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Abstract

The paper makes the case for a more systematic ex-ante assessment of the distribution of gains and losses from efficiency enhancing innovations that regulatory sandboxes are expected to test. It shows how a prior formal modelling of tests can inform the regulators on the possible need to control better upfront in the design of the sandbox for some otherwise underestimated but predictable distributional effects. Failing to do so is likely to lead to underestimate efficiency-equity trade-offs and other distributional issues, across stakeholders or within groups of stakeholders. Simple Industrial Organization models will often suffice to identify the potential issues at an early stage and allow better sandboxes designs and hence more reliable policy relevant results.

JEL Classification: K20, K21, K23, L12, L13, L15, L51, O31, O33

Key words: Regulatory sandboxes; innovation; governance; anti-trust; regulation; efficiency; equity; quality standards.

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1. Introduction

In a world in which standard regulatory environments can limit the incentives to try new approaches to doing business, designing, running or delivering processes, products or services in regulated activities, there is a growing policy and academic craving to introduce some temporary flexibility in standard regulatory requirements. This flexibility is specifically designed to allow trials of novelties before deciding whether to mainstream them and adjusting as needed the regulatory environment in which the consumers, firms and investors operate. The temporary regulatory derogations are expected to comply with the general commitments to protect all stakeholders from unfair treatments.[1]

In practice, this flexibility means that some rules, including entry/exit rules, are partially or fully relaxed to allow regulated firms to test specific innovations under the close monitoring of the public authorities. For instance, in 2021, the English energy regulator, OFGEM, allowed two regulated distribution firms (DSO), London Power Networks and Eastern Power Networks, to trial in Cambridge, Norwich and Redbridge a new price-discovery methodology to facilitate investment in on-street electric vehicle (EV) charge-point infrastructure. The trial offers a test of the extent to which the new pricing design would effectively enable higher EV take-up for those without access to off-street parking as argued by the firms.[2] Similar sandboxes focusing on other dimensions of electricity distribution regulation but also aiming at contributing to climate risks management are increasingly common in the sector. In Italy, for instance, standard unbundling rules impeding distribution companies to diversify into activities linked to EV charging facilities were temporarily overruled through a sandbox to allow the acceleration of the transition to less polluting vehicles in the country.[3] As argued by Schittekatte et al.(2021), these experiments allowed the DSO to undertake activities that under normal circumstances were not allowed.

These exceptions to the rules, and similar ones in other contexts, are thought of as well targeted tools allowing a fair test of the impact of an innovation in a real-world setting. They have to last long enough to allow the testing but be as short-lived as possible to avoid the risk of unjustified lasting distortions in the regulatory environment. In the Fintech sector, for instance, the timing of the experiments ranges from 2 weeks to 2 years, depending on their type and goals.[4] Since these experiments take place in a controlled environment, it has to be sufficiently long to allow an assessment of the impact of the innovation on the targeted population and activities but also on other dimensions of interest such as the environment.[5]

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[1] This "regulatory tool" was initially adopted formally in the UK in the mid-2010s in the finance sector (FCA (2017)) but has since been tested in various other countries in a wide range of other regulated sectors, including health, ICT, utilities and transport.

[2] The two firms requested a temporary suspension of the prevailing rules requiring the connecting customer to pay a proportion of the network reinforcement required to support the EV charging needs that is commensurate with their share of new capacity provided. The innovation proposed by the two firms involves replacing the Cost Apportionment Factor (CAF) with a price-point discovery mechanism allowing the identification of the optimum level of discount required to encourage investment in on-street public charging infrastructure.

[3] The diversity of experiments through sandboxes in electricity has produced a large number of insights on the ways in which sandboxes can be used to test how regulation can slow or accelerate the transition to cleaner sources and technologies. See for instance Beckstedde et al. (2022).

[4] World Bank (2020), based on the evaluation of 73 unique fintech sandboxes experiences in 57 countries.

[5] Sandboxes differ from "soft regulation" (Rhodes et al. 2021), which consists in implementing public policy tools that are less efficient but more easily accepted by public opinion; for example, to combat global warming, imposing renewable portfolios rather than a carbon tax. For the Council of European Energy Regulators, there are four complementary tools for implementing Dynamic Regulation: sandboxes, pilot regulatory projects, regulatory experiments, and pilot regulations (CEER, 2022).

This close monitoring and detailed evaluation process can make it easier for regulators to decide whether to permanently modify the standard regulatory environment once a new idea has been tested. Its use is expected to speed up. In Europe, for instance, the European Commission (EC), mainly relies on national sandboxes for innovations in its plan to boost the manufacturing of net-zero technology products. To reduce the risk of opportunistic hidden favoritism, Member States are required to coordinate their activities on these sandboxes and to cooperate within the framework of a Net-Zero Europe Platform. They also have to report annually to the EC on the results of their experiments, including good practices, lessons learnt and recommendations.[6]

The policy enthusiasm is reflected in the positive narrative provided by the fast-growing number of evaluations by international organizations such as the European Commission (2019), Inter-American Development Bank (2020), the OECD (2020), the United Nations (2021) or the World Bank (2020). It is matched by an academic interest reflected in its extensive coverage by the legal and competition policy literature and by sector specific publications such as energy (Beckstedde et al. (2023), Gangale et al (2023), Kanerva and Ekroos (2022)) or Schittekatte et al. (2021)), fintech (Ahern (2021), Bromberg et al (2017)), health (Leckenby et al. (2021), Sherkow (2022), Silverman et al. (2021)) and transport (Basu et al. (2021), Martin et al. (2023)).

While the multiple case studies and the legal diagnostics of the challenges associated with the adoption of sandboxes are quite helpful to appreciate the potential of the tool as an incentive to innovate, to our knowledge, their design has often been mostly based on extensive consultation with stakeholders that helped identify potential gains and losses, and winners and losers. The quality of the design thus depends on the effectiveness of these consultations and the coverage of stakeholders.[7] This may lead to key omissions on possible trade-offs between efficiency and equity concerns that are often included in the mandate of regulatory agencies.

In our review of the literature on the preparation of sandboxes, we did not come across evidence of systematic efforts to develop formal economic models of the impact of innovations across stakeholders.[8] Yet this would often allow an ex-ante assessment of the associated incentive issues and of potential distributional or equity effects that could influence the evaluation of the innovation. These types of models could, in particular, be quite useful to identify *ex-ante* the potential efficiency-equity trade-offs that should be accounted for in the sandbox design. Without thinking about these concerns upfront, there is a risk of an incomplete or misguiding sandbox.

Our main purpose here is to show how and how much this modeling effort can rely on relatively simple basic industrial organization (IO) models. They make it relatively easy to identify early on potential equity and distributional concerns as a complement to the usual static and dynamic efficiency concerns

[6] See article 26 in European Commission (2023). The EC is proving to be quite an enthusiastic user of sandboxes. In addition to those recommended as part of the net-zero initiative, sandboxes are also a key component of the regulation of Artificial Intelligence (AI) since 2021 and, in an April 2023, in a proposal to reform the EU's pharmaceutical legislation. Temporary exceptions will now be part of the rules built-in the new strategies of these sectors. For more details, see https://ec.europa.eu/commission/presscorner/detail/en/ip_23_1843.

[7] See Gangale et al. (2023) for a review of the experience in the European energy sector and FTA (2022) for an equivalent review of the US transport sector experience with sandboxes. See also the very useful process-oriented review produced by Johnson (2023).

[8] Exceptions include Silverman et al. (2021) and Acemoglu and Lensman (2023). Silverman et al. (2021) suggest relying on agent-based modelling as a sandbox to address issues often inaccessible to the traditional epidemiological toolkit for a number of technical and/or ethical issues. Acemoglu and Lensman (2023) study the optimal social regulation of transformative technologies that imply both benefits and costly risks to society such as Artificial Intelligence. They do so from a dynamic perspective accounting for interactions across sectors and compare sandboxes to other regulatory tools in that context.

typically covered by the design of the sandboxes. The fuller picture provided ex-ante should lead to more encompassing checklists of dimensions to track through the regulatory experiments and hence more sustainable policy decisions.

The paper is organized as follows. Section 2 presents a benchmark model to document the value added of the modeling effort for a benevolent regulator who is, however, not omniscient about the market it is regulating. It then extends the analysis to increase the transparency of associated distributional or equity effects. In Section 3, we look at how the heterogeneity of consumers should be picked up in the design of sandboxes to get a better sense of the possibility of efficiency-equity trade-offs. Section 4 expands the analysis to account for firm heterogeneity. Section 5 takes a macro perspective to highlight some of the limitations of sandboxes when cross-sectoral effects are considered. In section 6 we discuss how governance issues other than those associated with information asymmetries may influence the decision to rely on a sandbox, highlighting the relevance of context in the regulatory sandbox evaluation process. Section 7 concludes with a discussion of some of the policy implications and limitations of the analysis.

2. Modeling regulatory sandboxes for monopolies

Regulation can be modeled as a sequential game in which the leader (government or a delegated authority such as a regulatory agency) draws up a contract designed to force one or several followers (firm(s)) to behave in accordance with social rather than private interests. These interests can be defined in terms of efficiency only, but they can also cover other policy concerns such as equity, environmental or industrial goals for instance.[9] In the basic version of the game, managing these concerns is not expected to be a problem for the regulator since it is assumed to be *omnibenevolent, omnipotent and omniscient*, roughly the attributes of a “God”. Paraphrasing the argument of David Hume (1779) about evil, with such a regulator there can be no firm behaving badly, and everything is optimal.

In practice, regulators are not “God” like. In some countries, they are not *omnibenevolent* as they may have a private agenda that dominates their mandate to focus on the social welfare. They are often also not *omnipotent*, for instance, when the regulatory responsibility is atomized and distributed across government agencies, administrations or levels. Moreover, the division of labor is not always similar across countries or sectors. In some cases, regulators are expected to address both efficiency and equity concerns and in others they are expected to focus on efficiency only while finance or sector ministries deal with social and equity related issues. Finally, more generally maybe, regulators are seldom *omniscient* since they rarely have full information and full knowledge of key dimensions of the activities they are supposed to regulate.

