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Science as Civil Society: Implications for a Green Transition

Abstract

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JEL Classification: O31, L23, D91

Keywords: green innovation, Civil society, Motivated agents

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Abstract

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"If facts are the seeds that later produce knowledge and wisdom, then the emotions ... are the fertile soil in which the seeds must grow."

Rachel Carson (Biologist and writer) in *The Sense of Wonder*.

"What you do makes a difference, and you have to decide what kind of difference you want to make."

Jane Goodall (Primatologist and activist).

1 Introduction

In their classic paper, Aghion and Howitt (1992) studied the profit motive as a driver of innovation as firms seek a competitive edge. Important as this material driver is, Aghion et al (2008) emphasize that scientists themselves are often intrinsically motivated. Intrinsic motives may be particularly relevant when the future of the planet is at stake – the innovation process for climate-friendly green goods will likely play a key role in any green transition. In this paper, we present a canonical model of innovation where the motives of scientists matter for the innovation process and – as in Acemoglu et al (2012) and Aghion et al (2016, 2019) – there is scope for innovation in both green and brown sectors.

Scientists and their values In our approach, scientists form a part of civil society. Organizations like the National Academy of Sciences, the Royal Society, or the Royal Swedish Academy of Sciences project views and values that sometimes clash with political authority. Well-known personal examples of such activism in the pollution sphere were set by scientists Rachel Carson and Jane Goodall. They were among the first to alert the world to ugly pollution- and biodynamics more than half a century ago.

Reflecting this kind of engagement, the average scientist does indeed care more about the environment than the public at large. This is illustrated in Figure 1, which shows responses to the proposition that "it is important to care for the environment" among almost 416,000 participants in several waves of the European Social Survey.[1] The graph shows the difference in

[1]The ESS respondents in each wave are selected as a representative sample in each of 35 European countries. The question on environmental values appeared in all the nine available waves of the survey (every second year between 2002 and 2018). Based on the rich background information about respondents, we classify a particular respondent

shares for each answer between "scientists" and all others, when we adjust for country and survey year. Clearly, the distribution of responses among scientists is shifted to the right relative to that of others – an observation that we take that as motivation for our model.[2]

[**Figure 1 about here**]

Our model and its antecedents But even if scientists care about the environment, their actions must make a collective difference to have a societal impact. In our model, we suppose that the psychic payoffs they get from contributing actively to a better world make scientists willing to work for a lower wage in green firms, or demand a wage premium to work in brown firms. This mechanism translates into different innovation costs across sectors and spurs innovation towards a greener future.

But science can be more powerful still, if it encourages consumers to go green. In our model, we use an approach developed in Besley and Persson (2019, 2021). A similar mechanism has been studied by Bezin (2015, 2019). The key idea is that more citizens will change their lifestyle as the quality of goods available for green consumers improves. To see how this might work, consider the decision to drive an electric – rather than a conventional – vehicle. Our approach implies that more people are willing to switch when charging speeds and driving ranges of electric cars are improved. But this requires innovation to target better battery technologies, instead of better internal combustion engines. In our simple model, socialization from (cultural or biological) parents decides the future share of green consumers – the socialization process is based on future expected utility, which includes expectations about future technology

Seen from the other side, when producers/innovators expect more people to change their lifestyle, the expected market share for green (brown) goods goes up (down). This, in turn, increases (reduces) the relative profitability

as a "scientist" whenever she is employed in a STEM profession, according to some 30 occupational (ISCO) codes.

[2] The figure shows the differences in the raw data, but they are more or less exactly the same when we control for country and wave fixed effects. They also hold up when we control for basic demographics (gender and cohort), education and (household) income. Moreover, similar differences apply if we consider the responses to "science can solve environmental problems", "it is important to think creatively and have new ideas, and "I am interested in politics" (but not to "I vote for a green party").

of innovation in green (brown) goods. In the last paragraph's example, it becomes more profitable to improve battery technologies than combustion engines. While our model – as Bezin's – is about final goods, this mechanism is like the market-size effect on innovation in the existing work on directed innovation in clean vs. dirty intermediate goods (Acemoglu at el 2012, Aghion et al 2016, Acemoglu et al 2016).[3]

Together, the green-technology-driven socialization and the green-market-share effect on innovation give rise to a dynamic complementarity. In this setting, science's role in encouraging innovation contributes to more than a technology dynamic; it can also help change the course of society.

