(EW)^2} E}} + \left( \frac{\epsilon_{c,E}}{\frac{\epsilon_{\partial F(EW)}_{\partial(EW)} E}{\frac{\partial^2 F(EW)}{\partial(EW)^2} E}} \right) \left( \frac{c(E)}{P+c(E)} \right) \quad [8]$$

Where:

$\epsilon_{W,E} = \frac{\partial W}{\partial E} \frac{E}{W}$  is the efficiency elasticity of water use ( $W$ ).

$\epsilon_{c,E} = \frac{\partial c(E)}{\partial E} \frac{E}{c(E)} > 0$  is the efficiency elasticity of the water application cost ( $c(E)$ ).

$\frac{\epsilon_{\partial F(EW)}_{\partial(EW)} E}{\frac{\partial^2 F(EW)}{\partial(EW)^2} E} = \frac{\frac{\partial}{\partial E} \frac{\partial F(EW)}{\partial(EW)}}{\frac{\partial F(EW)}{\partial(EW)}} \frac{E}{\frac{\partial F(EW)}{\partial(EW)}} = \frac{\frac{\partial^2 F(EW)}{\partial(EW)^2}}{\frac{\partial F(EW)}{\partial(EW)}} EW < 0$  is the efficiency elasticity of the marginal productivity  $\left( \frac{\partial F(EW)}{\partial(EW)} \right)$  of water consumption ( $EW$ ).

Equation [8] shows the efficiency elasticity of water use ( $\epsilon_{W,E}$ ), i.e., the measurement of how the amount of water use ( $W$ ) changes in response to a change in irrigation efficiency ( $E$ ), quantified as the ratio of the percentage change in water use in response to a one percent change in irrigation efficiency. A negative elasticity means that a higher irrigation efficiency reduces water use, while a positive value means that the *Jevons' Paradox* occurs. Alternatively, if the efficiency elasticity of water use is zero water use is inelastic and the quantity demanded is fixed. The efficiency elasticity of water use contains the three effects identified above, namely:

- A *technical effect*, meaning that increasing irrigation efficiency by one percentage point would reduce water use by one percentage point, a reduction in water use proportional to the relative increase in irrigation efficiency (indicated by  $-1$ ).
- A *cost effect*, meaning that the higher application cost of water resulting from a more efficient irrigation technique will lead to a reduction in water use. This is measured by  $\left( \frac{\epsilon_{c,E}}{\frac{\epsilon_{\partial F(EW)}_{\partial(EW)} E}{\frac{\partial^2 F(EW)}{\partial(EW)^2} E}} \right) \left( \frac{c(E)}{P+c(E)} \right) < 0$ . The incidence of this effect on water use depends on two



ratios: the first ratio  $\left( \frac{\epsilon_{c,E}}{\frac{\epsilon_{\partial F(EW)}_{,E}}{\partial(EW)}} \right)$  is the quotient of the efficiency elasticity of the water

application cost ( $\epsilon_{c,E}$ ) to the efficiency elasticity of the marginal productivity of water consumption ( $\frac{\epsilon_{\partial F(EW)}_{,E}}{\partial(EW)}$ ); and the second ratio  $\left( \frac{c(E)}{P+c(E)} \right)$  is the quotient of the application cost ( $c(E)$ ) to the unitary water costs ( $P + c(E)$ ).

- A *productivity effect*, meaning that the increase in water productivity will lead to an increase in water use. This is measured by  $-\frac{1}{\frac{\epsilon_{\partial F(EW)}_{,E}}{\partial(EW)}} > 0$  and its importance depends on the value of  $\frac{\epsilon_{\partial F(EW)}_{,E}}{\partial(EW)}$ .