Even when there is no risk of non-benevolence and when regulators are omnipotent (i.e. have the full mandates over all relevant dimensions in the sector they are responsible for), information asymmetries make regulation unable to deliver on its social welfare goals. To help regulators do as well as possible, public administrations often make explicit effort to document and track the effects of regulation despite the information gaps. This is specifically where sandboxes can help but to do well, they need to be able to account for trade-offs built in the efforts to improve social welfare even when regulatory mandates are atomized and for the governance and informational context in which the regulatory trials take place. A specific sandbox may only be desirable in terms of efficiency but not in terms of equity or vice versa while both dimensions matter to social welfare. Similarly, differences in

[9] There is an on-going debate on the extent to which the mandates of regulatory agencies or competition agencies should be focused or atomized across policy goals. For a discussion arguing in favour of a focused approach see Tirole (2023). For an alternative vision, see Vestager (2018).

the degree of information asymmetry across countries, regions or sectors may explain why a sandbox may deliver a positive result in one case and a negative one in another.

To be able to decide on the desirability of the regulatory innovation to be tested, the design of the sandbox has to internalize all the relevant policy concerns and not only the efficiency ones. One way to take on the challenge ex-ante is to rely on a "toy model" of monopoly regulation that can be adapted and used to track both efficiency and equity effects of the adoption of an innovation. This ex-ante modeling exercise can then help the final design of the sandbox.

In the basic model, we consider the case of a firm allowed to test a welfare-improving innovation that is not implementable or authorized under existing rules. To highlight the importance of designing a test that accounts for both the efficiency and equity mandate, the modeling of the various dimensions of interest is progressive. In this core model, we initially assume that the regulator is benevolent and omniscient. These assumptions lead to a benchmark result against which the effects of more realistic assumptions can be compared. To add to the realism of the analysis, we augment the model to account for information imperfection and for possible equity concerns. These added assumptions increase the transparency of possible underlying efficiency-equity trade-offs that would not be typically addressed in a sandbox evaluation.[10]

2.1 Modeling the basic inefficient monopoly with a regulator perfectly informed

Our regulator is specifically concerned with an industry where a private monopolist produces the quantity q at cost $C(q)$, with $C'(q) > 0, C''(q) \geq 0$. The gross surplus of consumers is represented by the concave function $S(q)$, with $S'(q) > 0$ on the interval $[0, \bar{q} > 0[$. The unit price of the good is p. Consumers are price-takers.

From the maximization of the consumers' net surplus $NS = S(q) - pq$ with respect to q, we can derive the inverse demand function $p(q) = S'(q)$ with $p'(q) < 0$ since $S'' < 0$. Then the optimized net surplus of consumers is $NS(q) = S(q) - p(q)q$ with $NS'(q) = -qp'(q) > 0$ for all $q > 0$. The profit of the private monopoly is $\pi(q) = p(q)q - C(q)$ that we assume concave ($\pi''(q) < 0$). Then its best choice is $q^m = \arg\{\pi'(q) = 0\}$.

If the regulator has industry-specific powers, it maximizes the social gain $W(q) = NS(q) + \pi(q)$. The first-best output is then $q^f = \arg\{W'(q) = 0\}$. Since $NS'(q) > 0$ for all q, we conclude that $\pi'(q^f) < 0$, and given $\pi''(q) < 0$, we obtain the standard result $q^m < q^f$: because it does not internalize the consumers' surplus, the private monopolist undersupplies.

By imposing the rule $q \geq q^f$ the regulator will require the monopoly to produce at first best, provided that $\pi(q^f) \geq 0$. This is the basic textbook result against which the impact of sandboxes can be assessed. The rest of the discussion allows us to track the extent to which sandboxes can help the regulator improve social welfare, initially focusing only on efficiency and then adding equity concerns.

2.2 The regulatory margin to stimulate innovation sandboxes

Consider a scenario in which the regulated monopolist has some margin to innovate but existing rules do not allow the firm to do so. The regulatory policy decision that will endorse a request to not comply temporarily with the rule needs to go through several predictable diagnostics. In practice, however,

[10] In many countries, regulators need to consider these trade-offs, but they are generally not under the radar screen of the competition agencies The case to get competition agencies to focus on these trade-offs started to enjoy a high profile when L. Kahn took charge of the US anti-trust agency in 2021. It had already also been a concern of M. Vestager as Competition Commissioner at the European Commission since the late 2010s. See Baker and Salop (2015), Dunne (2020), Kahn and Vaheesan (2017), Vestager (2018) vs. Brennan (2018) or Shapiro (2017) for the debates between modern and traditional views on the role of competition policy.

the diagnostic boils down to answering the following simple question: will a regulatory decision allowing a temporary suspension of rules be in the interest of all stakeholders in society or only in the interest of the innovator? The answer will influence the social desirability of the sandbox and in the "real world" also define its political viability.

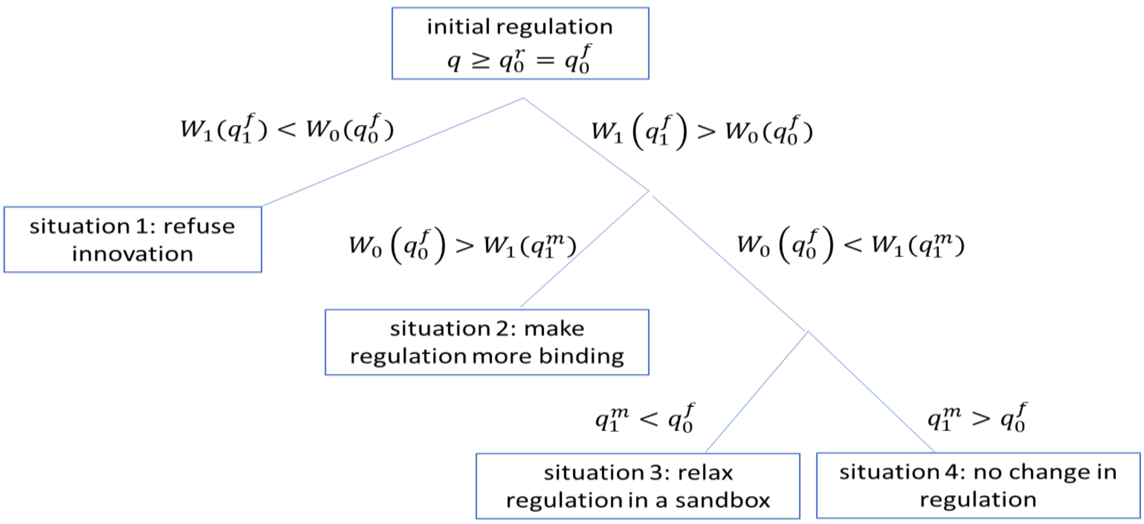
To be as precise as possible, the answer requires an explicit quantifiable comparison of the outcomes in terms of welfare *before and after* innovation with or without additional regulatory intervention. The sandbox will deliver a sense of the potential impact of the innovation in the specific sample for which it is tested and assuming that all the key incentives issues covering the various stakeholders have been accounted for.[11] This is where the progressive extension of the model proves to be useful to identify an early indication of each of the dimensions to be internalized in the impact evaluation. An initial strong indication on the limited margin a regulator has to assess the desirability of a sandbox is to internalize the relevance of information gaps in the optimization effort.

2.2.1. Omniscient regulator only interested in efficiency

Assume for now that the regulator is fully informed on all relevant dimensions needed to assess the potential social welfare payoffs of a sandbox allowing a simple comparison of the pre-innovation welfare level and of the post-innovation level once the sandbox experiment has been conducted. Assume also that it is still only interested in efficiency.

Let's index the timing of the pre-innovation situation by "0" and the situation after the innovation by "1". In the initial situation, the regulated monopolist is constrained to produce at least the first best quantity $q_0^r = q_0^f$ as discussed in section 2.1 and the social performance is $W_0(q_0^f)$. The potential innovation demanding a temporary regulatory adjustment through the sandbox would change the gross consumer surplus from $S_0(q)$ to $S_1(q)$ with $S_0(q) >$ or $< S_1(q)$ and/or costs from $C_0(q)$ to $C_1(q)$ with $C_0(q) >$ or $< C_1(q)$. These new surplus and cost functions would lead the profit maximizing output to become q_1^m, and the welfare maximizing output to become q_1^f. The ex-ante decision to support a regulatory sandbox will result from the likely net impact of the changes in *S* and *C* on the social outcome measure, i.e. $W(q) = S(q) - C(q)$. The regulator can anticipate four predictable possible situations. These are plotted in the screening tree reported in Figure 1.

Figure 1: Screening tree in terms of efficiency



[11] See for instance, Blind et al. (2017) and Majumdar and Marcus (2020).

Each likely social outcome implies a different optimal regulatory decision in a context in which the regulator is mandated to be focus only on efficiency, as is often the case when assessing sandboxes designed to test an innovation:

1) *If the social outcome will predictably deteriorate with the innovation*, i.e. $W_1(q_1^f) < W_0(q_0^f)$, there is no reason to change the regulatory framework since the innovation would leave society as a whole worse off, even though it could be beneficial for the monopolist. The innovation will be purely and simply blocked since the outcome would be predictably undesirable. There is thus no case *for* a sandbox. This is what would happen in the EV case discussed earlier if all of the added recharging capacity was supplied through generators that add up to more CO_2 emissions than would be achieved from simply relying on cleaner fuel-based engines for private and commercial vehicles rather than on EV. The producers could be better off but society would be worse off. In some countries, this may not be a risk because of the characteristics of the generation sector but in others, it will be a problem. This is one way in which context matters when assessing sandboxes.
2) *If the social outcome of allowing the innovation is potentially good for society*, *but there is a risk that the firm decides to produce at a level that is not socially optimal,* i.e. $W_1(q_1^m) < W_0(q_0^f) < W_1(q_1^f)$, the regulator must impose a minimum level of output (i.e. a minimum service obligation), requiring upfront the monopoly to produce at least q_1^r, so that $W_1(q_1^r) \geq W_0(q_0^f)$. In this situation, there is a potential case to support a sandbox if the regulator is willing or able to impose an additional output requirement on the monopolist allowing to reach the new first best $W_1(q_1^f)$. This would happen in the health industry, without some type of universal service obligation, if the monopolist was allowed to sell its innovation validated through a sandbox exclusively in developed countries because the affordability issues are less constraining than in emerging or poorer economies. Associating the sandbox with clear global output requirements allows both developed and developing countries to benefit from the innovation it allowed to test. Considering the suspension of some regulatory requirements to allow the test of an innovation may have to be matched with the margin available to eventually add another regulatory requirement to capture the gains from the innovation to achieve the social optimum.
3) *If there is scope for a global social benefit from innovation but the output that the innovator wishes to produce does not satisfy the key welfare and output constraints,* i.e. $W_1(q_1^m) > W_0(q_0^f)$ and $q_1^m < q_0^f$, the sandbox is likely to be a useful option to favour innovation and achieve an improved social outcome. Indeed, in this situation, regulation should be made more flexible to allow the monopolist to keep enough of the rent associated with innovation, i.e. tolerating of a "violation" of the standard regulatory requirement $q \geq q_0^r$, whereas $q_1^m < q_0^r$.[12] This, in turn, implies looking into the incentives built-in the distribution of the rent created by the innovation under the existing regulatory environment. In regulated industries, this often will imply considering giving up, as part of the experiment, traditional price-cap types of regulation in favour of output-based incentive regulation or other forms of regulation favouring the efforts to rely on innovative technologies.[13] In this context, the design of the sandbox should also produce information on the rent size that the regulator can eventually internalize in an update of the regulatory environment to deliver on the expected social welfare improvements. This is easily achieved for an omniscient regulator but is more challenging in a world of information imperfections as discussed in 2.2.2.