Outline of the paper The paper is organized as follows. In Section 2, we lay out a core model where households consume green and brown goods. These are produced by ranges of monopolistically competitive firms that can also invest in innovation to improve product quality. We show how motivation to work in green innovation affects the path of the economy. In Section 3, we extend the model to make the proportions of green and brown consumers endogenous through socialization. Complementarities between jointly evolving culture and technology imply that certain shifts can make society cross a critical juncture where a brown-to-green transition occurs. Science influences this process alongside its influence on technology. Section 4 offers some concluding comments.

2 Core Model

The model – and a number of extensions of it – are fully developed in Besley and Persson (2021), to which the reader is referred for details. We consider two sets of monopolistically competitive firms: one producing varieties of *brown* (polluting) goods, another producing varieties of *green* (non-polluting) goods. Consumers are of two types with different values (preference maps): green types (environmentalists) chiefly consume green goods and brown types (materialists) chiefly consume brown goods.

Consumers Each citizen has an exogenous endowment ε of a numeraire good, the consumption of which is x. The numeraire can be transformed into

[3] Acemoglu and Linn (2004) provide early empirical evidence that a higher expected market share indeed raises innovation (and entry) in the pharmaceutical industry.

two kinds of goods. A continuum of green goods is indexed by $i \in [0,1]$ with the quantity, quality, and price on green variety i being $\{y(i), q(i), p(i)\}$. Similarly, a continuum of brown goods is indexed by $j \in [0,1]$, with a corresponding triple $\{Y(j), Q(j), P(j)\}$. We focus on a case with symmetry within sectors where all brown face the same parameters as do all green firms. All firms in a sector thus take the same actions.

A unit mass of citizens/consumers are divided into green, $\tau = 1$, and brown, $\tau = 0$, with μ being the fraction of green. The two consumer types vary according to their consumption values, with green (brown) only valuing green (brown) goods. Preferences are

$$U = x + \frac{1}{1-\sigma}\left(\int_0^1 q(i)^\sigma y(i)^{1-\sigma} di\right)^\tau \left(\int_0^1 Q(j)^\sigma Y(j)^{1-\sigma} dj\right)^{1-\tau} - \theta\tau \int_0^1 \bar{Y}(j)\, dj \tag{1}$$

with $\sigma < 1$.[4] The last term in (1) represents concerns about the pollution of brown goods, which is related to their aggregate (average) consumption $\bar{Y}$. Thus, we assume that only the green consumers care about the environment.[5] The common budget constraint is

$$R \geq x + \int_0^1 P(j)\, Y(j)\, dj + \int_0^1 p(i)\, y(i)\, di, \tag{2}$$

where R includes profits, wages (of scientists) and an endowment of the numeraire good.

Maximizing (1) subject to (2), we find that brown (green) consumers buy only brown (green) goods with the resulting demand functions given by

$$Y = QP^{-\frac{1}{\sigma}} \text{ and } y = qp^{-\frac{1}{\sigma}}. \tag{3}$$

Firms, pricing and profits We suppose each green and brown variety is produced by a monopolist at the same marginal cost χ. Firms care only about their own profit and are infinitely-lived, run by successive generations

[4] A simple extension, which would produce qualitatively similar results, would suppose that all consumers have Cobb-Douglas preferences over the two types of goods with a higher weight on green goods among green consumers. Formally, a weight γ_τ would replace τ in (1), with $\gamma_1 > \gamma_0$.

[5] Again, a difference across consumer types with the green having larger costs than the brown of pollution would do.

of managers, who maximize long-run profits. Firms's profits are distributed to their shareholders (consumers) on an equal per capita basis.