These results provide an analytical framework to better understand the opposing effects existing behind an increase in the irrigation efficiency and to improve and guide the assessment of water saving policies in the agricultural sector

Consider for example the following extreme, but still likely, case. Assume an agricultural area where energy is heavily subsidized and the more efficient irrigation devices do not increase the cost of applying water (for the sake of the argument, let us assume that  $\epsilon_{c,E} = 0$ )<sup>10</sup>. In addition to that, water is scarce in such a way that most of the time there is idle irrigation capacity and the technical shift will allow higher water consumption at the same cost as before

$\left( \left| \frac{\epsilon_{\partial F(EW)}_{,E}}{\partial(EW)} \right| < 1 \right)$ . Then the productivity effect is higher than one  $\left( -\frac{1}{\frac{\epsilon_{\partial F(EW)}_{,E}}{\partial(EW)}} > 1 \right)$  and will

overcome the technical effect ( $-1$ ). In such a situation increasing the irrigation technology will lead to a *Jevons' Paradox* and, contrary to the common belief, water availability will decrease and the real outcome of the presumed water saving technologies will worsen the already unsustainable use of water. The intuition behind this example shows that water technologies might be less effective precisely in the situations where water savings are more needed; that is to say, in water stressed areas with subsidized infrastructures and low water and energy prices (this is the case in many Mediterranean countries like Portugal or Spain).

### 3. Conclusions

There are wide differences in the efficiency with which water is used wherever and for different purposes. In agriculture, the technical analysis of potential water savings if best available technologies are used shows that there is still significant leeway for further savings (FAO, 2007; OECD, 2013). As a result, subsidies to increase irrigation efficiency have rapidly become a widely used policy in water stressed countries as a means to reduce water use. However, the common belief that considers more efficient irrigation devices as synonymous to water saving technologies is rather naive as it tends to ignore the entire physical, economic

<sup>10</sup> The overall cost would still increase (to the public sector or whoever is paying the energy subsidies) and this is another drawback of this intervention.

and institutional framework where these alternatives are implemented. Consequently, in many areas all these efforts have not been reflected so far in a reversal of the long-term trend of increasing water use. Quite the contrary, several irrigation networks worldwide have experienced an increase in water demand parallel to the modernization of irrigation infrastructures (Ding and Peterson, 2006; Gutierrez-Martin and Gomez, 2011; Pfeiffer and Lin, 2010).

Making a real contribution to increase water savings out of a technical shift is a difficult task. Once the efficiency gap has been admitted, it is also important to understand what failure explains why water users do not do their best to bridge this gap and whether water policy may correct it. Why do not farmers massively invest in irrigation modernization spontaneously (i.e. without public support) if it is such a seemingly convenient investment? Why could public intervention be disappointing from a water policy perspective?

In many places where technical opportunities to increase the irrigation efficiency exist, farmers do not see them as financially attractive. They imply installing expensive equipment and assuming higher operational costs (due to the additional energy required for pumping and applying water in the field)<sup>11</sup>. Public subsidies remove or at least facilitate the initial investment costs and may make irrigation modernization attractive to farmers. However, this does not necessarily translate into reduced water use.

Nature and mankind adapt to new conditions in ways that need to be understood beforehand. Paradoxically, technological progress that increases the efficiency with which water is used may lead to the growth of water demand at a certain scale. In economic theory, this effect is conceptualized under the proposition of the so-called *Jevons' Paradox* or rebound effect . If a *Jevons' Paradox* occurs, the only way to harvest the opportunities associated to bridging the efficiency gap is through pairing them with the financial incentives in place.

In fact, if the policy goal is simply to use or consume less water for irrigation, there are other measures for doing this. They are direct, inexpensive and by definition effective: caps and/or pricing. However, the actual objective of irrigation modernization policies seems twofold: reducing water use without impairing agricultural income. More efficient technologies may help to attain this dual objective, but they should not be regarded as a panacea and need to be part of a comprehensive policy mix towards a sustainable water management. For example, the technical shift can increase farmers' income, and this may be used as an opportunity to agree upon a reduction in energy subsidies and/or the implementation of metering and volumetric tariffs. This policy mix, rather than a simple technical shift, can find the way to make the reduction of water scarcity compatible with the maintenance and eventual improvement of farmers' welfare. Technical options are only opportunities; the real challenge in the transition towards a sustainable water use relies on building better institutions with the ability to put the effective incentives in place.

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<sup>11</sup> Hence, irrigation efficiency is naturally higher in places where water is more productive, and irrigation modernization is perceived as a way to increase water productivity and to reduce exposure to water shortages.

