The Economics of Transferable Patent Extensions*

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Abstract

Faced with a scarcity of treatments for neglected diseases, experts and governmental organizations have lately proposed to build strong pull incentives around transferable vouchers. Inventors would be granted, and allowed to sell these vouchers to pharmas desiring to extend their exclusive IP rights. However, we know little about how such "Transferable Exclusivity Extensions" fare relative to prizes, who is likely to acquire them and at what cost for society, or how the burden is shared among nations. We shed light on these questions, both from a theoretical perspective and from an empirical analysis of European data.

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1 Introduction

The standard incentive scheme to foster innovation is intellectual property protection (IPP). Patents, trade secrets and copyrights confer monopoly power over a fixed duration, during which the innovator can recoup their investment. IPP however may not ensure the existence of a "business model". Small numbers (orphan diseases), limited ability to pay (drugs for LDCs), and externalities (antibiotics, vaccines) create a significant wedge between the social and private values of the innovation and motivate a different approach. For centuries, this alternative approach has been the granting of cash prizes, or in their modern form advanced market commitments (Kremer, 1998; Berndt et al., 2007; Kremer and Williams, 2010; Kremer et al., 2020).

While reinforced pull mechanisms usually take the form of prizes,[1] it has lately been proposed that inventors of new antibiotics[2] be rewarded with an original currency: transferable exclusivity extensions (TEEs) or "vouchers". The inventor would be given a patent extension right of a given duration, and this right could either be used by the inventor themselves or, more likely, be sold by the inventor to an entity with an existing IP right, that would then enjoy the extra period of exclusivity after the normal expiration date. Although a TEE pull mechanism has yet to be implemented, an early draft of the bipartisan 2018 US REVAMP Act[3] planned for transferable exclusivity vouchers for drugs designated as priority antimicrobial products (Rome and Kesselheim, 2020; Boyer et al., 2022), while a voucher system, similarly designed to support antimicrobial innovation, is currently under consideration in Europe (Årdal et al., 2020). Besides, "priority review vouchers", which were inspired by academic work, have been used in the US since 2007. While they differ economically from TEEs, they share their spirit of rewarding innovation through tradable vouchers.

At first sight, vouchers, which prolong monopoly distortions, would seem to be dominated by prizes, which do not. This reasoning however ignores two considerations. First, cash transfers must be financed from the general revenue, engendering a shadow cost of taxation. Second, and the novelty of this paper, the benefits of prizes are often overestimated, at least in the absence of a tight intervention into the production and delivery process. The generics experience demonstrates that when the knowledge underlying the branded drug falls into the public domain, prices remain far from competitive for multiple reasons: single supplier of generics or multiple colluding ones, consumer attachment to the branded prod-

[1] Together with extended patent lengths and expedited approval processes.

[2] The funding issue is prominent in the case of antibiotics, for which the dearth in the new-antibiotics pipeline raises concerns about impending bacteriological pandemics. The current push and pull mechanisms seem to provide low incentives for innovation in the domain. And there is widespread agreement on the stewardship-based need for delinking rewards from sales.

[3] Re-Valuing Anti-Microbial Products Act (HR6294).

uct, existing regulation.[4] Imperfect generics competition is of particular interest here, as it implies that ending the exclusivity of the branded drug operates a transfer away from the originator,[5] that is detrimental to the incentive to innovate without any corresponding benefit for the consumer. A striking conclusion of our empirical work is that an incentive reward of \$1 through a European voucher system costs less to the consumer/taxpayer than \$1 (and a fortiori less than the cost of a cash award of \$1) in most of the fifteen countries in our data set.

Let us clarify right away what this paper does and does not do. To this purpose, recall the innovation dilemma, that of rewarding inventors in proportion with their contribution to society while preserving public funds and consumers' access to innovation. This paper is not concerned with the incentive side and simply presumes that society has determined some level of reward for the innovation. Rather, this paper focuses on the second issue, the structure of the reward. Whether the reward is appropriate for the innovation is irrelevant for the structure study; for, the cost of providing the reward must be minimized whether the reward is well-picked or off-the-mark.

The contribution of this paper is theoretical and empirical.

Theory. On the theoretical side, this paper offers a model of the costs and benefits associated with a TEE scheme. Assuming that branded molecules are regulated (with an intensity of regulation that depends on the regulator's bargaining power), we compute a cost-over-reward ratio, which captures for each \$1 of additional benefit to the inventor awarded a TEE, how many \$-worth in social surplus are lost for society. If this cost-over-reward ratio is higher than $1 + \lambda$, with $\lambda \geq 0$ the cost of public funds,[6] then a TEE scheme is dominated by an equal-value prize to the inventor. In fact, while to the best of our knowledge, existing analyses of TEEs mainly focus on the length of the exclusivity extension, the relevant measure for a comparison of TEEs with alternative incentive schemes really is the cost-over-reward ratio. Furthermore, we show that the length of the exclusivity extension does not affect the cost-over-reward ratio of a TEE scheme, and is thus irrelevant for its comparison with direct payments to the inventor.[7]

Exclusivity extensions generate a loss of social surplus as they induce higher prices. Yet,

[4] For example, the French regulation secures a price of generics in the year after the exclusivity loss equal to 60% of that of the original brand. Needless to say, French generics prices largely exceed the (often very small) marginal cost.

[5] As we later show, this transfer may or may not have a counterpart in generics' profit, as this profit might be competed away through free entry in the generics market. The important point, though, is that whether generic prices translate into supranormal profits or the dissipation thereof, the opening to competition sacrifices some of the ex-ante incentives for R&D without any benefit for the consumer.

[6] We assume that the planner does not internalize the profits of the developer of the new antibiotic.

[7] Of course, the tailoring of the additional exclusivity length remains necessary to adjust the level of the reward, but such tailoring cannot provide *per se* any argument in favor or against TEEs as opposed to direct payments. We discuss in Section 2.3.2 how the length of a TEE could be optimally adjusted to deliver the appropriate reward.

in addition to their consumption-distorting impact, we highlight a *redistributive* impact of exclusivity extensions, from generics to the original branded drug company, whenever the generics market is not perfectly competitive. Which of these two effects dominates determines whether the cost-over-reward ratio of a TEE (in a single country) is higher (as is the case when generics are sold at marginal cost) or lower than 1.

Coalitions of countries are in general needed to compensate for the lack of business model. Within a union (such as the United States or Europe), decisions are made through majority, supermajority, or even unanimity voting, and to the extent that members can stay out of the financing, cash funding is ripe with free riding. Indeed, the difficulty in reaching a political agreement on a cash transfer was one of the key motivations behind the current European push for an antibiotics voucher scheme. The European Medicines Agency can delay granting licenses to new generics for the molecule that has purchased the voucher, for a time period equal to the length of the voucher, de facto enforcing the IP rights associated with the voucher and making it easier to raise the funds.

It is therefore important to compute the impact of a cash transfer or a voucher scheme on the various polities. This requires making some assumptions on how cash is levied in the case of a prize (for Europe we assume that contributions to the European budget are proportional to country income). A country tends to prefer a TEE scheme over a cash transfer scheme if its generics prices are high and the market share of generics low (such a country suffers less from a TEE); if its cost of public funds is high (such a country finds cash transfers more costly); and if the drug with extended exclusivity has a relatively small (per inhabitant) market in the country (say, an anti-cholesterol treatment faces less demand in Greece than in Finland).

We conclude the theoretical part with two observations. First, we endogenize the number of generics entrants and the price of generics. We assume that a fraction of consumers are loyal to the originator, while the complementary fraction are fine with generics. Furthermore generics can collude on a limit price such that the originator is willing to focus on loyal customers. Ending the exclusivity of the branded drug operates a transfer away from the originator, and the concomitant rent may be enjoyed by generics producers or dissipated through the entry mechanism.

Second, a pre-specified duration (say, a year) for a voucher creates uncertainty about the exact reward accruing to the antibiotic developer, as well as the overall costs incurred by patients and taxpayers, which raises concerns. The uncertainty can be eliminated by letting the voucher's potential buyers bid in terms of extension length. Namely, fix an arbitrary $ reward for the antibiotic developer. And let the buyers announce the minimum length for the voucher that makes them willing to pay this amount of money for the right to extend

their patent by this length. The winner of the voucher auction is the buyer who specifies the lowest length.