[12] We will see in section 2.3 that the regulator will have to adapt output requirements to be sure that consumers are not penalized.
[13] For a discussion of the adjustments needed in the energy sector, see CEER (2022).

4) Finally, *if the innovation is socially desirable and if it can be accommodated within the current framework,* i.e. if $W_1(q_1^m) > W_0(q_0^f)$ and $q_1^m > q_0^r = q_0^f$, there is no need for a sandbox.

Overall, thus, the upgraded simple IO model assuming that the regulator has full information on the technology, demand, profit and welfare functions already highlights that in some contexts, sandboxes are not a desirable tool. More specifically, it suggests that the 3rd situation is the only case in which there is a clear case for a sandbox. It identifies the 2nd situation as a possible second case but this requires an ability of the regulator to ensure ex-post, once the experiment has proven to be successful, that the potential output gains can be achieved to obtain the expected welfare gains by adding significant regulatory obligations. Adding imperfect information to the model assumptions makes the diagnostic somewhat harsher as discussed next.

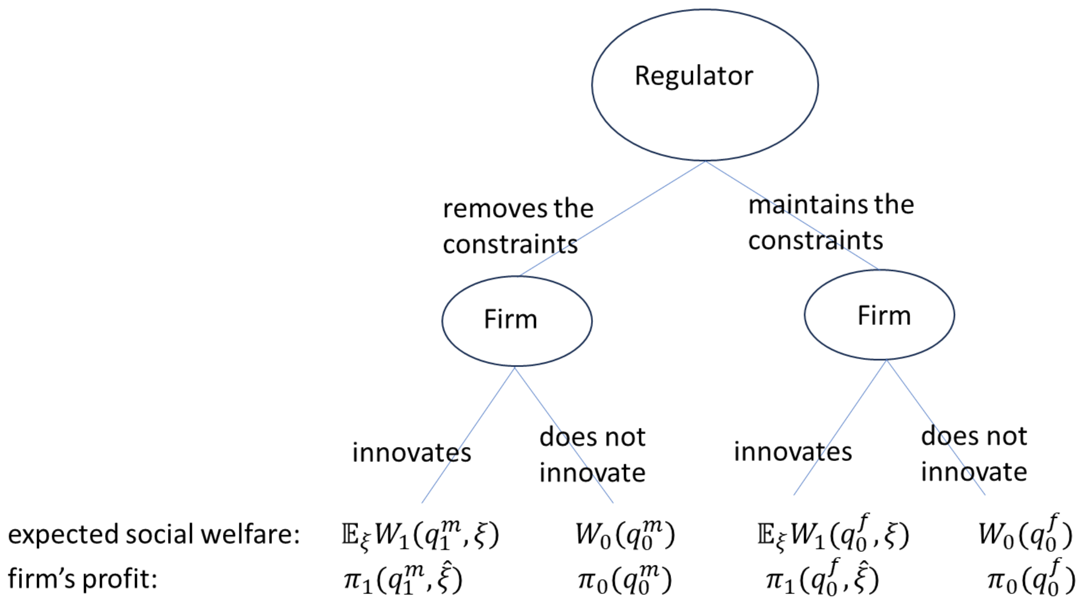
2.2.2. The case of poorly informed regulators

The regulatory screening described so far necessitates a perfect knowledge of the technologies and demand parameters and the capacity to calculate the quantities as well as the profit and welfare functions. In practice, the regulator has limited knowledge on these data, and the monopoly itself has only fuzzy valuations of its future performance. To illustrate the consequences of this lack of precise information, consider the following sandbox game portrayed in Figure 2:

-at time 0: when considering a project of innovation and having to decide whether to open a sandbox, the regulator knows the current relevant values $W_0(q_0^m), W_0(q_0^f), \pi_0(q_0^m), \pi_0(q_0^f)$ and has limited knowledge on the precise consequences of the innovation. Let ξ represent the missing pieces of information (state of nature and/or moral hazard). The regulator can only compute $\mathbb{E}_\xi W_1(q_1^m, \xi)$ and $\mathbb{E}_\xi W_1(q_0^f, \xi)$.

-at time 1: observing the exact state of nature $\hat{\xi}$, the monopolist decides to innovate or not to innovate by comparing $\pi_1(q_1^m, \hat{\xi})$ with $\pi_0(q_0^m)$ if the constraint has been removed, and $\pi_1(q_0^f, \hat{\xi})$ with $\pi_0(q_0^f)$ if the regulation is unchanged.

Figure 2: The sandbox game



Assuming that the regulator is risk-neutral, at time 0, it computes the expected gain from a sandbox as

$$\mathbb{E}W(sandbox) =$$
$$Prob\left[\,\pi_1(q_1^m,\hat{\xi}) \geq \pi_0(q_0^m)\right]\,\mathbb{E}_\xi W_1(q_1^m,\xi) + Prob\left[\,\pi_1(q_1^m,\hat{\xi}) < \pi_0(q_0^m)\right] W_0(q_0^m)$$

since the firm will innovate only if it finds out it is a profitable undertaking. The option to maintain the current regulation process will give the expected social gain

$$\mathbb{E}W(no\ sandbox) =$$
$$Prob\left[\pi_1\left(q_0^f,\hat{\xi}\right) \geq \pi_0\left(q_0^f\right)\right]\mathbb{E}_\xi W_1\left(q_0^f,\xi\right) + Prob\left[\pi_1\left(q_0^f,\hat{\xi}\right) < \pi_0\left(q_0^f\right)\right] W_0\left(q_0^f\right)$$

In this game, the challenge is to unbundle the incentive of the firm and of the regulator to bet on a sandbox based on the information available that we know is different for the firm and for the regulator. Let's focus first on the polar cases:

i) when the state of nature $\hat{\xi}$ is revealed, it appears that the innovation is costly to the firm and it will mainly benefit consumers, so that $\pi_1\left(q,\hat{\xi}\right) < \pi_0(q)$ no matter the level of production. In that scenario, the firm will clearly prefer not to innovate and to take advantage of the sandbox to produce q_0^m rather than q_0^f, with a negative social consequence since $\mathbb{E}W(sandbox) - \mathbb{E}W(no\ sandbox) = W_0(q_0^m) - W_0\left(q_0^f\right)$ is negative. If the innovation is actually potentially useful to consumers ($NS_1(q) > NS_0(q)$), despite the reluctance of the monopoly, it would make no sense for the regulator to bet on a sandbox since it would not convince the firm to innovate. But it would make sense to incentivize it by some other means, such as subsidies or tax advantages.

ii) the innovation mainly allows to decrease the production costs, so that $\pi_1\left(q,\hat{\xi}\right) \geq \pi_0(q)$ for any q, i.e. the innovation allows the monopoly to make a profit no matter the level of production. Then the innovation is certain and the regulator's decision must be based on whether $\mathbb{E}W(sandbox) - \mathbb{E}W(no\ sandbox) = \mathbb{E}_\xi W_1(q_1^m,\xi) - \mathbb{E}_\xi W_1\left(q_0^f,\xi\right)$ is positive or negative. The decision can lead to the two classical errors:

- type I error: $\mathbb{E}_\xi W_1(q_1^m,\xi) < \mathbb{E}_\xi W_1\left(q_0^f,\xi\right)$ and it later appears that the state of nature $\hat{\xi}$ is such that $W_1\left(q_1^m,\hat{\xi}\right) > W_1\left(q_0^f,\hat{\xi}\right)$: there is mistaken rejection of a socially profitable innovation;

- type II error: $\mathbb{E}_\xi W_1(q_1^m,\xi) > \mathbb{E}_\xi W_1\left(q_0^f,\xi\right)$ and it later appears that $W_1\left(q_1^m,\hat{\xi}\right) < W_1\left(q_0^f,\hat{\xi}\right)$, that is the failure to reject an innovation that is not profitable for society.

The current momentum in favor of sandboxes observed in many countries and industries is probably due to the fear to make type I error. This fear seems to be quite common in the context of the craving to support innovations that will accelerate the energy transition.

iii) More generally, if $1 > Prob\left[\,\pi_1(q_1^m,\hat{\xi}) \geq \pi_0(q_0^m)\right] > 0$ and $1 > Prob\left[\pi_1\left(q_0^f,\hat{\xi}\right) \geq \pi_0\left(q_0^f\right)\right] > 0$, the decision to open a sandbox will depend on the context and in particular on the degree to which the regulator is benevolent and to the extent to which it is omnipotent, two real possibilities we have assumed away in our modeling. We will return to these in the final discussion of the paper. For now, it is useful to mention, that the governance context may explain why some governments are more likely to be associated with a specific type of error. For instance, in countries with a strong risk of capture or corruption, type II is more likely to be observed.[14]

We see that, even when the regulator is only expected to focus on efficiency, the decision to open a sandbox can be risky as there are many instances in which the desired social outcome could fail to materialize. This simple model is powerful enough to reveal the situations in which the sandboxes are likely to be the wrong decision to try to stimulate an innovation. It also shows that the potential to lead to improvements in social welfare will generally have to be associated with changes in output requirements or service obligations so that enough consumers benefit from the innovation being tested. Finally, it highlights the importance of monitoring each of the components of social welfare, *NS* and π as well as its total *W* when assessing the desirability of a sandbox. The next subsection shows that adding equity to the mandate of the regulator will make the decision even harder and increasing the monitoring challenges than when the regulator is only expected to focus on efficiency.