Taking the demand function and marginal cost into account, profits for a typical green-variety firm is $\mu\left[q^{\sigma}y^{1-\sigma}-\chi y\right]$, while that for a brown-variety firm is $(1-\mu)\left[Q^{\sigma}Y^{1-\sigma}-\chi Y\right]$. Profit maximizing prices have a constant mark-up over marginal cost:

$$p = P = \frac{\chi}{(1-\sigma)}.$$

Profits per firm are therefore given by

$$\pi(q) = \mu q\kappa \quad \text{and} \quad \Pi(Q) = (1-\mu) Q\kappa\ , \tag{4}$$

where $\kappa = \sigma\left[\chi/\left(1-\sigma\right)\right]^{1-\frac{1}{\sigma}}$. These profits are scaled by $1-\mu$ and μ, as the market size for each variety of green and brown goods reflects the share of green and brown consumers, respectively.

Innovation Any existing brown (green) firm can improve the quality of its variety by hiring N (n) inventors/scientists as in Krusell (1998).[6] The collective action of scientists can work via market allocation if scientists who care about pollution may be more attracted to green sectors.[7] A fraction Ω of the population can train to become inventors/scientists at some (psychic) cost. This cost is w (W) in a green (brown) firm.

We suppose that scientists are part of civil society and are "motivated agents" in the language of Besley and Ghatak (2005). Their willingness to train as scientists is higher if they obtain a green-sector rather than a brown-sector innovation job. Consequently, the psychic costs fulfill $W > w$.

By recruiting scientists, the firm raises its (next-period) product quality to

$$q\left[1+\left(\frac{n}{q}\right)^{\varphi}\right] \quad \text{and} \quad Q\left[1+\left(\frac{N}{Q}\right)^{\varphi}\right]. \tag{5}$$

Since $\varphi < 1$, inventive activity has decreasing returns. The innovation model will allow us to study the growth of technologies in response to changes in

[6]In his model – unlike this one – inventors work on improving intermediate goods that serve as inputs to produce (a single form of) final goods.

[7]https://www.bloomberg.com/news/articles/2019-08-01/the-oil-industry-s-talent-pipeline-slows-to-a-trickle reports that fossil fuel companies are now having increasing difficulties in attracting new graduates.

environmental values and policy over time. We focus on the case where $(1-\mu)\int_0^1 Ndj + \mu\int_0^1 ndi < \Omega$, so the (latent) supply of scientists is ample enough that all of them accept to work for a wage that just compensates for their training cost.

Euler equations and equilibrium growth Time is infinite, discrete, and indexed by s. The quality levels in each sector are state variables which evolve over time and are indexed by s. Qualities are determined by firms' investments in innovation, which are chosen to maximize the expected discounted sum of profits, using a discount factor denoted by β. We can write the value functions associated with this problem as

$$\begin{aligned}\tilde{\pi}(q) &= \arg\max_{n\geq 0}\{\pi(q) - \omega n + \\ &\quad \beta\tilde{\pi}\left(q\left(1+\left(\frac{n}{q}\right)^{\varphi}\right)\right)\}\end{aligned}$$

$$\begin{aligned}\tilde{\Pi}(Q) &= \arg\max_{N\geq 0}\{\Pi(Q)(1-\mu) - \omega N + \\ &\quad \beta\tilde{\pi}\left(Q\left(1+\left(\frac{N}{Q}\right)^{\varphi}\right)\right)\}.\end{aligned}$$

The Euler equations associated with optimal green and brown innovation are

$$\left(\frac{n}{q}\right)^{\varphi-1}\beta\varphi\sigma\kappa\mu = w \quad \text{and} \quad \left(\frac{N}{Q}\right)^{\varphi-1}\beta\varphi\sigma\kappa(1-\mu) = W. \tag{6}$$

Firms thus hire scientists until their expected marginal gain in future profits equals their marginal cost. Having motivate scientists acts much like a subsidy to green innovation and a tax on brown innovation.

The equilibrium growth rates of green and brown product qualities are:

$$\hat{g} = \left[\frac{\beta\varphi\sigma\kappa\mu}{w}\right]^{\frac{\varphi}{1-\varphi}} \quad \text{and} \quad \hat{G} = \left[\frac{\beta\varphi\sigma\kappa(1-\mu)}{W}\right]^{\frac{\varphi}{1-\varphi}}. \tag{7}$$

These depend on the size of the markets for green and brown goods as determined by μ and $(1-\mu)$, and on the strength of scientists' intrinsic motivations as reflected in W and w. This is the market-size effect in innovation, familiar from the endogenous-growth literature, which we discussed in the introduction.