Empirics. On the empirical side, to the best of our knowledge, our paper is the first to provide an estimation of the costs and benefits associated with a TEE scheme. We use a rich dataset containing all drugs sold in 15 European countries, including the main European economies, over the period 2002-2012 (see Section 3). We calibrate our model based on this data, providing estimates of demand and market parameters, as well as the values and potential acquirers of one-year vouchers during the period 2002-2012. Crucially, we provide estimates of the cost-over-reward ratios of TEEs in each country, as well as in a (fictitious) union composed of the 15 countries in our data. Relying on estimates from the literature for marginal cost of public funds, we are able to give a first approximation of who in such a union would favor a union-wide TEE, and who would oppose it. According to our model and our data, and subject to the (important) caveats we discuss along the exposition, among the 15 countries in our union, all but two would quite unambiguously prefer a TEE scheme to a direct payment to the antibiotic inventor. By contrast, the two remaining countries, namely Sweden and Finland, would be either close to indifference (Sweden) or quite unambiguously against (Finland) a TEE scheme relative to a direct payment. This result fits our model's predictions, for Sweden and Finland have low marginal costs of public funds and highly competitive generics markets, and thus for whom exclusivity extensions entail high social costs.

Related literature. The literature on transferable exclusivity extensions is still nascent.[8] Rome and Kesselheim (2020) provide an estimation based on US data (2007-2019) of the costs associated with one-year exclusivity extension for fast-track drugs. From a theoretical perspective, their analysis is limited to financial costs and does not consider user welfare. Moreover, while the length of exclusivity extension they consider is motivated by the proposed 2018 REVAMP Act, it could (in theory and possibly in practice) be adjusted to match the amount needed. Hence their analysis falls short of providing a comparison with alternative funding schemes. Relatedly and in the same fashion, a prior literature investigated the costs and benefits from the US FDA Pediatric Exclusivity Extension (started in 1997), which gave pharmaceutical manufacturers 6 additional months of market exclusivity for performing pediatric clinical trials of brand-name drugs widely used in adults.[9] Sinha et al. (2018) thus find that "the costs to consumers have been high, exceeding the estimated costs of investment for conducting the trials", but it is again not clear whether an adjusted (shorter) exclusivity

[8] See Lakdawalla (2018) for a thorough review of the literature on the economics of the pharmaceutical industry.

[9] The extension was earned if trials were completed, regardless of whether the drug was found to be safe or efficacious in pediatric populations.

length would have made the exclusivity extensions more efficient than alternative funding schemes. Moreover, the Pediatric Exclusivity Extension featured no voucher market.

Outterson and McDonnell (2016) and Boyer et al. (2022) provide careful discussions of how TEE schemes should be tailored, emphasizing that the length of the exclusivity extension be adapted to the investment need of antibiotic development, as well as what curtains should be set to prevent market abuse – e.g. sufficient advance notice of the exclusivity extension to generic manufacturers. However their discussions remain mostly informal and only consider US patients and markets. Imperfect tailoring and regulation of TEEs may significantly reduce their desirability. Yet, Outterson and McDonnell (2016) and Boyer et al. (2022) point out that TEEs may be easier to implement, albeit imperfectly, than alternative incentive schemes, such as direct cash transfers, due to budgetary rules and political constraints.

Lastly, another literature, pioneered by Ridley et al. (2006), investigates transferable "priority review vouchers". Gans and Ridley (2013) notably provides a rich analysis of the value of such vouchers depending on their tradability and on the characteristics of medical R&D. Our paper differs from this literature on methodological grounds by providing closed-form formulas to compare vouchers with alternative funding schemes (see in Appendix A how our approach could help derive such formulas in the case of transferable priority review vouchers). On a more conceptual level, while the "transferability" of such vouchers is akin to ours, the impacts and trade-offs involved by priority review vouchers on the one hand, and transferable patent extensions on the other hand differ significantly. We provide in Appendix A an illustration: The cost-over-reward ratio of transferable priority review vouchers decreases with the degree of competition in the generics market, whereas the cost-over-reward ratio of TEEs increases with it.

The paper is organized as follows. Section 2 offers a theoretical study of the costs and benefits associated with TEEs, and compares them with those of a direct payment to the inventor, both in the case of a single country and for a union with national pricing regulations. Section 3 develops an empirical analysis on European data, calibrating our model and discussing the likely empirical values of the costs and benefits of a TEE scheme among the 15 European countries in our data, ultimately identifying who in the union would favor, resp. oppose a TEE scheme over a direct payment to the inventor. Section 4 concludes.

2 The Social Costs and Benefits of a Voucher

In theory, the acquirer of the voucher is the pharmaceutical company with the highest benefit from an extension among the various molecules in its patent portfolio. Let us start

with some simple observations. An IP owner's monetary value Υ of an extension Δ of the protection length of a patent due to expire at horizon T is equal to:

$$\Upsilon = (\pi_E - \pi_{NE}) \int_T^{T+\Delta} e^{-r\tau} d\tau$$

where π_E is the profit during the exclusivity period, π_{NE} the profit when exclusivity is lost (the molecule is off-patent), r is the rate of interest and T is the remaining length of time until the patent expires in the absence of a voucher.

Observation 1. *The voucher is more valuable to its acquirer the longer the exclusivity extension (Δ), but also*

- *the shorter the remaining time (T) before the patent expires,*
- *the most profitable the patent (the higher π_E is),*
- *the less profitable the molecule once it is off-patent (the lower π_{NE} is), that is the higher the market share of generics, or the lower the consumers' perception of differentiation between the original branded drug and generics.*

Extending the reasoning, the voucher is particularly valuable for a patent about to expire when a generic company has already invested in a facility and is therefore in the starting blocks to compete with the incumbent. This temporary stranding of the generic, which must incur maintenance costs during the exclusivity extension or even renew its entry investment, is *per se* socially wasteful. We abstract away from such a case in the following, assuming that sufficient prior notice of the identity of the acquirer of the exclusivity extension is given to generics companies.

2.1 Baseline Model: The Case of a Single Country

Let us assume in a first stage that buyers have no market power in the market for the voucher, that is, the winner of the auction pays her willingness to pay for the patent extension. [We discuss market power in Section 2.3.2.]

The cost of the voucher policy is measured by the loss in social welfare for a given reward level. This loss is, for the molecule that will benefit at horizon T from the patent extension:

$$L \equiv (S_{NE} - S_E) \int_T^{T+\Delta} e^{-r\tau} d\tau,$$

where S_R is the consumer net surplus in regime $R \in \{E, NE\}$.

Therefore, $L = \rho\Upsilon$ where the cost-over-reward ratio ρ is given by:

$$\rho = \frac{S_{NE} - S_E}{\pi_E - \pi_{NE}}.$$

We compute consumer surplus for a given price p as $S(p) = \int_p^\infty q(\tilde{p})d\tilde{p}$.

Our flexible parameterization for demand is inspired from Weyl and Tirole (2012). Namely, the demand for the drug that will benefit from the TEE is given by: for any $p \leq m$,

$$q(p) = \sigma \frac{k+1}{m}\left(1 - \frac{p}{m}\right)^k,$$

where $\sigma(k+1)/m$ is market size, i.e. the size of the population of individuals who potentially benefit from the drug, m a measure of quality (m is the highest WTP in the population), and $k \geq 0$ a parameter governing the curvature of demand. Our normalization ensures that as k varies, total consumer surplus at price 0 remains constant,[10] equal to σ.

The pharmaceutical company that buys the exclusivity extension faces a constant marginal cost of production, denoted by $c \geq 0$ ($c \leq m$ to ensure there is a market for the drug), for the drug to which it applies the exclusivity extension. We assume that this cost does not depend on the drug being on- or off-patent. Generics face the same constant marginal cost of production c.

Hence, for a given price p and under exclusivity, profit is given by:

$$\pi_E(p) \equiv \sigma \frac{k+1}{m}(p-c)\left(1 - \frac{p}{m}\right)^k.$$

(Exclusivity) profit is locally concave whenever $p < [2m + (k-1)c]/(k+1)$, which holds in particular for any price p below the monopoly price $(m + kc)/(k+1)$.

Consumer surplus is given by

$$S(p) \equiv \int_p^m \sigma \frac{k+1}{m}\left(1 - \frac{\tilde{p}}{m}\right)^k d\tilde{p} = \sigma\left(1 - \frac{p}{m}\right)^{k+1}.$$

The elasticity of demand at a given price p, $kp/(m-p)$ increases with p, decreases with m and increases with k (i.e. decreases the more concave the demand).

Generics partially take over at the end of the exclusivity period. We denote by $p_g \geq c$ the generics' price. If the generics market is perfectly competitive, $p_g = c$. In practice however,

[10] This normalization as well as market size are irrelevant for the exclusivity price and the cost-over-reward ratio. The parameter k must be weakly below 1 for demand to be globally concave. A lower k implies a more concave demand: the lower k, the larger the share of the population for whom the drug benefits are high/the larger the share of patients who have a high WTP for the drug. In the limit for $k = 0$, all patients have the same WTP equal to m.

the generics' price p_g may be strictly higher than the marginal cost c due to either regulation guaranteeing a high price to generics,[11] or imperfect competition (see Section 2.3.1).