2.3 The equity-efficiency trade-off

In many situations, in particular in the context of innovation with predictable social effects, the identification of the potential effects of a sandbox will have to account for the possibilities of efficiency-equity trade-offs. This demands a much more precise tracking of the net impact of innovation on social welfare than the model developed so far has been able to document. The relative values of consumers' net surpluses $NS_1(q_1^m)$ and $NS_0(q_0^r)$ matters just as much as comparisons of $W_1(q_1^m)$ with $W_0(q_0^r)$.

For instance, an exceptionally successful innovation from a social welfare perspective may leave a large share of the consumers out of the potential beneficiaries as it is sometimes argued in assessments of the risks of an increase in the role of technology in many services. Indeed, in many countries, the benefits of the digitalization of banking, postal, social or tax services tend to exclude many in the older population. This has too often been underestimated by many of the trials conducted prior to their mainstreaming. Costs may have been cut enough to increase total welfare, but, in the short run at least, total *NS* may not always have been as positively impacted as expected because of underestimated adjustment costs for large segments of the potential beneficiaries of the innovation. Many consumers end with less service than before the innovation was adopted.

Conceptually, being able to address jointly efficiency and equity concerns requires an explicitly separate evaluation of the overall payoffs to the consumers and to the producers and not just an assessment of their net effect on the total social welfare outcome. This is essential to obtain a first look at the equity across stakeholders of the regulatory mandate.

To see this more concretely, consider the following model specification for the case of a monopoly delivering a regulated public service. Let the consumer welfare be $S(q) = \left(a - \frac{bq}{2}\right)q$ and the cost function faced by the monopolist be $C(q) = cq$. Since the consumers are price-takers, the demand function is $p(q) = a - bq$. Then, their net surplus is $NS(q) = bq^2/2$. The monopolist's profit is

$$\pi(q) = p(q)q - cq = (a - c - bq)q,$$

and the welfare function is

$$W(q) = \pi(q) + NS(q) = \left(a - c - \frac{bq}{2}\right)q.$$

The monopolist would like to produce $q^m = (a-c)/2b$ but the regulator constrains the firm to produce more, e.g. at least the output that maximizes welfare, that is $q \geq q^f = (a-c)/b$, resulting

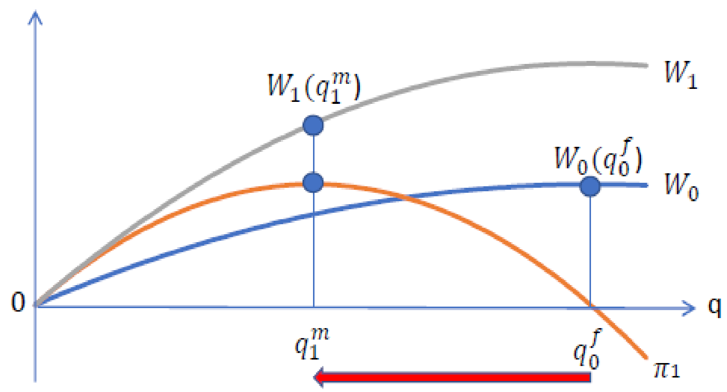
[14] "*…when derogations are granted on a case-by-case basis, regulators must be conscious of the risk of discrimination and distortion of the* level playing field" (CEER (2022), p.10.

in $\pi(q^f) = 0$ and $W(q^f) = NS(q^f) = (a-c)^2/2b$. This is the result already seen in section 2.1 more generally.

We now move to the comparison of welfare changes and their sources as a result of the authorization to introduce an innovation that would not have been considered under usual regulatory requirements. To make the comparison more concrete, let's focus on a specific numerical example. Assume that, in state 0, we have $a_0 - c_0 = 10$ and $b_0 = 1$ so that $q_0^f = 10$ and $W_0(q_0^f) = 50$. The incumbent can innovate to reach state 1 where $a_1 - c_1 = 20$ and $b_1 = 2$. The monopoly output is $q_1^m = 5$ and for this value we obtain $W_1(q_1^m) = (20-5)5 = 75$.

Figure 3 illustrates why, while $W_1(q_1^m) > W_0(q_0^f)$, suggesting that it is efficient to accept the innovation, the output produced by an optimizing monopolist after the innovation is actually lower than the output requirement $q_1^m < q_0^f$. This is situation 3 depicted in subsection 2.2.1. To implement the innovation necessitates relaxing the regulatory constraint. But there is a risk that some consumers will be worse off.

Figure 3: Profit and welfare functions before (0) and after (1) innovation



The numerical details of our example provide additional insights on some of the difficulty of designing a sandbox precise enough to allow a fair decision on its endorsement or its rejection. Observe that $NS_1(q_1^m) = 25 < NS_0(q_0^f) = 50$ whereas $\pi_1(q_1^m) = 50 > \pi_0(q_0^f) = 0$. Consequently, if the regulator has equity concerns, it faces a trade-off between the rent to abandon to the firm and the compensation afforded to consumers. To reach $NS_1(q_1^r) = 50$, we need approximatively $q_1^r = 7 > q_1^m = 5$ and the firm earns $\pi_1(q_1^r) = 42 < \pi_1(q_1^m)$, which can be dissuasive for innovating. From a strict regulatory perspective, the example shows that the regulation constraint needs to be relaxed since $q_1^r < q_0^f = 10$, but less than if the distributive effect is not taken into consideration since $q_1^r > q_1^m$. The details are summarized in Table 1. If the design of the sandbox does not pick this up, it could lead to an undesirable social outcome.

A detailed look at Table 1 provides an additional illustration of the extent to which the stakes associated with sandboxes designed to provide an incentive to innovate are not only about efficiency gains but also about the distribution of the efficiency gains achieved. This is why.

	Table 1: Comparing outcomes in the example			
		(1)	(2)	(3)
		Situation at time 0	Situation at time 1 without social regulatory intervention	Situation at time 1 with social regulatory intervention
(1)	q^m	5	5	7
(2)	q^f	10	10	10
(3)	q^r	10	-	7
(4)	NS	50	25	50
(5)	Π	0	50	42
(6)	W	50	75	92

First, focus on the welfare (*W*) line, line (6). It shows that providing an opportunity through a sandbox to innovate is good news for society as a whole in this example. But lines (4) and (5) also show why the distribution of the gains could lead to conflicts between stakeholders. The comparison of columns (2) and (3), i.e. with or without regulatory intervention to manage the social impacts of innovation, shows that the monopolist's incentives to push for sandboxes is the strongest when this sandbox is the only change to the rules but it reduces its output and hence consumer welfare. However, when the regulator decides to add an output requirement to minimize the impact on consumers, it also reduces the monopolist's potential payoffs to innovation in terms of profits. This may not offset the gains from innovation but may reduce the desire to change anything to a business-as-usual scenario, if the hassle to go through, not modeled here, is accounted for. Transaction costs matter, but not only. The preferences for rent capture are also important, even if not usually modeled in the identification of optimal regulatory decisions.

The broader insight of this example is that negotiations between stakeholders surrounding sandboxes may be picked up in political debates because of their distributional implications, irrespective of their efficiency payoffs. Part of the political dimension stems from the fact that the distribution of the gains and losses can be influenced by regulatory interventions. It is this margin of influence that stimulates the incentive to negotiate and possibly related political debates as in the case of environmental discussions linked to the need to start experimenting new solutions to address the growing climate change concerns.

2.4 What does it all mean for the design of sandboxes in theory and in practice?

This basic model can be extended in many ways, including to cases of informational bias: risky innovation, adverse selection if the regulator is not sure of the firm's ability to carry out its innovation, and moral hazard if the regulator cannot control the firm's R&D expenditure. But "as-is" the discussion so far already shows that considering the relaxation of some regulatory rules through sandboxes must be matched by a clarification of the mandate assigned to regulators (and/or competition agencies in the many cases in which they rely on sandboxes): are they solely responsible for maximizing global social welfare or should they also be concerned with how the social surplus is distributed among shareholders and customers? Once more, these concerns should be at least discussed at the sandbox design stage to avoid ending up with a successful narrow sandbox that will never be scaled up because it is politically unsustainable. Think of the challenges of enforcing lockdowns and social distancing during the Covid crisis for instance.

More generally, in many situations, one of the key social challenges is an equity one and is linked to the heterogeneity of the consumers group. Is there thus a case to differentiate across consumers, say rich vs. poor (in many public services), young vs. old (in the context of climate change), farmers vs.

tourists (when considering the use of water resources) or victims of common pathologies vs. victims of orphan diseases? And if yes, can sandboxes be designed to internalize possible equity concerns while testing the efficiency gains to be achieved through an innovation?

Getting to any of these questions requires more precise quantitative diagnostics than some of those usually conducted to assess the performance of sandboxes and deserves an ex-ante conceptual assessment through the types of models discussed here. More precise versions should allow a test of the importance of equity concerns in the comparison between $NS_1(q_1^m)$ and $NS_0(q_0^f)$ linked to restrictions to access to the innovation or to its affordability. It could also reveal the extent to which a loss of welfare could come from an underestimated distributional effect. The loss to some users may offset the gains to others.

To illustrate the need for sandboxes to start accounting for these distributional issues in more details, it may be useful to review one common case in which quality standards have social implications. It concerns innovations that change the quality options available to consumers as discussed next.