Green vs. brown growth Scientists in our model act atomistically, but in a value-driven way. Collectively, their values do affect the future path of the economy by encouraging green innovation and discouraging brown innovation. As demand for each variety is increasing in quality, the quality implications mean that brown consumption will not grow as fast as green consumption over time. To see this, note that we can write the relative growth rates as

$$\frac{\hat{g}}{\hat{G}} = \frac{q}{Q} \cdot \left[\frac{\mu}{(1-\mu)} \cdot \frac{W}{w} \right]^{\frac{\varphi}{1-\varphi}}, \tag{8}$$

an expression which is increasing q/Q, W/w, and $\mu/(1-\mu)$. These properties illustrate how a society with more motivated scientists experiences greener growth, as does one with a larger share of green consumers or with a higher relative quality of green goods. Market activities thus respond to the values of those who consume and produce the fruits of innovation.

3 Cultural Dynamics

One key feature of the green transition is changing values towards green consumption. However, so far, we have taken the share of green consumers – i.e., the value of μ – as fixed. We now use the model of Besley and Persson (2019, 2021) to explore what happens if this share is subject to cultural change. Suppose therefore that $\mu \in [0, 1]$ is time dependent, with dynamics determined by a socialization process.

The timing in each period s is as follows:

1. The economy begins current qualities of all green (brown) firms at q_s (Q_s), and a current fraction of green (brown) consumers μ_s $(1 - \mu_s)$.

2. Current production (prices) and consumption maximizes current profits and consumer utility.

3. Parents socialize their children, such that the future fraction of green consumers μ_{s+1} reflects the future "relative fitness" of holding green vs. brown values $\Delta\left(\mu_{s+1}\right)$.

4. To innovate, firms contract with scientists and determine (quality) growth rates $\hat{g}_{s+1}$ and $\hat{G}_{s+1}$.

We have already derived the optimal behavior at stages 2 and 4. It remains to specify the outcome of the socialization at stage 3.

Cultural evolution In the models developed by Besley and Persson (2019, 2021), the dynamics of the green-consumer share follows an equation

$$\mu_{s+1} - \mu_s = \varkappa 2\mu_s \left(1 - \mu_s\right) \left[F\left(\beta\Delta\left(\mu_{s+1}\right)\right) - \frac{1}{2}\right], \tag{9}$$

where

$$\begin{aligned} \Delta\left(\mu\right) \;=\; & \frac{\sigma\left(\chi\right)^{1-\frac{1}{\sigma}}}{\left[1-\sigma\right]^{\frac{1}{\sigma}}} \left\{ q \left[1 + \left[\frac{\beta\varphi\sigma\kappa\mu}{w}\right]^{\frac{\varphi}{1-\varphi}}\right] - \right. \\ & \left. Q\left(\frac{\sigma\chi + \left(1-\sigma\right)\theta}{\sigma\chi}\right) \left[1 + \left[\frac{\beta\varphi\sigma\kappa\left(1-\mu\right)}{W}\right]^{\frac{\varphi}{1-\varphi}}\right] \right\} \end{aligned}$$

is the anticipated utility difference between being a green and brown consumer in period $s+1$. An equation like (9) can be derived from a variety of micro-founded models analogous to those studied in Bisin and Verdier (2001), Tabellini (2008), or Besley and Persson (2019). This reflects an influence on a new generation where (biological or cultural) parents endow their children with values, but the costs and benefits of holding specific values (and thus preferences for consumption) help shape the socialization process. So a world in which it is more attractive to "go green" will see more children becoming green consumers.

It is straightforward to show that $\Delta\left(\cdot\right)$ is an increasing function such that a larger expected share of green consumers in the future makes it optimal for more families to go green. This property is driven entirely by the fact that a larger share of green consumers will induce more innovation in the green sector – that is, by the market-size effect in innovation discussed in the previous section.

Putting the innovation and socialization dynamics together, we obtain a dynamic complementarity which drives divergent dynamics, where the path taken depends on the initial conditions: $\{q_0, Q_0, \mu_0\}$.