Generics meet the demand of a fraction $(1-x)$ of consumers, with $x \in [0,1)$, while the complementary fraction x of consumers remains captive of the original branded drug company (e.g. it does not trust the generics). As a consequence, $\pi_{NE} = x\pi_E$ and denoting by p the exclusivity price, $L = (1-x)[S(p_g) - S(p)] \int_T^{T+\Delta} e^{-r\tau} d\tau$, and thus $\rho = [S(p_g) - S(p)]/\pi_E$, which does not depend on x, the share of captive consumers.

We assume that the regulator and the pharmaceutical company (Nash) bargain on the price of the original branded drug p^* under exclusivity and after exclusivity loss – they do not bargain on the length of the (initial) exclusivity period which is fixed by intellectual property law.Letting α denote the regulator's bargaining power, the (Nash-bargained) under-exclusivity and post-exclusivity-loss prices maximize:

$$\left[(p-c)\left(1-\frac{p}{m}\right)^k\right]^{1-\alpha}\left[\left(1-\frac{p}{m}\right)^{k+1}\right]^{\alpha}.$$

The (Nash-bargained) regulated price p^* for the original branded drug is thus the same under exclusivity and after exclusivity loss, and is given by

$$\frac{p^*}{m} = \frac{1-\alpha}{k+1} + \frac{k+\alpha}{k+1}\frac{c}{m}.$$

We assume that the generics' price is below the original branded drug price: $p_g \leq p^*$.

At the (Nash-bargained) regulated price, the extra profit per unit of time due to the exclusivity extension is given by $(1-x)$ times

$$\pi_E = \sigma(1-\alpha)\left(\frac{k+\alpha}{k+1}\right)^k\left(1-\frac{c}{m}\right)^{k+1},$$

while the social cost per unit of time, of buying the original branded drug at the exclusivity price p^* instead of generics at price p_g because of the exclusivity extension is given by $(1-x)$ times

$$S(p_g) - S(p^*) = \sigma\left[\left(1-\frac{p_g}{m}\right)^{k+1} - \left(\frac{k+\alpha}{k+1}\right)^{k+1}\left(1-\frac{c}{m}\right)^{k+1}\right]$$

Proposition 1. *(i) The cost-over-reward ratio of a TEE scheme with constant marginal cost of production c, generics price p_g and demand parameters $\{\sigma, m, k\}$ for the drug*

[11] In France, generics are guaranteed to receive 60% of the price of the branded molecule in the year after the exclusivity loss.

benefiting from the exclusivity extension, is given by

$$\rho = \frac{\left(1-\frac{p_g}{m}\right)^{k+1} - \left(\frac{k+\alpha}{k+1}\right)^{k+1}\left(1-\frac{c}{m}\right)^{k+1}}{(1-\alpha)\left(\frac{k+\alpha}{k+1}\right)^{k}\left(1-\frac{c}{m}\right)^{k+1}}.$$

(ii) The cost-over-reward ratio is independent of the consumers' potential benefit from the drug σ and share of captive consumers x, decreases with the generics' price p_g and with the regulator's bargaining power α, but increases with the marginal cost of production c and drug quality m.

(iii) The cost-over-reward ratio of a TEE scheme is greater than 1 if and only if the generics' price p_g is sufficiently low:

$$\rho \geq 1 \qquad \Longleftrightarrow \qquad \frac{p_g}{m} \leq 1 - \frac{k+\alpha}{k+1}\left(1-\frac{c}{m}\right)\left(\frac{k(2-\alpha)+1}{k+\alpha}\right)^{\frac{1}{k+1}}.$$

(iv) For a perfectly competitive generics market ($p_g = c$), the cost-over-reward ratio of a TEE scheme is greater than 1, strictly so unless $\alpha = 1$ (full bargaining power to the regulator) or $k = 0$ (inelastic demand: all patients have the highest WTP for the drug, m). It increases with k.[12]

Proof. The results derive from straightforward computations, except claim (iv), for which we provide details in Appendix D. □

Remark: Distortion vs redistribution. A TEE distorts consumers' demand by maintaining a higher price. Yet, unless the generics' price is equal to the marginal cost, a TEE also induces a redistribution from the generics to the original branded drug (in the limit case where $p_g = p^*$, a TEE is pure redistribution and entails a zero social cost). Which effect dominates determines whether ρ is greater or smaller than 1.

Proposition 1 implies that when the generics market is perfectly competitive ($p_g = c$), the less elastic the demand is, the lower the cost-over-reward ratio.

2.2 Heterogeneous National Impacts of a TEE in a Union

Consider N heterogeneous countries, indexed by i. We maintain our previous assumptions regarding production costs, sales and profits under exclusivity and non-exclusivity, allowing

[12] However, numerical simulations seems to suggest that for p_g sufficiently above c and α sufficiently close to 1, the cost-over-reward ratio decreases with k.

all the parameters except production costs to differ from one country to another.[13] In particular, the exclusivity price in country i is (as is the case in the European Union) Nash-bargained between country i and the pharmaceutical company, with α_i denoting country i's bargaining power.

We first investigate the national costs and benefits of a voucher scheme in the union, depending on national characteristics. We then turn to the comparison between a union-wide voucher scheme and a union-wide cash transfer, from the perspective of each member state.

Let γ_i denote the ratio of the marginal utility of (national) income y_i for country i over the marginal utility of therapeutical benefit for country i from the drug benefiting from the exclusivity extension (see Appendix C for details).[14] Demand in country i at a given price p_i is given by

$$q_i(p_i) = \sigma_i \frac{k_i+1}{m_i}\left(1-\frac{\gamma_i p_i}{m_i}\right)^{k_i}.$$

Proposition 2. ***(TEE scheme in a union of countries)*** *Suppose that the exclusivity extension associated with a voucher applies to a union of countries, while the regulation of national prices is each country's prerogative. A country tends to prefer a TEE scheme over a cash transfer scheme if its generics prices are high and the market share of generics low; if its cost of public funds is high; and if the drug with extended exclusivity has a relatively small (per inhabitant) market in the country.*

Proof. TEE. The pharmaceutical manufacturer's reward at a given price p_i writes as

$$\sigma_i \frac{k_i+1}{m_i}(p_i-c)\left(1-\frac{\gamma_i p_i}{m_i}\right)^{k_i}\frac{(1-e^{-r\Delta})e^{-rT}}{r}$$

The social surplus at price p_i expressed in terms of country i's utility writes as

$$\int_{p_i}^{m_i/\gamma_i} \sigma_i\gamma_i \frac{k_i+1}{m_i}\left(1-\frac{\gamma_i\tilde{p}}{m_i}\right)^{k_i} d\tilde{p} = \sigma_i\left(1-\frac{\gamma_i p_i}{m_i}\right)^{k_i+1},$$

and the social cost to country i of a price p_i with respect to a price $p_{g,i} \leq p_i$, where $p_{g,i}$ is the generics' price in country i, writes as

$$\frac{(1-e^{-r\Delta})e^{-rT}}{r}\int_{p_{g,i}}^{p_i} \sigma_i\gamma_i \frac{k_i+1}{m_i}\left(1-\frac{\gamma_i\tilde{p}}{m_i}\right)^{k_i} d\tilde{p} = \frac{(1-e^{-r\Delta})e^{-rT}}{r}\sigma_i\left[\left(1-\frac{\gamma_i p_{g,i}}{m_i}\right)^{k_i+1} - \left(1-\frac{\gamma_i p_i}{m_i}\right)^{k_i+1}\right].$$

[13] Were the marginal production costs to vary across countries – which should be unlikely in a single market –, the same insights would hold, together with the comparative statics with respect to domestic costs derived in Proposition 1.

[14] We focus on the case in which $\gamma_i c \leq m_i$, since otherwise, the drug benefiting from the extended exclusivity would face a zero demand while on patent in country i.