3. Dealing with heterogeneous consumers' preferences for quality

Quality and quality perceptions matter in most industries and certainly in regulated industries (renewable vs. thermal energy, fiber vs cable internet, generic vs. brand medication, 1st class vs. 2nd class in transport, rail vs. road vs. plane, and so on). It is thus not surprising that quality changes are commonly covered by sandboxes. But getting the full picture on what these changes imply is not as simple as it sounds. Indeed, it is often not easy to identify the extent to which the quality levels chosen by regulated firms (and sometimes those imposed through political decision by authorities) can be or not inefficient in a broad social welfare sense.

If a sandbox is considered to guide the policy decision, unless it is designed to test the social value of allowing for quality differentiation and the associated equity and distributional effects, the conclusion of any evaluation is likely to be biased. For instance, in many countries, social concerns are commonly raised in the context of the efforts to get firms and households to test new technologies to implement the national energy transition commitments. The fact that cleaner options tested end up often not being the cheaper options can be quite socially and hence politically sensitive. The difference in price between an EV and a gasoline comes to mind. Green driving is not yet an affordable option for a large share of the population. This is why is it useful to consider accounting for these social biases in the design of technological sandboxes. In this section, we suggest a model assessing the social welfare impact of underestimating the relevance of quality preferences and its incidence on various user groups as part of the evaluation of sandboxes.

Consider again a basic IO model, this time accounting explicitly for quality concerns. Assume that there is a continuum of potential consumers for a product, the quality of which is measured by z. Each consumer is identified by her/his valuation θ of quality. The gross surplus of θ is given by the Mussa-Rosen function: $S(\theta, z) = \theta z$. The valuation θ is uniformly distributed on the interval [0,1]. Each θ consumes either 1 or 0 unit of the product.

The quality level is assumed to only impact fixed costs $c(z)$, with $c'(z) > 0, c"(z) > 0$.[15] Since there is no variable cost, if some quality is available, it must be provided to all θ. Then the optimal level of quality is the one that solves

$$max_z\, W(z) = \int_0^1 \theta z \, d\theta - c(z) \Rightarrow \frac{1}{2} = c'(z) \;\; \Rightarrow \; z^* = c'^{-1}(\frac{1}{2}).$$

[15] We follow Ronnen (1991) rather than Crampes and Hollander (1995) who assume that quality impacts the variable cost of production. See also Michaelis and Ziesemer (2022).

We assume that $W(z^*) > 0$, i.e. getting to the optimum level of quality is good news for society considered in aggregate.

Now, suppose there is one single producer.[16] It charges the price p for one unit of good with quality z. The net surplus of θ is $\theta z - p$ if the consumer buys one unit of the good and zero if it does not.

If the regulator is mandated to track the social or equity effects of any change in quality standards, it should be interested in its ability to separate the potential consumption base into two groups, those buying the good or service at the set level of quality and those deciding not to do so. This differentiation is needed to be able to assess their relative importance, notably to get a sense of the share of the population left out by any change in quality levels delivered by the market.

Imagine, for instance, that the market of interest is for hybrid cars with specific emissions limits. Assume for now that this market is a monopoly because only one firm has the ability to produce the vehicle that meets the specific standards.[17] In that market, any increase in the standard will make the vehicles costlier to produce and thus more expensive to buy in the short run. The welfare impact will depend, as usual, on how sensitive the population is to the price matching the quality standard.

Conceptually, this can be assessed by identifying in the continuum of consumers the one indifferent between buying one unit of the good with quality z and buying nothing. This individual determining the share of self-excluded consumers is identified by $\theta = p/z$ and this leads to an effective demand of $q(p,z) = \int_{p/z}^{1} d\theta = 1 - \frac{p}{z}$. Unsurprisingly, this tells us that the regulator interested in increasing the share of the population considering hybrid cars with a specific limited emissions level can play with two variables: price (possibly subsidies) and quality standards (i.e. emissions standards for hybrid cars, knowing that better standards imply more expensive cars).

The trade-off on the consumption side is predictable and can probably be built-in the design of a sandbox without too much difficulty. For instance, in many countries, in the case of our example, these social concerns fuel the need to increase the number of public transport alternatives and frequency. But this is not enough in general. Focusing the sandbox on the improvement of a specific quality standard underestimates the necessity to anticipate also the reaction of the supplier of the improved technology. This is where the ex-ante conceptualization of the regulatory change considered is useful before the design of the actual sandbox.

To get some intuition on how the supplier will react, we can continue to exploit our simple formal model. It shows that the monopoly solves $max_{p,z}\, q(p,z)p - c(z) = \left(1 - \frac{p}{z}\right)p - c(z)$. From the first order condition (FOC) with respect to p, we can conclude that $\frac{p}{z} = \frac{1}{2}$ and from the FOC with respect to z that $\frac{p^2}{z^2} = c'(z)$ since the additional cost from upgrading quality must be compensated by a marginal increase in revenues.

Considered jointly, the two partial results mean that, in practice, the monopolist will undersupply. In our example, we will have fewer hybrid cars than desirable. Indeed, combining both the information on the demand side and on its own preference, the monopolist will deliver a quality of $z^m = c'^{-1}\left(\frac{1}{4}\right) < z^*$ where z^* is the quality needed to ensure that the share of the population aimed at by

[16] Since the marginal cost is nil and there is a positive fixed cost, perfect competition is not sustainable.

[17] This was the situation Toyota enjoyed when, in 1997, it put the first mass produced hybrid on the market. They were the only ones to do so for a while. Ferdinand Porsche has actually produced the first hybrid car in 1899 but for a much smaller market since it added up to only 300 vehicles until the early 1910s. One of the main reasons why the market failed to take off was that Henry Ford started to produce lower cost gas-powered vehicles in mass in 1904. Prices already mattered then!

the policy is reached, in our case that all consumers are served. In practice, since $\frac{p}{z} = \frac{1}{2}$, we have that $q(p, z) = \frac{1}{2}$. The monopoly caters to the richest segment of the population—which is what is happening with hybrid cars in most countries.

Unless sandboxes are designed to assess jointly the demand and the supply side aspects of a change in regulation, the evaluation will end up ignoring the full extent of these biases. Failing to pick the need to conduct the joint assessment may lead to innovations tested through sandboxes failing to deliver on the expected general social welfare improvements. Moreover, the model also shows that "naïve" policy design will underestimate the complexity of the ways in which part of the population are likely to be excluded. Internalizing these social concerns in the sandbox should not be too difficult but demand a willingness to think them through ex-ante.[18]

In this specific setting, the model shows that increasing the number of consumers willing to rely on a new technology requires a decrease of the hedonic price *p*/*z* which means either a decrease in *p* or/and an increase in *z*. In practice, in our example, the main instrument to consider is a lowering of the price rather than lowering the standard below z^*. This, in turn, is likely to imply a subsidy. The design of this subsidy has to be a key part of the assessment of the level of emissions to be imposed for the hybrid cars to become attractive to a growing number of users and producers.[19] In other words, unless the design of the sandbox deals jointly with the environmental and the equity concerns as well as the concerns of producers, it is likely to deliver a lower social welfare.[20]

4. The case for dealing with producers' heterogeneity

In section 3, we showed that equity matters but the reaction of the supply side of the market may matter as well and invalidate the results obtained in the previous section. Simply considering the aggregate effect on the supply side may not be enough either. From a competition agency perspective, it is also often necessary to monitor the differences in impact of sandboxes across firms, accounting for differences in their characteristics. Producers are often as heterogeneous in many dimensions as consumers are.[21] In this context, the issue is the extent to which the different firms are treated fairly or not when additional regulatory requirements are imposed.

To get a sense of the extent to which unfairness on the supply side can be a concern, consider a situation in which the authorities decide to test ways of opening some segments of the market originally controlled by the monopoly to competition to diversify the quality options available to consumers. We will then see how imposing a Minimum Quality Standard (MQS), for instance to address new environmental concerns, leads to somewhat counterintuitive results that need to be documented as part of the evaluation of the sandbox and hence reflected in indicators identified at the design stage.

[18] Note that this example and many others illustrate how well-intended but poorly assessed innovation ideas fail because regulators are indeed often not as omniscient as they would want to be. Sandboxes may be useful to mitigate the consequences of these imperfections, but they can also be counterproductive if they are not as precise as they should be to fully address the key information gaps.

[19] In the "real world", it also means a better coordination with the emission impact of alternative transport modes to contribute effectively to the management of total emissions associated with mobility.

[20] If the regulator mainly worries about quality, it may impose for example $z \geq z^*$. But without a constraint on the price, the firm will fix the price that maximizes $q(p, z^*)p = \left(1 - \frac{p}{z^*}\right)p$, then $\frac{p}{z^*} = \frac{1}{2}$, which still excludes half of consumers from the market.

[21] See for instance Ducci and Trebilcock (2019) for a review of the various ways in which the concept of fairness applies to the treatment for firms.

The transport sector is (again) a good example of cases in which temporary changes in market structure designed to diversify the supply of quality can be tested. In the US, multiple transport sandbox experiments covering a wide range of purposes including improvement in access for users with disabilities, reductions in the use of personal cars or reductions in waiting or delay time have been designed and tested.[22] In many of these situations, the market evolved into one in which one supplier focuses on a low quality and another one on high quality service. The core insights observed in the market ex-post could have largely been identified conceptually ex-ante as follows.

4.1 Sandboxes and non-monopolistic market structures when quality matters

To make the modeling as simple as possible, we focus on a market characterized by only two firms and two types of quality while the experiment takes place: "low" quality z_L and "high" quality z_H with $z_L < z_H$. The roles are already assigned, i.e. there is no competition to decide which firm will be *L* and which will be *H*. We also assume that the cost function is the same for both. There are no quality variable costs but the quality fixed cost is an increasing and convex function, $c(z)$.

In this simple market, the firms play a two-stage game. First, they independently and simultaneously choose the levels of z_L and z_H based on their assessment of the market potential for each of the quality levels. Second, knowing the two quality levels, they independently and simultaneously fix the unit prices p_L and p_H. We discard the possibility of one firm excluding the other and the case of Bertrand competition (i.e. $z_L = z_H$) since it would result in $p_H = p_L = 0$, hence the impossibility to cover the fixed costs and would limit the usefulness of the sandbox in a key dimension.