Convergence to a green steady state? We get a transition to a green steady state with $\mu = 1$ if and only if

$$\frac{q}{Q}\left[\frac{1+\left[\frac{\beta\varphi\sigma\kappa\mu}{w}\right]^{\frac{\varphi}{1-\varphi}}}{1+\left[\frac{\beta\varphi\sigma\kappa(1-\mu)}{W}\right]^{\frac{\varphi}{1-\varphi}}}\right] > \left(\frac{\sigma\chi+(1-\sigma)\theta}{\sigma\chi}\right). \tag{10}$$

It is natural to think about a starting point, where brown firms have a quality advantage – i.e., $q/Q \leq 1$. As the right-hand side expression is a number larger than 1, a *necessary* condition for a green transition is then that the green-quality growth rate exceeds the brown-quality one, thus making the expression in square brackets larger than 1.

In our simple model, this is possible *only if* $W > w$ – i.e., if scientists are motivated as we discussed above. If (10) holds, then we will get rising quality and quantity of green consumption/production, and falling quality and quantity of brown consumption/production. And the latter will bring about a reduction in pollution. The driver of this structural change is that motivated scientists help engineer a green transition based on innovation in the green sector. The rising relative quality of green goods persuades more people to become green consumers, which feeds back to yet stronger incentives for green innovation. And so on *ad infinitum*.

One way to think about this effect is in terms of a *cultural multiplier* on the relative growth rates due to scientists motivation. Formally, let $W = \varpi w$ where $\varpi \geq 1$. Differentiating (8) yields

$$d\log\left(\frac{\hat{g}}{\hat{G}}\right)/d\varpi = \frac{\varphi}{1-\varphi}\left[1+\frac{d\mu/d\varpi}{\mu(1-\mu)}\right]$$

where the second term in square brackets is the cultural multiplier. This effect makes civil society not only the driver of a green transition, but magnifies the effects of this driver in that transition.

In a situation where (10) does not hold, one could think about events that might bolster ϖ. This could include a stronger slant in science education to learning about the costs of pollution. Another possibility is that civil society could become more organized, increasing the salience of working for green rather than brown firms. A positive shock to ϖ induced by such changes, would have the potential for changing the trajectory of a society around critical junctures, where $\Delta(\mu)$ is initially close to zero.

One could also get a further complementarity if scientist values were evolving in the same direction as consumer values – formally, ϖ would be positively related to μ. This would further magnify the dynamic effect of shocks to ϖ.

4 Conclusions

This paper proposes a simple model to illustrate how environmentally minded scientists can help foster a brown-to-green shift in innovation, consumption, and production. We have stressed that motivated science changes the market signals compared to purely profit-driven innovation. Such motivation can serve an important social role in the wake of an externality – like carbon emissions – that needs to be curbed, especially if the benefits of curbing are long-term and global and thus collide with the propensity of elected politicians to focus on short-term and domestic payoffs. We have seen that motivated science may play a further and more subtle role in a green transition – our model stresses the complementarity of innovation and lifestyle changes.

To highlight the implications of motivated science, we have abstracted away from a whole host of other factors. Besley and Persson (2021) discuss a class of political mechanisms including a tax on pollution. They make the more general point that disappointment with conventional politics creates greater climate activism which works directly via the private sector and indirectly via the political sector. Scientists following their values is another expression of this point, which rhymes well with the observation that science has been key in drawing the perils of climate change to the attention of society.

Whether we think of policy as endogenously determined in the analysis or not, the role of alternative policy instruments is an important concern. Theory can be a valuable guide as to which policies could be leveraged to promote a green transition, but which policies appear useful depends on the mechanisms highlighted by the theory. The model in this paper puts the focus directly on the values instilled by the education system both of the general population and in the STEM education of scientists. Indirectly, it suggests that policies which subsidize innovation will have a higher marginal effect on growth in the green sector when scientists have a greater intrinsic motivation or green projects.

Although we have dealt with pollution and climate change, our paper raises a wider set of issues around the role of science in society. Economists have tended to focus on profit-driven innovation. The Schumpterian tradition of Aghion and Howitt (1992) pioneered this view, which led us to better appreciate the role of market structure. But science and entrepreneurship also reflect imagination and visions of the future that are not primarily driven by a hunger for economic gain, as in Aghion et al (2008). While it would be dangerous to discount the role of profit-seeking, leading entrepreneurs are often also visionary leaders whose products can have societal affects beyond the wealth that they generate. Such visions could well turn out to be a powerful force in tackling the climate crisis.