The (Nash-bargained) exclusivity price maximizes

$$\left[(p_i - c)\left(1 - \frac{\gamma_i p_i}{m_i}\right)^{k_i}\right]^{1-\alpha_i}\left[\left(1 - \frac{\gamma_i p_i}{m_i}\right)^{k_i+1}\right]^{\alpha_i}.$$

Hence the (Nash-bargained) exclusivity price in country i is given by the first-order condition:

$$\frac{\gamma_i p_i}{m_i} = \frac{1-\alpha_i}{k_i+1} + \frac{k_i+\alpha_i}{k_i+1}\frac{\gamma_i c}{m_i}.$$

As a result, the social cost for country i is given by

$$(1-x_i)\sigma_i\left[\left(1 - \frac{\gamma_i p_{g,i}}{m_i}\right)^{k_i+1} - \left(\frac{k_i+\alpha_i}{k_i+1}\right)^{k_i+1}\left(1 - \frac{\gamma_i c}{m_i}\right)^{k_i+1}\right]\int_T^{T+\Delta} e^{-r\tau}d\tau,$$

while the total gain for the buyer of the exclusivity extension, and thus in the absence of buyer power on the TEE market, the total reward Υ for the antibiotic developer is:

$$\left[\sum_j (1-\alpha_j)(1-x_j)\frac{\sigma_j}{\gamma_j}\left(\frac{k_j+\alpha_j}{k_j+1}\right)^{k_j}\left(1 - \frac{\gamma_j c}{m_j}\right)^{k_j+1}\right]\int_T^{T+\Delta} e^{-r\tau}d\tau.$$

Cash transfer. Let us now consider a cash transfer at the union's level. We assume that the contribution of country i to the developer's reward is proportional to country i's aggregate income. [The model generalizes straightforwardly to any sharing rule among the union members.] Hence, for a total reward Υ, country i contributes $(y_i/\Sigma_j y_j)\Upsilon$ to the union's cash transfer. The cost to country i of such a contribution is given by $\gamma_i(1+\lambda_i)(y_i/\Sigma_j y_j)\Upsilon$, where λ_i is country i's cost of public funds.

As a consequence, for a given reward level Υ, country i favors a TEE over a cash transfer at the union's level if and only if

$$\frac{(1-x_i)\sigma_i\left[\left(1 - \frac{\gamma_i p_{g,i}}{m}\right)^{k_i+1} - \left(\frac{k_i+\alpha_i}{k_i+1}\right)^{k_i+1}\left(1 - \frac{\gamma_i c}{m_i}\right)^{k_i+1}\right]}{\sum_j (1-\alpha_j)(1-x_j)\frac{\sigma_j}{\gamma_j}\left(\frac{k_j+\alpha_j}{k_j+1}\right)^{k_j}\left(1 - \frac{\gamma_j c}{m_j}\right)^{k_j+1}} \leq \frac{\gamma_i(1+\lambda_i)y_i}{\sum_j y_j}.$$

The end of the proof involves straightforward computations. □

Remark: National and union-wide TEEs. Let us denote by ρ_i the cost-over-reward ratio of a *national* TEE scheme in country i. Using our analysis in Section 2.1,[15]

$$S_i(p_{g,i}) - S(p_i^*) = \rho_i \pi_E(p_i^*).$$

[15] In Section 2.1, we implicitly normalized γ_i to 1.

Hence, rewriting the last inequality in the proof of Proposition 2, and denoting

$$z_i \equiv (1-\alpha_i)(1-x_i)\frac{\sigma_i}{\gamma_i}\left(\frac{k_i+\alpha_i}{k_i+1}\right)^{k_i}\left(1-\frac{\gamma_i c}{m_j}\right)^{k_i+1}$$

yields that country i favors a *union-wide* TEE over a union-wide cash transfer if and only if

$$\left(\frac{z_i}{\sum_j z_j}\Big/\frac{y_i}{\sum_j y_j}\right)\rho_i \leq 1+\lambda_i,$$

while country i favors a *national* TEE over a national cash transfer if and only if $\rho_i \leq 1+\lambda_i$. It is thus possible that countries do not favor a national TEE over a cash transfer but do prefer a union-wide TEE depending on the correlations between national income, and determinants of z_i which include the regulator bargaining power (α_i), the policies towards generics substitution (x_i), the demand elasticity (k_i), the marginal utility of income (γ_i).

2.3 Extensions

We briefly discuss two issues affecting the desirability of a TEE scheme: (i) market power in the supply of generics; (ii) market power in the voucher market, and auctioning vouchers.

2.3.1 Market power in the supply of generics

The desirability of a TEE scheme is higher, the less competitive the generics market is. Therefore, setting aside any regulation of the generics' price (e.g. aimed at guaranteeing a continuous, diversified supply), we investigate the outcome of collusion among generics.

As before, a fraction x of consumers are loyal to (or captive of) the originating brand, whereas the generics and the original branded drug are perfect substitutes for the remaining fraction $1-x$ of consumers.[16] We assume that loyalty/captivity is independent of WTP for the drug, hence both submarkets have the same demand, up to a factor x or $(1-x)$. [We study in Appendix B a case of correlation.] There are N generics companies (this number will be endogenous). We assume that generics can form a cartel charging the same price p. [We discuss in Appendix B the possibility that the original branded drug company joins the cartel.]

Let δ denote the discount factor and assume for simplicity that the marginal cost of production is nil ($c=0$).

The highest price $p \leq p^*$ (where p^* is the original branded drug's bargained price under

[16] We resume the normalization of Section 2.1, and set $\gamma = 1$.

exclusivity[17]) that can be sustained by the cartel is given by:

$$x\pi_E(p^*) = pq(p)$$

This defines a function $p(x)$ with $p'(x) > 0$ (and $p''(x) > 0$ if $p \mapsto pq(p)$ is concave.)

The ratio of the welfare gain from patent expiration over the profit loss is

$$\rho = \frac{S_{NE} - S_E}{\pi_E - \pi_{NE}} = \frac{(1-x)\int_{p(x)}^{p^*} q(\tilde{p})d\tilde{p}}{(1-x)\pi_E(p^*)} = \frac{\int_{p(x)}^{p^*} q(\tilde{p})d\tilde{p}}{p^*q(p^*)}$$

At $x = 0$, i.e. for the case of highly effective generics entry/no captive consumers, this ratio is strictly greater than 1. However, this ratio is decreasing in x, and is below 1 for x sufficiently high, converging to 0 as x goes to 1. In other words, when generics form a cartel, the cost-over-reward ratio of a TEE scheme in a single country depends on the share of captive consumers of the original branded drug x, and a TEE is preferred to a cash transfer whenever x is sufficiently high.

In contrast to the conventional wisdom that lower prices increase consumer surplus by an amount greater than the profit loss, here generics entry can be wasteful in that "the bang for the buck" can be small. This brings us to the description of generics entry. Suppose that an entering generics company must sink an investment cost $I > 0$, and that the level of entry is determined by a free-entry condition (ignoring integer problems):

$$(1-x)p(x)q(p(x)) = NI,$$

as long as $N \leq \bar{N}$, where $\bar{N}$ is the maximum number of firms that allows generics producers to sustain the collusive equilibrium:

$$\bar{N} = \frac{1}{1-\delta}.$$

For a low investment cost, the number of generics entrants is equal to $\bar{N}$. The entry of an N-th generics, $N \geq 2$, is then wasteful as long as $N \leq \bar{N}$ for it does not affect the cartel's existence and price.

Proposition 3. *When generics form a cartel, the cost-over-reward ratio of a TEE is decreasing in the share of captive users x, and a TEE is preferred to a cash transfer whenever x is sufficiently high. [For a single country, the cost-over-reward ratio of a TEE does not depend on x (see Proposition 1).]*

[17]For simplicity, we assume that the regulated price of the original branded drug remains equal to p^* even if generics collude – e.g. because captive consumers would refuse to buy generics even if the original branded drug were missing, or because during the bargaining, the regulator does not foresee the generics' collusion.

The generics cartel price $p(x)$ is given by $p(x)q(p(x)) = x\pi_E(p^*)$, and increases with x. If there is free entry and the generics entrants form a cartel, the number of generics active in equilibrium is given by (ignoring integer constraints):

$$N = \min \left\{ \frac{x(1-x)\pi_E(p^*)}{I}, \frac{1}{1-\delta} \right\},$$

which is first increasing, then constant, then decreasing in $x \in (0,1)$.

Consistently with our theoretical analysis, in our data the generics' price increases with the share of captive consumers x.[18]

2.3.2 Voucher auctions and market power

a) We assumed that the length of a TEE could be tailored to match the desired reward for the antibiotic developer. However, in practice, for a given reward target, adjusting the length of a TEE requires information on the buyer's profit. While prices and quantities may be observable, production costs are not. At the other extreme, a pre-specified duration for a voucher creates uncertainty about the exact reward accruing to the antibiotic developer, as well as the overall costs incurred by patients and tax-payers, which raises concerns.

To adjust the length of a TEE and eliminate this uncertainty, one can let the voucher buyers bid in terms of extension length.[19] Namely, fix a reward Υ for the antibiotic developer, the same as the one the antibiotic developer would receive under a cash transfer (a monetary prize). Letting for each potential voucher buyer, Δ_i be implicitly defined by

$$[\pi_{E,i} - \pi_{NE,i}] \int_{T_i}^{T_i+\Delta_i} e^{-r\tau} d\tau = \Upsilon,$$

then the holder of patent i is willing to pay Υ in exchange of any extension of the exclusivity length $\Delta \geq \Delta_i$. The winner of the auction is the one announcing the lowest extension length against cash transfer Υ.