Given a pair of qualities and a pair of prices, we can determine the consumer indifferent between buying quality z_L and quality z_H: $\theta^{LH} = \frac{p_H - p_L}{z_H - z_L}$, and the consumer indifferent between buying quality z_L or buying nothing: $\theta^{0L} = \frac{p_L}{z_L}$. This implies that:

consumers with θ below θ^{0L} buy nothing from these two providers,

consumers with $\theta^{0L} \leq \theta < \theta^{LH}$ buy one unit of product with quality z_L,

consumers with $\theta^{LH} \leq \theta$ buy one unit of product with quality z_H.

This gives an assessment of the relative importance of the potential number of buyers for low and for high quality. It can be compared to the number of buyers for a single quality option provided by the monopoly analyzed in the previous section and hint at an initial observation of some of the equity effects of experimenting with two levels of quality.

In this dual quality world, the profits of the producers are respectively

$$\pi_L(z_L, z_H, p_L, p_H) = \left(\frac{p_H - p_L}{z_H - z_L} - \frac{p_L}{z_L}\right) p_L - c(z_L)$$

$$\pi_H(z_L, z_H, p_L, p_H) = (1 - \frac{p_H - p_L}{z_H - z_L}) p_H - c(z_H)$$

In the price subgame, the *L*'s best response is determined by :

$$0 = \frac{\partial \pi_L}{\partial p_L} = \left(\frac{p_H - p_L}{z_H - z_L} - \frac{p_L}{z_L}\right) - p_L \left(\frac{1}{z_H - z_L} + \frac{1}{z_L}\right)$$

$$= \frac{z_L p_H - z_L p_L - p_L(z_H - z_L)}{(z_H - z_L) z_L} - p_L \frac{z_H}{z_L(z_H - z_L)}$$

[22] For details, see Martin et al. (2023).

Then, recalling that $(z_H - z_L) > 0$,

$$z_L p_H - z_L p_L - p_L(z_H - z_L) - p_L z_H = 0,$$

so that the best response of L is $p_L(p_H) = \frac{p_H}{2}\frac{z_L}{z_H}$

As for firm *H*, $0 = \frac{\partial \pi_H}{\partial p_H} = \left(1 - \frac{p_H - p_L}{z_H - z_L}\right) - \frac{p_H}{z_H - z_L}$, then, $p_H(p_L) = \frac{1}{2}(z_H - z_L + p_L)$

Combining the two best response functions, we obtain the second stage (price) equilibrium:

$$p_H = 2z_H \frac{z_H - z_L}{4z_H - z_L}, \quad p_L = \frac{p_H}{2}\frac{z_L}{z_H} = \frac{z_H - z_L}{4z_H - z_L} z_L.$$

We see that the consumer indifferent between the two qualities is $\theta^{LH} = \frac{p_H - p_L}{z_H - z_L} = \frac{2z_H - z_L}{4z_H - z_L}$.

Then, demands in terms of qualities are

$$q_H(z_H, z_L) = 1 - \frac{2z_H - z_L}{4z_H - z_L} = \frac{2z_H}{4z_H - z_L}, \qquad q_L(z_H, z_L) = \frac{2z_H - z_L}{4z_H - z_L} - \frac{z_H - z_L}{4z_H - z_L} = \frac{z_H}{4z_H - z_L}$$

We derive *H*'s operating revenue $R_H(z_H, z_L) = \frac{4z_H^2(z_H - z_L)}{(4z_H - z_L)^2}$, and its marginal revenue

$$MR_H = \frac{\partial R_H}{\partial z_H} = \frac{4z_H}{(4z_H - z_L)^3}[4z_H^2 - 3z_H z_L + 2z_L^2].$$

By equating MR_H with the marginal cost $c'(z_H)$, we can determine the best response of H to L in the quality space $b_H(z_L)$.[23] Then, combining the latter with the best response of L, $b_L(z_H)$, we derive the unconstrained duopoly equilibrium in qualities (z_L^d, z_H^d) determined by

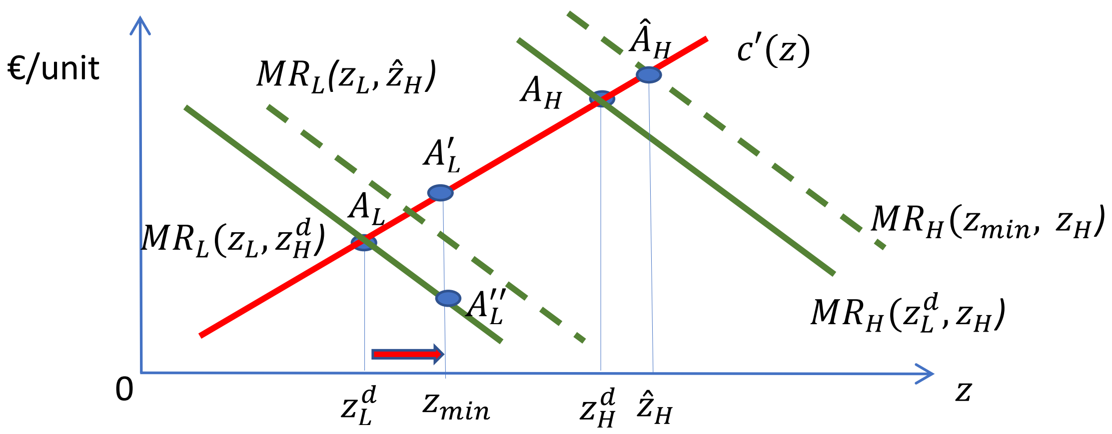
$$z_H^d = b_H(z_L^d), \quad z_L^d = b_L(z_H^d)$$

or, in terms of marginal revenues and marginal costs

$$MR_L(z_L^d, z_H^d) = c'(z_L^d), \quad MR_H(z_L^d, z_H^d) = c'(z_H^d))$$

represented respectively by points A_L and A_H in Figure 3.

Figure 3: Unconstrained and constrained duopoly



Summing up, the modeling shows that there is a clear market for low levels of service quality, an information relevant to any regulation or competition agency assessment and this is something that

[23] Since $\frac{\partial MR_H}{\partial z_H} < 0$ and $c(z_H)$ is convex, there is one single crossing of marginal revenue and marginal cost.

could be validated through a sandbox. But for an agency with a mandate going beyond efficiency, it is also useful to note that the lower quality level may be a better match for the lowest income populations for instance. This is because it is potentially contributing to increase social welfare and reducing the risks of efficiency-equity trade-offs when setting up quality requirements. This is something that, unless thought about ex-ante, will often not be picked up by a sandbox.

More generally, the modeling exercise shows that quality standards, while often necessary, can raise social concerns and not only distributional ones. For instance, the lower quality offered may represent some risk, says to safety or the environment. In that case, a useful second regulatory experiment is to track the changes in the market that would be associated with a MQS since it could have equity effects on both the demand side and the supply side, as well as other concerns that need to be picked up. This is discussed in the next section.

4.2 Testing for the welfare effects of a MQS in a duopoly

So let's look next into the types of insights the sandbox should cover to pick up all of the social welfare effects of a MQS, tagged z_{min}. Assume that the standard is determined exogenously, for example, to address safety or environmental concerns in a situation in which the unconstrained low quality does not meet: $z_L^d < z_{min}$. It is not unreasonable to assume that the standard may not be affordable to some suppliers. It thus is necessary to think through whether a change in standards (or any other type of regulation) may imply that the firm specializing in lower quality may be penalized by the new standard as compared to the other firms.

To track down the effects, we start with a look at what occurs in the constrained equilibrium. This can be done analytically, but Figure 3 may also help get a more concrete visual sense of the impact on both the supply and the demand sides of the market of the adoption of a MQS.

Analytically, when required to fix $z_L \geq z_{min}$, before any adaptation by firm *H* to this new regulation, it is easy to see from the vertical distance between points A_L' and A_L'' that firm *L* is earning less than with quality z_L^d since $c'(z_{min}) > MR_L(z_{min}, z_H^d)$.

From the consumers' viewpoint, the perspective is more positive. Indeed, since we know from our earlier computations that $q_H(z_H, z_L) = 2q_L(z_H, z_L) = \frac{2z_H}{4z_H - z_L}$, the forced increase in z_L to z_{min} observed on the horizontal axis is beneficial to consumers. This can be derived from the fact that $\frac{\partial q_L}{\partial z_L} > 0$, meaning that some low-income become buyers and that $\frac{\partial q_H}{\partial z_L} > 0$, meaning that some medium-income can switch to the high quality.

From a social welfare perspective, however, this is an incomplete diagnostic. Indeed, if the sandbox only focuses on these changes, it misses part of the adjustments that will play out as all the actors react to the initial innovation. Picking up the relevant details demands a closer look at the drivers of the adjustments made by the two firms. And here also, the conceptualisation helps.

The model shows that increasing the quality standard z_L also triggers a change in firm *H*'s choice. Indeed, one can easily compute that $\frac{\partial MR_H}{\partial z_L} > 0$. This effect identified *ex-ante* needs to be tracked down and can be measured as part of any experiment *ex-post*.[24] The reason for this change is difficult to

[24] The actual change will obviously depend on the slopes of the marginal cost and revenue functions. Getting a sense of this sensitivity can also become part of the design of the sandbox and is part of the information set that can be collected ex-post from the experiment.

internalize in a sandbox without an explicit effort to do so. Indeed, it stems from the fact that both firms dislike the narrowing of the gap between z_L and z_H as it pushes them towards a price war.

To limit this *de facto* product homogenization, firm *H* increases its quality level to $\hat{z}_H = b_H(z_{min})$, its best response determined by $MR_H(z_{min}, \hat{z}_H) = c'(\hat{z}_H)$. But, for the very same reason, the low quality firm *L* also gains. Indeed, $\frac{\partial MR_L}{\partial z_H} > 0$ as it picks up some of the consumers unwilling to go for the higher cost high quality. The net effect thus depends on the comparison of the size of the changes in quality decided by the two types of firms.

More concretely, the underestimated insight from an exclusive focus on the direct effect is that the adjustment by the high quality firm *H* makes the adaptation of the low quality firm *L* to the MQS z_{min} less costly by shifting its marginal revenue function up to $MR_L(z_L, \hat{z}_H)$, which partially offsets the consequence of the regulation for firm *L*.