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Appendix I: The Efficiency Elasticity of Water Use ( $\epsilon_{W,E}$ )

According to equation [7]:

$$\frac{dW}{dE} = - \left( \frac{W}{E} + \frac{\frac{\partial F(EW)}{\partial(EW)}}{\frac{\partial^2 F(EW)}{\partial(EW)^2} E^2} - \frac{\frac{\partial c(E)}{\partial E}}{\frac{\partial^2 F(EW)}{\partial(EW)^2} E^2} \right)$$

Which, after multiplying both sides by  $\frac{E}{W}$ , results in:

$$\frac{dW}{dE} \frac{E}{W} = \epsilon_{W,E} = -1 + \frac{\frac{\partial F(EW)}{\partial(EW)}}{\frac{\partial^2 F(EW)}{\partial(EW)^2} EW} - \frac{\frac{\partial c(E)}{\partial E}}{\frac{\partial^2 F(EW)}{\partial(EW)^2} EW}$$

Now we transform the previous equation as follows in order to represent the efficiency elasticity of water use ( $\epsilon_{W,E}$ ) as a function of the efficiency elasticity of the water application cost ( $\epsilon_{c,E}$ ) and the efficiency elasticity of the marginal productivity of water consumption ( $\epsilon_{\frac{\partial F(EW)}{\partial(EW)},E}$ ). First we make some simple transformations:

$$\epsilon_{W,E} = -1 + \frac{1}{\frac{\frac{\partial^2 F(EW)}{\partial(EW)^2} EW}{\frac{\partial F(EW)}{\partial(EW)}}} - \left( \frac{\frac{\frac{\partial c(E)}{\partial E} E}{c(E)}}{\frac{\frac{\partial^2 F(EW)}{\partial(EW)^2} EW}{\frac{\partial F(EW)}{\partial(EW)}}} \right) \left( \frac{1}{\frac{\frac{\partial F(EW)}{\partial(EW)} E}{c(E)}} \right)$$

Using the chain rule we obtain:

$$\epsilon_{W,E} = -1 + \frac{1}{\frac{\partial \frac{\partial F(EW)}{\partial(EW)}}{\partial E} \frac{E}{\frac{\partial F(EW)}{\partial(EW)}}} - \left( \frac{\frac{\frac{\partial c(E)}{\partial E} E}{c(E)}}{\frac{\partial \frac{\partial F(EW)}{\partial(EW)}}{\partial E} \frac{E}{\frac{\partial F(EW)}{\partial(EW)}}} \right) \left( \frac{1}{\frac{\frac{\partial F(EW)}{\partial(EW)} E}{c(E)}} \right)$$

Using equation [4] ( $\frac{\partial F(EW)}{\partial(EW)} = \frac{P+c(E)}{E}$ ) and operating, we obtain:

$$\epsilon_{W,E} = -1 + \frac{1}{\frac{\partial \frac{\partial F(EW)}{\partial(EW)}}{\partial E} \frac{E}{\frac{\partial F(EW)}{\partial(EW)}}} - \left( \frac{\frac{\frac{\partial c(E)}{\partial E} \frac{E}{c(E)}}{\frac{\partial \frac{\partial F(EW)}{\partial(EW)}}{\partial E} \frac{E}{\frac{\partial F(EW)}{\partial(EW)}}}}{\frac{\partial \frac{\partial F(EW)}{\partial(EW)}}{\partial E} \frac{E}{\frac{\partial F(EW)}{\partial(EW)}}} \right) \left( \frac{c(E)}{P + c(E)} \right)$$

Which, alternatively, can be expressed as equation [8]:

$$\epsilon_{W,E} = -1 + \frac{1}{\frac{\epsilon_{\partial F(EW)}^{\partial(EW),E}}{\frac{\partial F(EW)}{\partial(EW)},E}} - \left( \frac{\epsilon_{c,E}}{\frac{\epsilon_{\partial F(EW)}^{\partial(EW),E}}{\frac{\partial F(EW)}{\partial(EW)},E}} \right) \left( \frac{c(E)}{P + c(E)} \right)$$

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