For example, in a Vickrey auction,[20] and for demanded lengths $\Delta_1 \leq \Delta_2 \leq \Delta_3$..., the bidder demanding length Δ_1 obtains a TEE of length Δ_2. Such an auction is optimal under

[18] More generally, such correlation may be explained either by collusion among generics (a higher share of captive consumers allowing a higher cartel price as we show), or by reverse causality, the price of generics being high for other reasons (e.g. regulation), more users stick to the original branded drug (which they perceive as higher quality). Maybe less convincingly, such correlation could also be generated by a negative correlation between WTP and captivity, i.e. if the "most captive" users (perceiving the largest quality differential in favor of the original branded drug) are those with the lowest WTP for the drug.

[19] Unlike the least-present-value-of-revenue auction of Engel et al. (2001), which has been used to auction off highway franchises, here the firms would not bid a transfer but a length of exclusivity. But in both cases, the aim is to eliminate risk. In Engel et al, the risk is about future demand and the length of the franchise is adjusted accordingly. Here the uncertainty concerns the value for bidders of exclusivity extensions.

[20] The equivalent of a reserve price in such an auction is a maximum length $\bar{L}$.

the usual assumptions (symmetric draws of valuations from a distribution with monotone hazard rate, appropriately chosen reserve price).

Observation 2. *To eliminate the uncertainty about the value of a voucher for the inventor, one can set the reward's level and have potential voucher acquirers bid the minimum length of exclusivity extension for which they are willing to pay this reward to the inventor.*

b) In practice, competition in the voucher market may be imperfect because the top-earning drugs may be unequally profitable. As a consequence, the voucher's buyer – e.g. the auction winner – who pays the second-highest bid may pay less than its WTP for the voucher. Hence, while the social cost from the exclusivity extension remains the loss in social surplus from the exclusivity extension of the winning drug, the reward accruing to the antibiotic developer decreases down to the additional profit of an exclusivity extension for the second-highest profitable drug.[21] Therefore, the cost-over-reward ratio of a TEE scheme increases.

Observation 3. *Market power in the voucher market increases the cost-over-reward ratio of TEEs.*

Let us finally mention two important caveats about market power in the voucher market (buyers' side). The first arises when the same firm owns the two molecules that would benefit the most from an extension: The firm would not let the second compete with the first in that case. The second caveat is more interesting: If multiple vouchers are awarded sequentially, buyers may have incentives to wait for being in a market in which they will face little competition from rival buyers. Attrition in that market may occur when some molecules turn off-patent and are replaced by generics or when some molecules have already acquired a TEE – which also depends on the supply of TEEs, i.e. on the supply of new antibiotics, both in terms of quantity and timing. Complex timing and bidding strategies in the successive auctions of TEEs may then arise. As a consequence, TEE schemes may involve in practice a higher uncertainty than in our simple benchmark, which may reduce their desirability.

3 An Empirical Analysis on European Data

We now turn to a calibration of the theoretical model on European data.

[21] Admittedly, the buyer's rent (difference between own WTP and second-highest one) may provide an additional incentive to develop an innovation in the first place.

3.1 Data Sources

We use IMS (IQVIA) data on sales of all drugs in 15 European countries (Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Norway, Poland, Portugal, Spain, Sweden, Switzerland, UK) from the year 2002 to 2012. These data are available quarterly and include all prescription drugs. Quantities of each drug are measured in terms of standard units (the smallest possible dose available for each molecule). The same source of data was used on an older period by Dubois et al. (2015) to estimate the elasticity of innovation to market size in drugs markets, as well as in many other papers on specific drug markets. The data allow us to observe manufacturer-level sales values in local currencies and sales quantities in standard units. We compute total country level and European level sales values and volumes by product by year, aggregating the different formats, dosage, strength, packs of a same product and also aggregating the generics of a molecule. We convert local currencies into euros for countries with their own Sovereign currency. Overall the data allow us to observe the sales of more than 5,000 molecules.

3.2 Estimating the Value of a Voucher

We start by using these data to estimate the likely value of vouchers had they been implemented during the data period of 2002-2012. Denoting π_{ijt} the revenue for the original branded drug j in country i during year t, and $T(j)$ the year of exclusivity loss[22] and generics entry for the molecule of drug j, we compute the ratio of post-exclusivity-loss revenue π_{ijt} for $t = T(j)+1$ and pre-exclusivity-loss revenue for $t = T(j)-1$ for all drugs with exclusivity loss year $T(j)$.

We thus compute the ratios $\frac{\pi_{ijT(j)+1}}{\pi_{ijT(j)-1}}$ across products j whose exclusivity loss year $T(j)$ is between 2003 and 2012. We denote by μ_i the median of these ratios within country i. This ratio varies across countries depending on the regulation of prices when generics enter, the regulatory rule concerning generic substitution and the specific price drop and revenue decrease that firms experience after loss of exclusivity. We assume that this proportional revenue loss is anticipated by firms who may want to purchase an exclusivity extension to avoid this loss.

Assuming that the owner of a transferable exclusivity extension can extract its full value (e.g. because purchasers have no market power and no strategic interest to wait for cheaper vouchers in the future), the value of an extension by one year of the exclusivity period in country i for drug j whose exclusivity expires at the end of year t is then the value of profits with exclusivity, minus the expected counterfactual value of profits in case of exclusivity loss:

[22] With our previous notation, the time T before patent expiration for j, at year t is thus given by: $T = T(j) - t$.

$\pi_{ijt} - \mu_i \pi_{ijt}$. If the voucher is used at year t for extending the exclusivity of a drug j expiring at year $T(j) \geq t+1$, this value needs to be discounted and it is given at t by

$$V_{jt} \equiv \delta^{T(j)-t-1} \sum_{i=1}^{I} \pi_{ijT(j)}(1-\mu_i) = \delta^{T(j)-t-1} V_{jT(j)}$$

where $\{1, .., I\}$ is the set of countries where it would apply and δ is the yearly discount factor. We can then define the largest potential benefit at time t from an exclusivity extension as

$$V_t^1 \equiv \max_{\{j|T(j)\geq t+1\}} V_{jt}$$

and the drug with this highest value $j^1(t) \equiv \arg\{\max_{\{j|T(j)\geq t+1\}} V_{jt}\}$, as well as the second highest value V_t^2 and iteratively, the n-th highest value V_t^n.

The seller of a transfer exclusivity extension at year t will then choose the highest value among all drugs expiring in the future, provided a voucher has not already been purchased for the same drug before.

However, in the data, we observe revenues and not profits. To compute the value of the voucher, i.e. a buyer's additional profit, we thus build an upper bound estimate of the marginal cost of each molecule. This upper bound is obtained using the minimum price for this molecule observed in any country in Europe over all time periods, which is a valid upper bound if there are no country-specific effects on marginal costs of products within a molecule. For older molecules, this upper bound is typically a generic price (we observe a generic version for 1,428 molecules of the 5,352 molecules in our sample). For recent molecules, we do not observe generics yet, and this upper bound is too conservative; however, some of the countries in our data set negotiate low prices, so that the minimum price may be a reasonable estimate of cost. Under this condition, which is reasonable, our estimate is a conservative one (an upper bound on ρ), as we may underestimate the extent of collusion among generics. Denoting by $\tilde{\pi}_{ijt}$ the profit accounting for the variable cost of production (quantity times the marginal cost estimates), we can consider it as a lower bound on the true profits. The value based on revenue is then an upper bound (since it is based on a marginal cost of zero). We denote $\underline{V_t^n}$ and $\bar{V_t^n}$ the lower and upper bound on these values.

Table 1 reports the estimates of μ_i, the median of the ratios of revenue for the patent holder one year after generic entry over the one the year before. These values depend on each country's regulation of generic prices, generic substitution policy and branded drug prices after generic entry, which explains why they vary across countries. We can consider that firms take these values as the anticipated relative decline of revenue after exclusivity expiration in each country. This table shows that companies can expect roughly to lose more than 60%

of their revenue in Norway and Sweden when exclusivity ends, 50% in Germany, 40% in Italy, the UK and Belgium, 33% in France and 25% in Spain. The table also documents the number of exclusivity losses observed during that time period of our data that vary across countries because of differences in available products. We also report the share of captive consumers denoted x_i for country i which we will use for computation of the cost-over-reward ratio. These shares are computed as the quantity share of a molecule sold in generic form one year after exclusivity losses of the original brand.