A minimum standard may thus not be as penalizing to the low-cost, low-quality, firms as would seem reasonable to believe at first glance. Indeed, when focusing now on total revenues rather than marginal revenues, since $\frac{\partial R_H}{\partial z_L} < 0$ and $\frac{\partial R_L}{\partial z_H} > 0$, if z_{min} is not too large as compared to the unconstrained value z_L^d, the MQS may end up making firm *L* better off and firm *H* worse off.[25] This paradoxical result reflects the fact that, under a constraining MQS, the quality subgame is no longer simultaneous; it is a sequential game where *L* is the (forced) leader.

From a consumers' viewpoint, the model shows that the drivers of the two key thresholds identified earlier, $\theta^{0L} = \frac{\hat{z}_H - z_{min}}{4\hat{z}_H - z_{min}}$ and $\theta^{LH} = \frac{2\hat{z}_H - z_{min}}{4\hat{z}_H - z_{min}}$ will influence their enthusiasm for the change in regulation to be tested through the sandbox.

The first effect to consider is the magnitude of the reaction of the high-quality firm *H* to the new minimum standard. To see this, we can anticipate from the assumption of convexity of the cost function that $\frac{d\hat{z}_H}{dz_{min}} = b_H'(z_{min}) < 1$. This means that the high-quality firm *H* will not match the full adjustment in quality associated with the adoption of the minimum standard when deciding its own improvement in quality. This implies that the two thresholds are decreasing in z_{min}.

Without the type of ex-ante modeling suggested here to prepare the sandboxes, the competition or regulatory agency may miss or underestimate the somewhat counterintuitive effect of the change in regulation. Increasing the MQS may not have the negative social effect sometimes blamed on a strengthening of standards, in particular in the context of environmental policies for instance.

The model suggests that it could indeed lead to an increase in the share of the population being able to consume because of the prices' adjustment that may be ignored in a sandbox focusing only on the effects of a change in standard on the type *L* firms and on their clients. The positive effect is the consequence of the fiercer competition between the two firms as the differentiation gap $z_H - z_L$ is narrowing. Additionally, the consumers who were served before regulation, now receive a higher quality. This can only be picked up by an effort to cover the full market in the design of the sandbox or through a simple model as the one suggested here.

From a policy perspective, the main insight is that the MQS can be designed to improve welfare if it allows the increased competition effect resulting from the higher quality standard to play out. The corollary is that relaxing a MQS in a sandbox would be socially counterproductive … except if the

[25] See the proof in Ronnen (1991) and Crampes and Hollander (1995).

objective is to attract a challenger to reduce the market power of a monopoly and the entry cannot be beneficial without some regulatory help, for example because $c(z_{min})$ is too high.

The main general lesson of this modeling exercise is thus that the design of the sandbox to be relied on to assess the desirability of an MQS or its relaxing needs to internalize a diversity of sensitivities too often underestimated in basic experiment designs. This has to be done to inform the regulators as to whether it will influence social desirability of the innovation tested. This, in turn, requires tracking the winners and the losers quite systematically. At least four stakeholders are involved: high-income and low-income consumers, the high quality and the low-quality producers. The payoffs to each group need to be picked up as well. A sandbox should be able to identify the key drivers of the thresholds for each group and this can then also help identify the MQS that is socially profitable. But a sandbox may not be able to cover all consequences as discussed next.

5. Switching from a micro to a macro view of the impact of sandboxes

We know, from the former sections, that there is a case for the design of sandboxes to rely on longer checklists of impacts than often observed in documented case studies. This is simply because consumers and firms are heterogeneous and not all are impacted in a similar way by the innovations to be tested through sandboxes. This longer list thus needs to account for equity and distributional issues as well as efficiency issues. But this may not be enough to deliver a full evaluation. Indeed, they may actually underestimate the extent of the challenges associated with the identification of other stakeholders impacted indirectly by the innovations being considered. [26]

To see this, let's focus on the potential spillovers to other industries or other segments of the economy (G) that may have to enter the checklist. A simple way of formalizing this is to start with an expansion of the social welfare function W as follows:

$$W = NS + \pi + G$$

Let Φ denote the feasible set defined by the parameters under the regulator's control. We are interested in what happens to $\frac{\Delta G}{\Delta \Phi}$, in particular to the sign of the change.[27] To be able to track the effects, it is useful again to go through a formalization of the underlying incentive issues in a simple way as follows.

Consider that the value of spillovers is a function $G(\boldsymbol{x})$ of the vector of performances $\boldsymbol{x} = (x_{\boldsymbol{1}}, \ldots, x_{\boldsymbol{j}}, \ldots, x_{\boldsymbol{n}})$ such as employment $(\frac{\Delta G(\boldsymbol{x})}{\Delta x_{\boldsymbol{j}}} > 0)$ or imports $(\frac{\Delta G(\boldsymbol{x})}{\Delta x_{\boldsymbol{j}}} < 0)$. Given the limited competencies of regulatory or competition agencies, these effects will normally not be considered in the sandboxing decision. For example, if the innovation proposed by the monopoly in section 3 necessitates an increase in imports $(\frac{\Delta x_{\boldsymbol{j}}}{\Delta \Phi} > 0)$ from countries using polluting technologies $(\frac{\Delta G(\boldsymbol{x})}{\Delta x_{\boldsymbol{j}}} < 0)$, including $\frac{\Delta G(\boldsymbol{x})}{\Delta x_{\boldsymbol{j}}} \frac{\Delta x_{\boldsymbol{j}}}{\Delta \Phi} < 0$ in the evaluation of the innovation profitability could overturn the decision.

To make the discussion quite concrete, think of the assessment of an innovation tested in the context of a new industrial policy. This is an increasingly common situation in OECD countries. Indeed, since the succession of global economic and political crises that started in 2008, many countries are developing new industrial policies to increase their autonomy in key sectors ranging from

[26] This is equivalent to the macro perspective taken on optimal regulation, including through sandboxes, by Acemoglu and Lensman (2023) in their assessment of the impact of changes such as the adoption of Artificial Intelligence through a multi-sector technology adoption model.

[27] Note that by the 'Le Chatelier principle', any derogation to the current rules imposed to the regulated firms enlarges their feasible set, so that $\frac{\Delta \pi}{\Delta \Phi} \geq 0$.

pharmaceutical products to the production of electric cars. In many cases, these policies imply changes in the trade volume and trading partners of the country considering the innovation. How well are these concerns addressed in the evaluation of sandboxes designed to test the ability of countries to innovate in specific activities? Often, these more macroeconomic dimensions will not be addressed by sector regulators and only marginally, if at all, by competition agencies.

Yet, once the sandbox has validated the innovation and the exceptions they tested become the new rule, these effects are likely to be significant. In the case of pharmaceutical products, the industrial policy could reduce imports and potentially increase exports. This could be good news. In the case of electric cars, it could lead to a greater dependence on producers of batteries or at least producers of lithium, like it has been the case with photovoltaic panels. This leads to other types of concerns that may not have been picked up in the design of the sandbox. More generally, changes in trade volume, patterns and partners or changes in employment levels or skill need to be accounted for but they may be difficult to assess through the sandbox. This is because at the scale of experiment conducted through a sandbox, these types of impacts may be initially too small to be picked up by the sandbox evaluation.

The point is that these "macro" changes will eventually matter and should be accounted for in the evaluation of the scope to scale up the innovation. Even if they can be picked up as part of the checklist prepared at the design stage, sandboxes will generally only have a limited ability to inform on their size or on the resource needs they imply at an aggregate level. In the context of the energy transition or in the case of the desire to rely more on Artificial Intelligence, the sorts of spillovers effects that would have to be considered will have to be estimated in other ways. Similarly, in experiments testing new pricing techniques aiming at improving demand management or social targeting, for instance in the case of utilities, ignoring the impact this can have on the financial and environmental viability of the suppliers may not be easy to pick up as part of a sandbox but is a necessary component of any evaluation of the change being considered.

In sum, sandboxes can guide many decisions on policy, process, regulatory or technology changes, but they should only be considered as one of the dimensions of an evaluation of these decisions. This is particularly valid when the mainstreaming of the innovation tested through the sandbox is likely to have multiple spillover effects outside of the sector.

6. When governance issues go beyond information gaps

Since sandboxes alter the usual mandate of regulators, it is useful to briefly discuss how their effectiveness can be influenced by specificities of regulatory governance and, in particular, some key characteristics of the regulators defined broadly to cover all agencies involved in the use of sandboxes. We have already established that regulators may not be omniscient and need to take many of their decisions on the design of sandboxes with imperfect information on the key dimensions they need to focus on. But the challenge may be further fueled by the fact that regulators may not always be as omnipotent nor omnibenevolent as assumed in the models discussed earlier and that these governance weaknesses can themselves bias the design and hence the outcomes of sandboxes. These weaknesses should lead to comparisons with other instruments when trying to stimulate innovation experiments and to the recognition that, when sandboxes are a realistic option, differences in governance contexts may imply that the testing of the same novelty is best tailored to each context as discussed next.

6.1 On non-benevolence

Considering the recurring nature of controversies surrounding the benevolence of the State, it seems reasonable to assess the extent to which it matters to the decision to bet on regulatory sandboxes. In a nutshell, it matters because, depending on whether one sees the regulators as benevolent or not, sandboxes will represent a risk or an asset. The *public choice theory* and the *public interest theory*, maybe the two main schools of thoughts on the benevolence of the State and hence on the reliability of regulators, are likely to reach opposite views on the desirability of sandboxes.

In the "*public choice theory*" view of the world, originally developed by Buchanan and Tullock (1962), sandboxes could be seen as a desirable tool. If indeed regulation is inefficient, as that school of thought argues, it is because it eventually erects entry barriers to the benefit of incumbents and/or public decision makers.[28] Any limitation to regulation that increases the transparency should thus be good news. Sandboxes can moderate what is perceived to be the excessively discretionary and opaque power of regulators, notably due to the detailed monitoring of all stakeholders during the innovation testing phase. In line with this theory, sandboxes should be encouraged, notably in countries or in sectors with significant governance and corruption problems. They could provide an opportunity to deliver in the interest of all groups in society precisely because the transparency their permanent evaluation imposes reduces also the risks of inequitable regulatory capture.