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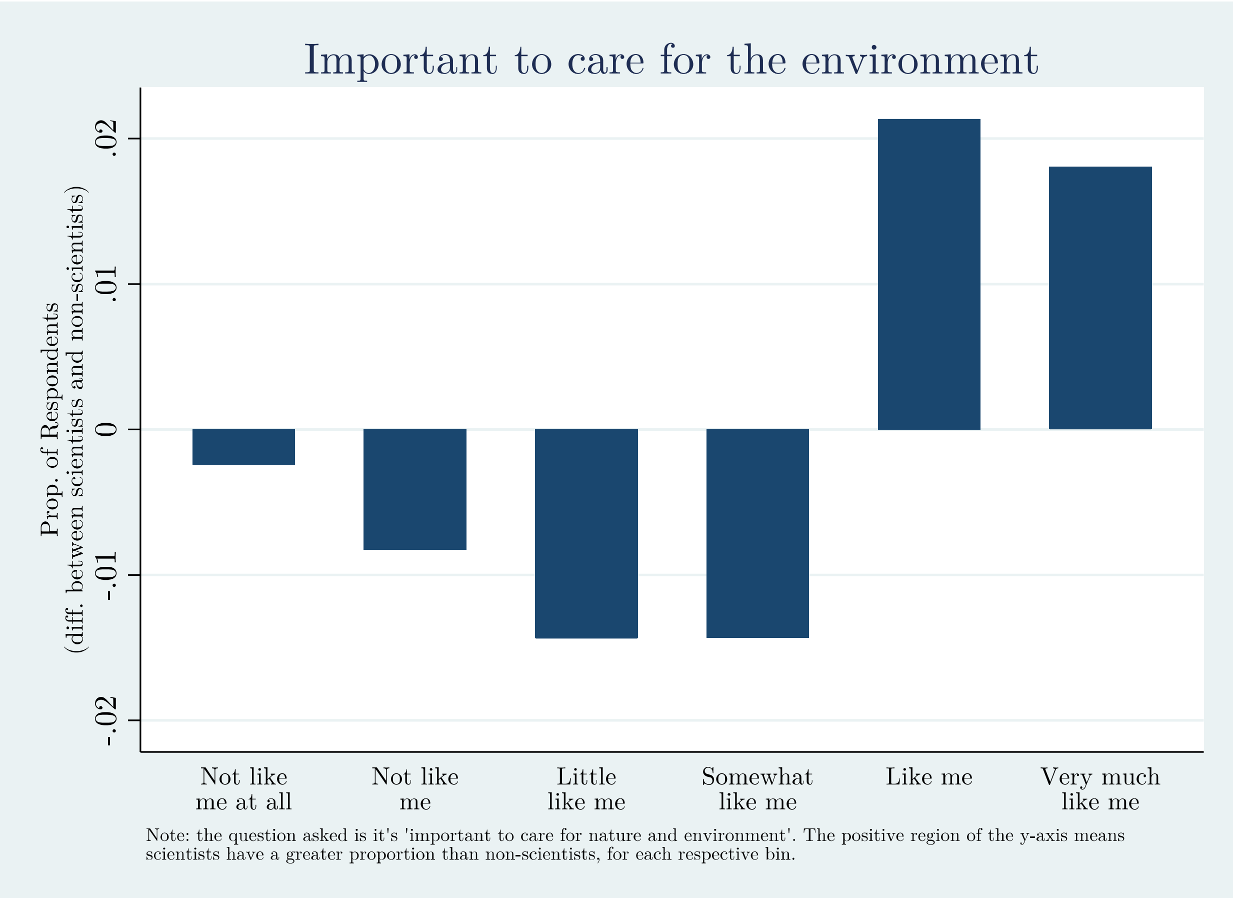
Figure 1



Notes: The figure shows the difference in the raw data between the proportions of scientists and non-scientists, who provide an answer in each category to the proposition “it is important to care for the environment”. For example, 2.1 percent more scientists than non-scientists said “Like me” (hence the positive outcome on the y-axis) about that proposition, while 1.5 percent fewer scientists than non-scientists said “Little like me” (hence the negative outcome on the y-axis).