These parameters μ_i allow us to estimate the value of a voucher providing one year of exclusivity extension in the 15 countries in our data. Table 1 also details the share of captive users of the branded drug version after generic entry[23].

Table 1: Relative Loss of Revenue and Share of Captive Users after Generic Entry by Country

Country	Number of exclusivity losses	Preservation revenue μ_i	Share captive x_i
AUSTRIA	20	0.603	0.511
BELGIUM	19	0.597	0.563
FINLAND	18	0.451	0.400
FRANCE	29	0.663	0.329
GERMANY	138	0.473	0.394
GREECE	21	0.950	0.454
IRELAND	14	0.880	0.437
ITALY	39	0.585	0.473
NORWAY	33	0.391	0.379
POLAND	33	0.869	0.148
PORTUGAL	24	0.821	0.408
SPAIN	25	0.740	0.483
SWEDEN	53	0.340	0.460
SWITZERLAND	15	0.613	0.459
UK	20	0.564	0.313

Notes: Second column is the number of drugs on patent that lost exclusivity during 2003-2012 and the third column is the median μ_i of ratios $\frac{\pi_{ijT(j)+1}}{\pi_{ijT(j)-1}}$ across products j whose exclusivity loss year $T(j)$ is between 2003 and 2012.

Table 2 reports our computation of the five largest vouchers values $\bar{V}_t^n$ if delivered in any year at the European level between 2002 and 2011. It also reports which product would have been given the exclusivity extension (bought by its owner), and for which year of exclusivity expiration. The values are discounted ones. For instance, if Plavix buys in 2008 a one-year voucher for its patent expiring that year it would pay a larger price than

[23]To avoid timing issues when a generic entry enters at the end of a year, we consider generics have entered once they reach at least 10% market share of sales quantities of a molecule, which usually happens quickly in all European countries.

Table 2: Value of One-Year Voucher by Year (in k€)

Year	$\bar{V}_t^1$	$\bar{V}_t^2$	$\bar{V}_t^3$	$\bar{V}_t^4$	$\bar{V}_t^5$
2002	PLAVIX (2008)	ZOCOR (2002)	LIPITOR (2011)	NORVASC (2003)	PANTOZOL (2008)
	468,221	463,005	459,136	348,136	285,430
2003	PLAVIX (2008)	LIPITOR (2011)	NORVASC (2003)	PANTOZOL (2008)	ZYPREXA (2010)
	482,702	473,337	358,904	294,257	280,059
2004	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	SEROQUEL (2011)
	497,631	487,976	303,358	288,720	280,623
2005	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	SEROQUEL (2011)
	513,021	503,068	312,740	297,650	289,302
2006	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	SEROQUEL (2011)
	528,888	518,627	322,413	306,855	298,250
2007	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	SEROQUEL (2011)
	545,245	534,667	332,384	316,346	307,474
2008	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	SEROQUEL (2011)
	562,109	551,203	342,664	326,130	316,984
2009	LIPITOR (2011)	ZYPREXA (2010)	SEROQUEL (2011)	NEXIUM (2010)	TAXOTERE (2010)
	568,250	336,216	326,787	295,677	287,107
2010	LIPITOR (2011)	ZYPREXA (2010)	SEROQUEL (2011)	NEXIUM (2010)	TAXOTERE (2010)
	585,825	346,615	336,894	304,821	295,986
2011	LIPITOR (2011)	SEROQUEL (2011)	ZOMETA (2012)	SINGULAIR (2012)	VIAGRA (2012)
	603,943	347,313	149,702	147,214	128,432

Notes: Voucher values $\bar{V}_t$ for one year TEE, in 1000 Euros, with yearly discount factor $\delta = 0.97$ for vouchers purchased in a given year for extending the exclusivity several years ahead. The values for the end of sample, particularly 2010 and 2011 are not reliable because our sample stops in 2012 and thus once we lack observation of other drugs whose exclusivity stops in or after 2012.

if buying it for example in 2003 because in 2003 it would discount the future benefit of the exclusivity extension to happen in 2008 only. This table shows that the highest profits that can be reaped by users of a voucher would be around half a billion euros, but it exhibits a strong historical dependence. Indeed, the largest value among available vouchers can vary substantially depending on the history of past vouchers, which is hard to predict as it depends on the innovation outcomes for which one would like to grant TEEs. For example, if a voucher had been granted in 2002, Table 2 shows that it would have likely been purchased by Sanofi for Plavix, but Sanofi would then have not been competing for the 2003 voucher, which would then have likely been purchased by Pfizer for Lipitor (which is the second largest value in 2003). However, if no voucher had been granted before say 2008, then Plavix would have purchased it in 2008. Another example of varying outcome depending on the arrival of innovation qualifying for vouchers: if two arrive in 2002 and none in 2003 instead of one in 2002 and one in 2003, then the next available voucher in 2004 would be Lipitor in the first case but Pantozol in the second case, thus leading to a much smaller value of 303 millions instead of 487 millions.

This highlights that the value of vouchers depends on the historical path of voucher-eligible innovations. However, this table still shows that a unique voucher granted during

one of the 10 years of our data would have had a value varying substantially, from 468 millions euros to 603 million euros depending on years. The table also shows that the delivery of a voucher in a given year is sometimes purchased by a company whose product is going to expire the year after, but sometimes only several years later.

Table 5 in Appendix E.1 reports the same quantities as Table 2 using alternatively the lower-bound estimates $\underline{V}_t^n$, which happen not to be much different from the upper-bound estimates in Table 2.

3.3 An Empirical Calibration of the Cost-Over-Reward Ratio of a TEE

We are interested in the costs and benefits of a TEE scheme were the 15 European countries in our data to form a union and implement a union-wide TEE scheme. In order to estimate the social cost of such a TEE scheme, we need to evaluate the shape of the demand function for a molecule in each country. To do so, we use our data to perform a calibration using the time variation over years of prices and quantities per molecule. Following our theoretical model, for each country i, we assume that the demand in year t for each molecule j is given by:

$$q_{ijt}(p_{ijt}) = \sigma_{ijt}\frac{k_{ijt}+1}{m_{ijt}}\left(1-\frac{\gamma_i p_{ijt}}{m_{ijt}}\right)^{k_{ijt}}$$

where $\sigma_{ijt} = \sigma_{ij}\exp(\epsilon_{ijt})$ is the aggregate demand shock, and m_{ijt} the maximum willingness-to-pay for drug j in country i at time t, and k_{ijt} a parameter that affects the shape of demand. To filter out some noise in the data and avoid excessive variations in the estimated shape of demand functions, we approximate the maximum willingness-to-pay m_{ijt} by $m_i \equiv \max_{j,t}\{p_{ijt}\}$ and the demand parameter k_{ijt} by k_i, which are country-specific, but drug- and time-independent. Put differently, we assume that the shape of demand (as a function of price) is determined by country-specific effects – e.g. related to population characteristics, lifestyle, environment, etc. –, up to a multiplying factor which is drug- and time-specific. We further assume that $\sigma_{ij} = \sigma_i$ for all j and report in Appendix E.3 the case where we allow σ_{ij} to be heterogenous across molecules. When $\sigma_{ij} = \sigma_i$, we obtain the following demand function of country i for drug j at time t:

$$q_{ijt}(p_{ijt}) = \sigma_i\exp(\epsilon_{ijt})\frac{k_i+1}{m_i}\left(1-\frac{\gamma_i p_{ijt}}{m_i}\right)^{k_i}$$

Taking logs, and doing a linear approximation when $\frac{\gamma_i p_{ijt}}{m_i} \ll 1$, we can identify $(k_i\gamma_i)$ using the price coefficient $\widehat{(k_i\gamma_i)}$ of the following simple linear regression assuming that ϵ_{ijt}

is uncorrelated with p_{ijt}:

$$\log q_{ijt} \approx \log(\sigma_i \frac{k_i + 1}{m_i}) - (k_i \gamma_i) \frac{p_{ijt}}{m_i} + \epsilon_{ijt} \tag{1}$$

Then, we use the relationship derived in Section 2 between the regulated prices, marginal cost, maximum willingness to pay and bargaining parameters, that we assume satisfied in expectation for each drug j and thus for the average price, such that:

$$\frac{\gamma_i \bar{p}_i}{m_i} = \frac{1 - \alpha_i}{k_i + 1} + \frac{k_i + \alpha_i}{k_i + 1} \frac{\gamma_i \bar{c}_i}{m_i} \tag{2}$$

where $\bar{p}_i = \frac{1}{J(i)\overline{T}} \sum_{j,t} p_{ijt}$ is the mean price per molecule in country i and $\bar{c}_i = \frac{1}{J(i)} \sum_{j \in i} c_j$ is the mean cost per molecule for drugs in country i ($J(i)$ being the total number of drugs present in country i, and $\overline{T}$ the length of the data time period).