In the "*public interest theory*", in contrast, sandboxes are likely to be less attractive because they could imply a reduction in the ability of regulators to fine-tune as needed with enough flexibility and discretionary power. State officials, including regulators, are indeed assumed to be largely benevolent and competent. In this alternative vision of the role of the state, sandboxes will need to be tightly controlled to ensure that they do not excessively interfere with a regulation otherwise well designed to protect all stakeholders. The concern is more likely to be with situations in which sandboxes relax regulation allowing non-compliant products or services to compete unfairly and harm some consumers more than others.

In practice, the experience shows that there is some truth to both schools of thoughts. Corruption, limited competence and various forms of governance weaknesses are a fact of life globally and there is no single way to deal with them in the context of regulation.[29] In some cases, the hands-off mainstream regulation will be the desirable option. In many others, however, sandboxes will provide a safe hands-on solution, in particular if they can be used *ex-ante* to increase the transparency of the possible outcomes of new regulatory decisions in contexts in which there is a need to improve accountability for these decisions. Sandboxes may thus help limit, or at least control, non-benevolence and do so more or less easily according to culture, sector or legal biases in which regulation is being framed. And this, in turn, is linked to the degree of omnipotence of a government as discussed next.

6.2 On omnipotence

In all democracies, the government has limited powers. This is even truer of sectoral regulatory agencies. They were created to enforce legal rules and not entitled to modify them, although they can be granted some degree of autonomy to deal with information gaps or random shocks. This is intended to reassure consumers, operators, investors and taxpayers that they can be protected from arbitrary adjustments to prevailing rules. The need to maintain this protection explains why deciding to rely on a sandbox needs to be associated with transparent evaluation processes and tight controls over the limited additional leverage allowed to the regulators and innovators through the sandboxes.

For example, in France, the article of the "Energy-Climate Law" of November 8th, 2019 (art. 61) introducing a regulatory sandbox in the energy sector is quite precise on the margin allowed by the

[28] For an illustration, see the analysis of the regulation of entry of start-up firms in 85 countries by Djankov et al. (2002).

[29] For a discussion of the various ways in which corruption can impact social concerns in regulatory design, see chapter 14 in Auriol et al. (2021).

sandbox and its limitations:[30] "... *the Energy Regulatory Commission may … grant exemptions to the conditions of access to and use of networks and facilities for the experimental deployment of innovative technologies or services in favor of energy transition and smart grids and infrastructures."* Derogations are granted for a maximum period of four years, renewable once at most for the same period and under the same conditions as the derogation initially granted.[31] And the government retains a veto power since "*Within two months of the notification of the derogation request, the Minister responsible for energy and, where appropriate, the Minister responsible for consumer affairs may object to the granting of all or part of these derogations. The Energy Regulatory Commission may not grant such derogations until this period has expired*."

The same article of Law stipulates that the administrative authority may also grant derogations. This may require the sector regulator to negotiate the limits of its areas of competence. The French Conseil d'Etat (2019), the highest administrative court, considers that experimental regulations often lack rigor. Citizens run the risk of not knowing which rules apply and who is in charge of what.[32]

With the benefit of the details available on multiple case studies, there is solid evidence that the optimal design of sandboxes will vary across countries and across sectors and they do so for reasons similar to those that explain the differences in benevolence. France did it its way as do any of the countries adopting sandboxes. Context matters as different countries, even different sectors within countries and sometimes different states or regions within countries, may have very different preferences for the limits on regulators' omnipotence.[33]

These differences to be accounted for in the design of sandboxes may simply reflect very differences in technical and resources capacity or simply different ideological preferences within or across countries. Any of these differences in preferences may influence the balance of the efficiency-equity trade-offs as much as the differences in the degree of omniscience that characterizes the regulators of the sector discussed earlier in the paper. But they are not the only one since other types of information gaps may have distributional consequences as well as discussed next.

6.3 A last word on omniscience

Information gaps will not only impact today's society but also future generations. A fair treatment of this concern would require a dynamic version of the type of models discussed so far. This is needed to be able to minimize both the static and dynamic risks associated with this "ignorance" on some of the longer term changes that will result from an experiment conducted through a sandbox. Being too lax on the margin given to the innovators' experiments runs the risk of allowing dangerous or undemocratic technologies to develop. This is part of the debate in the context of betting on sandboxes to design the optimal type of regulation to apply to Artificial Intelligence (AI) applications for instance.[34] But it is not the only one.

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[30] Since 2003, the French Constitution stipulates that laws and regulations may contain provisions of an experimental nature for a limited purpose and duration (art. 37.1).

[31] For instructions (in French) on how to apply, see Regulatory Sandbox - CRE. The Ofgem's version is available at https://www.ofgem.gov.uk/sites/default/files/docs/2020/07/sandbox_guidance_notes.pdf.

[32] On "*the risk of loss of accountability and that of institutional conflicts and lack of policy coordination*", see Tirole (2023). On the institutional problems associated with the assignment of mandates across agencies see also CEER (2022) p. 14.

[33] Think of the differences in reaction speed in the recent energy crisis linked to the Russian invasion of Ukraine. Different cultural, legal and political contexts influenced the degree of risk aversion with respect to innovation in regulation, pricing and subsidies across countries.

[34] See again Acemoglu and Lensman (2023) for a much more detailed discussion.

AI is indeed evolving fast with regulator running behind the innovators rather than learning them as sandboxes would allow them to do. Many of the wide range of technical innovations that allows AI to transform the economies were not anticipated under the existing legal and regulatory frameworks. Now regulators are trying to adjust knowing that they are still likely to run behind for a while. In that race, sandboxes can be helpful to catch up some of the lags, even if not all of them.[35] But not trying in combination with other forms of regulatory experiments would be a mistake. The risk is that the steady flow of changes offered to many of the users of regulated industries is increasingly associated with a growing social risk of inequitable digital gaps as already mentioned. The efforts of the European authorities, for instance, to keep control of these developments by binding experiments to harmonized sandbox rules are thus necessary.[36]

From a very pragmatic viewpoint, this uncertainty surrounding the diversity of effects of some dramatic innovations reinforces the case made here to consider ex-ante the careful modeling of risks to be monitored through sandboxes. Once the insight from the modeling has been internalized, it also makes the case to give some margin to regulators to update the experiments to internalize the information produced by sandboxes early and to eventually fine tune the experiments to improve the potential regulatory intervention as needed.[37]

7. Concluding comments

There are many recent assessments of the costs and benefits of sandboxes (see for instance Attrey et al. (2020), European Council (2020), IDB (2020), Knight and Mitchell (2020) or World Bank (2020)). They generally provide a balanced view of both the potential and the limitations that characterize sandboxes. But they are mostly based on case studies rather than on detailed formal analysis of the costs and benefits they are associated with. They focus on sets of indicators identified by the designers to document specific outcomes linked to the innovation being tested. This focused, and often narrow approach, may explain why they may be underestimating some recurring gaps in the design of sandboxes.

Maybe the most important recurring gap in the reported coverage of case studies is the underestimation of a diversity of distributional or equity issues that can arise in the efforts to focus the assessments on their efficiency payoffs. Somewhat oddly, this concern for equity has been a recurring theme in the recent competition literature rather than in the regulatory literature reviewing the sandbox experiences. Yet this literature does not usually go into details on the type of distributional and equity issues illustrated in this paper. Nor do most of the case studies.

To some extent, possibly to a large one, this may be the consequence of a mismatch between the mandate assigned to agencies assessing the case to support or reject innovations requests and those assigned to the teams designing, preparing and implementing the sandboxes. In the context of sector regulation, the mandates of the core sandbox teams tend to be quite focused on efficiency while those assigned to regulators tend to also cover equity and financial/fiscal viability concerns (e.g. Auriol et al. (2021)).

To some extent, the overwhelming focus on efficiency observed in evaluations may be linked to the fact that sandboxes are often seen as distorting competition, even if only temporarily. This risk is

[35] The uncertainty with respect to the negative long run effects of AI in society is one of the main reasons why sandboxes are being advocated in this sector. The narrative has tended to highlight the positive payoffs, but recent issues raised by applications such as ChatGPT have raised concerns which could be assessed, at least partially, through a sandbox approach.

[36] European Parliament (2022); see also Ranchordas (2021).

[37] This ability to adjust sandboxes as information is acquired boils down to considering opting for the equivalent of Bayesian designs of sandboxes.

something that anti-trust/competition agencies tend to focus traditionally, and this may have influenced the focus of regulators in their evaluation of sandboxes, somehow omitting to include the social dimensions.

This bias is likely to change for two main reasons. First, in a growing number of countries, competition agencies are increasingly being explicitly concerned with distributional issues in addition to their concerns for general consumer welfare. This agenda change is currently being debated in Australia, Europe and the US as discussed earlier notably through the voice of Khan and Vaheesan (2017) and Vestager (2018). The idea that competition and anti-trust policy is also about fairness in treatment of all stakeholders and the associated social and equity concerns has become a real topic in many policy circles, but it is not settled yet.[38] Second, the return of industrial policy to the agenda of many governments is linking innovations to social concerns quite explicitly.[39] This should convince all policymakers that sandboxes should consider both the impact of innovations on the growth prospects of an economy and the social impacts associated with the transition to the new world industrial policy is expected to lead to.

Whether the mandates of competition will be expanded to cover social or equity goals and whether regulators will be able to comply with their broader mandates in the context of sandboxes is still uncertain. However, what is certain based on the diagnostic conducted in this paper is that the checklists that the current limited mandates lead to are, and will continue to be, incomplete as long as they do not fully address some of the social and equity issues raised here.

Once a decision is taken to broaden the coverage of outcomes estimated through sandboxes, the sort of modeling illustrated in this paper should become part of the upfront agenda of teams preparing their design. Regulators will never really be omniscient as theory often assumes, but the suggestions made here may reduce the information gaps regulators suffer from in their evaluation of the effects of a wide range of potential innovations. In many cases however, when "macroeconomic spillovers" of the innovations being tested are unlikely to be tracked through the sandboxes, the case for alternative or at least complementing evaluation methods should not be underestimated.

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[38] See Alaassar et al. (2020) for the relevance of consultations with all stakeholders in the preparation of sandboxes.

[39] For a detailed discussion of the complementarity of the social and efficiency effects of industrial policy, see Estache and Foucart (2021).

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