We thus search for parameters γ_i, k_i, α_i solution of equations (1) and (2) and such that $0 \leq \gamma_i \leq m_i/c_j$ for all j in country i (meaning that demand should not be zero when price is equal to marginal cost). In principle, this problem could lead to an infinite set of possible parameters satisfying these constraints. However, because of measurement errors and approximations, the set of parameters satisfying these constraints for all drugs is empty. We thus search for the parameters that satisfy all constraints at country level and that maximize the set of drugs for which the constraints ($\gamma_i \leq m_i/c_j$) is satisfied. We thus solve the following problem:

$$\max_{\alpha_i \in (0,1), k_i \in (0,1), \gamma_i} \quad \sum_j 1_{\{0 \leq \gamma_i c_j \leq m_i\}}$$
$$s.t. \quad (1), (2)$$

where (1) implies that $\widehat{k_i \gamma_i}$ is obtained by equation (1).

Table 3 reports the estimated values for α_i, k_i, γ_i as well as the market size parameter $\frac{\sigma_i(k_i+1)}{m_i}$ in relative terms among the countries which allows us to compare these estimates to the share of total pharmaceutical expenditures or total GDP that each country represents. We can see that for the largest countries, these relative market size estimates are in general smaller than their share of GDP (except for Spain).

Table 3 shows then the cost-over-reward ratio of country-wide (and not union-wide) TEE

Table 3: Demand and bargaining parameters, and cost-over-reward ratio by country

Country	α_i	k_i	γ_i	ρ_i	ρ_i^{gen}	$\mathcal{E}_i$	$\frac{y_i^{ph}}{\sum_j y_j^{ph}}$	$\frac{y_i^{gdp}}{\sum_j y_j^{gdp}}$	$\frac{\frac{\sigma_i(k_i+1)}{m_i}}{\sum_j \frac{\sigma_j(k_j+1)}{m_j}}$
AUSTRIA	0.7529	0.9645	32.00	1.0693	0.6012	-0.167	0.022	0.058	0.035
BELGIUM	0.7916	0.9581	28.00	1.0570	0.6476	-0.150	0.030	0.027	0.051
FINLAND	0.7016	0.9530	21.00	1.0857	0.8705	-0.201	0.013	0.013	0.033
FRANCE	0.8018	0.9615	36.00	1.0539	0.5524	-0.146	0.202	0.149	0.121
GERMANY	0.8558	0.9789	39.00	1.0385	0.8974	-0.112	0.203	0.209	0.102
GREECE	0.8413	0.9679	25.00	1.0424	0.0847	-0.125	0.026	0.020	0.066
IRELAND	0.7892	0.8999	14.00	1.0559	0.1914	-0.148	0.011	0.013	0.030
ITALY	0.8625	0.9502	33.00	1.0360	0.7775	-0.116	0.143	0.135	0.119
NORWAY	0.8472	0.9316	16.00	1.0399	1.0815	-0.119	0.009	0.018	0.014
POLAND	0.8007	0.9748	23.00	1.0547	0.2406	-0.165	0.027	0.047	0.064
PORTUGAL	0.8664	0.9566	17.00	1.0350	0.2895	-0.101	0.021	0.018	0.074
SPAIN	0.8154	0.9388	25.00	1.0493	0.4894	-0.152	0.115	0.093	0.133
SWEDEN	0.7038	0.9588	19.00	1.0852	1.0876	-0.204	0.023	0.025	0.035
SWITZERLAND	0.8281	0.9536	17.00	1.0459	0.6178	-0.124	0.021	0.026	0.029
UK	0.8851	0.9858	55.00	1.0303	0.7778	-0.095	0.133	0.149	0.093

Notes: We also report each country's share of union pharmaceutical expenses, share of union GDP, and share of union market size.

schemes which, accounting for the parameter of marginal utility of income, γ_i, writes as[24]:

$$\rho_i^{gen} = \frac{\left(1 - \frac{\gamma_i \bar{p}_{ig}}{m_i}\right)^{k_i+1} - \left(\frac{k_i+\alpha_i}{k_i+1}\right)^{k_i+1}\left(1 - \frac{\gamma_i \bar{c}_i}{m_i}\right)^{k_i+1}}{(1-\alpha_i)\left(\frac{k_i+\alpha_i}{k_i+1}\right)^{k_i}\left(1 - \frac{\gamma_i \bar{c}_i}{m_i}\right)^{k_i+1}}$$

where $\bar{p}_{ig}$ is the average generic price level for country i. The table also reports the mean price elasticity $\mathcal{E}_i = -k_i \frac{\gamma_i}{m_i} \bar{p}_i$ where $\bar{p}_i$ is the mean price. Interestingly, we find that if the generics price is equal to marginal cost, the cost over reward ratios ρ_i are above 1 (as the theory predicts) meaning that the cash transfer would be preferable to a country wide voucher if there are no cost of public funds. However, it shows that with relatively mild cost of public funds (which are usually estimated above 1.3, as in Barrios et al. (2013)) the voucher is preferable and less costly for society than a cash transfer. Even more interestingly, as the prices of generics are typically above marginal costs, the correct cost-over-reward ratio in this case should be ρ_i^{gen} which is often lower and even lower than 1 in most countries. This means that a voucher is preferable to a cash transfer even without costs of public funds.

This remains true when we use an alternative specification for (1) using molecule fixed

[24] In case the generics price is equal to marginal cost: $\rho_i = \frac{1 - \left(\frac{k_i+\alpha_i}{k_i+1}\right)^{k_i+1}}{(1-\alpha_i)\left(\frac{k_i+\alpha_i}{k_i+1}\right)^{k_i}}$.

effects as shown in Table 7 in Appendix E.3 shows that in that specification we obtain a less elastic demand shape and to cost-over-reward ratios even more favorable to vouchers.

Table 4 reports the values of the cost-over-reward ratio for a union-wide TEE scheme. From our theoretical model, country i favors a TEE over a cash transfer given marginal cost of public funds $1+\lambda_i$, if and only if[25]

$$\tilde{\rho_i}^{gen} \equiv \frac{(1-x_i)\sigma_i\left[\left(1-\frac{\gamma_i p_{g,i}}{m}\right)^{k_i+1}-\left(\frac{k_i+\alpha_i}{k_i+1}\right)^{k_i+1}\left(1-\frac{\gamma_i c}{m_i}\right)^{k_i+1}\right]}{\sum_j(1-\alpha_j)(1-x_j)\frac{\sigma_j}{\gamma_j}\left(\frac{k_j+\alpha_j}{k_j+1}\right)^{k_j}\left(1-\frac{\gamma_j c}{m_j}\right)^{k_j+1}} \leq \frac{\gamma_i(1+\lambda_i)y_i}{\sum_j y_j}.$$

where x_i is the share of country i's consumers who remain captive of the original branded drug company. and y_i the country i GDP.

Table 4: Union level TEE cost over fixed reward ratio by country

Country	(1) $\tilde{\rho_i}$	(2) $\tilde{\rho_i}^{gen}$	(3) $\frac{\gamma_i y_i^{gdp}}{\sum_j y_j^{gdp}}$	(4) $\frac{(1)}{(3)}$	(5) $\frac{(2)}{(3)}$	(6) $1+\lambda_i$	(7) $\frac{pop_i}{\sum_j pop_j}$	(8) $\frac{y_i^{ph}}{\sum_j y_j^{ph}}$	(9) $\frac{y_i^{gdp}}{\sum_j y_j^{gdp}}$
AUSTRIA	0.930	0.523	1.841	0.51	0.28	1.82	0.049	0.022	0.058
BELGIUM	1.267	0.776	0.763	1.66	1.02	1.98	0.025	0.030	0.027
FINLAND	0.759	0.609	0.279	2.72	2.18	1.61	0.012	0.013	0.013
FRANCE	7.827	4.102	5.351	1.46	0.77	2.41	0.147	0.202	0.149
GERMANY	6.502	5.619	8.140	0.80	0.69	1.96	0.189	0.203	0.209
GREECE	0.751	0.061	0.511	1.47	0.12	1.59	0.025	0.026	0.020
IRELAND	0.283	0.051	0.179	1.59	0.29	1.33	0.010	0.011	0.013
ITALY	3.564	2.675	4.453	0.80	0.60	1.68	0.136	0.143	0.135
NORWAY	0.141	0.146	0.285	0.49	0.51	1.2	0.011	0.009	0.018
POLAND	0.739	0.169	1.073	0.69	0.16	1.63	0.088	0.027	0.047
PORTUGAL	0.583	0.163	0.307	1.90	0.53	1.82	0.024	0.021	0.018
SPAIN	2.752	1.284	2.330	1.18	0.55	1.79	0.103	0.115	0.093
SWEDEN	0.831	0.833	0.476	1.75	1.75	2.06	0.021	0.023	0.025
SWITZERLAND	0.313	0.185	0.448	0.70	0.41	1	0.018	0.021	0.026
UK	8.088	6.106	8.212	0.98	0.74	1.81	0.142	0.133	0.149

Note: We also report each country's share of union population, share of union pharmaceutical expenses, and share of union GDP. We rely on estimations in Barrios et al. (2013) for the countries' marginal costs of public funds as they provide individual estimates for each country in our data, based on data from the same time period as ours. We set it to one for Switzerland for which Barrios et al. (2013) do not provide estimates. Yet, as can be seen from the Table, the comparison between TEEs and cash transfer would be robust to other, not-too-distant estimates.

Interestingly, Table 4 suggests that, according to our model and our data, among the 15

[25]When generics are priced at their marginal cost ($p_g = c$), the condition becomes:

$$\tilde{\rho_i} \equiv \frac{(1-x_i)\sigma_i\left[1-\left(\frac{k_i+\alpha_i}{k_i+1}\right)^{k_i+1}\right]\left(1-\frac{\gamma_i \bar{c}_i}{m_i}\right)^{k_i+1}}{\sum_j(1-\alpha_j)(1-x_j)\frac{\sigma_j}{\gamma_j}\left(\frac{k_j+\alpha_j}{k_j+1}\right)^{k_j}\left(1-\frac{\gamma_j \bar{c}_j}{m_j}\right)^{k_j+1}} \leq \frac{\gamma_i(1+\lambda_i)y_i}{\sum_j y_j}.$$

countries in our union, 13 would quite unambiguously prefer a TEE scheme to a cash transfer to the inventor. By contrast, the two remaining countries, namely Sweden and Finland, would be respectively close to indifferent (Sweden) and quite unambiguously against (Finland) a TEE scheme with respect to a cash transfer. This result fits our model's predictions, for Sweden and Finland have not too high marginal costs of public funds, and highly competitive generics markets (see columns 4 and 5 in Table 1), and thus for whom exclusivity extensions entail higher social costs. Lastly, we provide in Appendix E.2 the values of cost-over-reward ratios for a fourteen-country-union TEE without the unwilling country (Finland), and show that in this case, all 14 countries would prefer a TEE.

These results show that a TEE scheme is socially preferable to a cash transfer rewarding innovators.

4 Conclusion

The introduction covered the main insights of our analysis. As this is a first attempt at comparing TEEs and prizes, we repeat some of the caveats regarding policy implications. On the one hand, free-riding within the union may hinder the prize mechanism, providing an additional argument in favor of TEEs. On the other hand, market power and strategic intertemporal bidding in the vouchers market may well increase the cost-over-reward ratio. We need to improve our understanding of these issues.

This paper is, to the best of our knowledge, the first to provide a conceptual framework to study TEEs, as well as the first to provide estimates of their impacts. Given the likely addition of this new approach to the innovation policy toolbox, we hope that it will motivate future research and policy reflexions.

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A Comparing "Priority Review Vouchers" to cash transfers

We sketch a model of "priority review vouchers (PRV)" (Ridley et al., 2006) in order to emphasize the malleability of our methodological approach.

Let T denote the patent length, T_R the standard review time, and $\Delta \in (0, T_R)$ the reduction induced by a priority review. The value of a priority review voucher to the buyer is thus equal to

$$(e^{-r(T_R-\Delta)} - e^{-rT_R})\left(\frac{1-e^{-rT}}{r}\pi_E + \frac{e^{-rT}}{r}\pi_{NE}\right),$$

where $\pi_E = \pi(p^*)$ and $\pi_{NE} = x\pi(p^*)$. Letting p^* and p_g denote, respectively, the original branded drug regulated price and the generics price, the additional social surplus brought by a priority review is equal to

$$(e^{-r(T_R-\Delta)} - e^{-rT_R})\left(\frac{1-e^{-rT}}{r}S(p^*) + \frac{e^{-rT}}{r}\left[xS(p^*) + (1-x)S(p_g)\right]\right).$$

Suppose that the authority incurs the additional cost $(1+\lambda)\phi(\Delta)$. Let us compare a PRV to a prize. A prize Υ costs $(1+\lambda)\Upsilon$ to the government. Under a PRV, to achieve a reward Υ, the reduction of review time must satisfy:

$$(e^{-r(T_R-\Delta)} - e^{-rT_R})\left(\frac{1-e^{-rT}}{r}\pi(p^*) + \frac{e^{-rT}}{r}x\pi(p^*)\right) = \Upsilon.$$

This defines a function $\Delta(p^*, x)$, decreasing in both arguments (as long as $\Delta(p^*, x) \leq T_R$, otherwise a PRV cannot yield reward Υ). Hence, a PRV is preferred to a prize if and only if

$$\begin{aligned}\phi(\Delta(p^*,x)) \leq\ & (e^{-r(T_R-\Delta(p^*,x))} - e^{-rT_R})\left(\frac{1-e^{-rT}}{r}\pi(p^*) + \frac{e^{-rT}}{r}x\pi(p^*)\right) \\ & + (e^{-r(T_R-\Delta(p^*,x))} - e^{-rT_R})\left[\frac{1-e^{-rT}}{r}\frac{S(p^*)}{1+\lambda} + \frac{e^{-rT}}{r}\left(x\frac{S(p^*)}{1+\lambda} + (1-x)\frac{S(p_g)}{1+\lambda}\right)\right].\end{aligned}$$

Observation 4. *As opposed to TEEs, the cost-over-reward ratio of priority review vouchers increases with the generics' price (for the drug benefiting from the voucher, keeping x constant). Put differently, priority review vouchers are more desirable the more competitive the generics market, whereas TEEs are more desirable the less competitive the generics market.*

All else being equal, this observation suggests reversed preferences for countries with respect to both schemes (against cash transfers): the strongest supporters of TEEs (against cash transfers) would be the strongest opponents of PRV (against cash transfers), and vice versa. [Depending on parameter values, the strongest opponents of PRV may still favor PRV over cash transfers, and the strongest supporters of TEEs may still prefer cash transfers.]

B Market power in the supply of generics

We investigate in more details the generics' optimal cartel. Suppose the marginal cost of production c is equal to zero. Suppose N generics enter the market once the exclusivity expires. The N generics face two options:

(i) collude among themselves, leaving the original branded drug company set the monopoly price for its captive consumers;

(ii) include the original branded drug company in the cartel.

We first assume that a consumer's captivity to the original branded drug is independent of her WTP, hence both the demand of captive and non-captive consumers is given by $q(\cdot)$, up to a size factor. We study below a polar case of correlation.

Collusion among generics only. The no-deviation condition for generics writes as $N \leq 1/(1-\delta)$ with δ the firms' (common) discount factor. The original branded drug company is unwilling to undercut the cartel's price $p \leq p^*$ if and only if

$$x\pi^* \geq pq(p),$$

where $\pi^* \equiv \pi_E(p^*)$ is the regulated monopoly profit given demand q.

As a consequence, the generics-only cartel is described by two constraints:

$$\begin{cases} N \leq 1/(1-\delta) \\ pq(p) \leq x\pi^* \end{cases}$$

Each cartel member makes a profit given by

$$\frac{x(1-x)\pi^*}{N},$$

which, interestingly, is non-monotonic in x.

Collusion including the original branded drug company. The no-deviation condition for generics writes as $N+1 \leq 1/(1-\delta)$. The no-deviation condition for the original branded drug company writes as

$$\left(x + \frac{1-x}{N+1}\right) pq(p) \geq (1-\delta)pq(p) + \delta x\pi^*.$$

Hence for the largest feasible cartel, $N+1 = 1/(1-\delta)$, and the original branded drug company' no-deviation condition writes as

$$pq(p) \geq \pi^*,$$

and thus $p = p^*$ (the cartel sustains the regulated monopoly price!). Each generic, resp. the original branded drug company, makes a profit

$$\frac{(1-x)\pi^*}{N+1}, \qquad \text{resp.} \qquad \left(x + \frac{1-x}{N+1}\right)\pi^*,$$

which decreases, resp. increases, with x.

Do generics coopt the original branded drug company in their cartel? The original branded drug company always prefer to be on board. Generics prefer the original branded drug company to be on board if and only if

$$\frac{(1-x)\pi^*}{N+1} \geq \frac{x(1-x)\pi^*}{N}, \qquad \text{i.e.} \qquad N \geq \frac{x}{1-x}.$$

This condition holds in particular for any $N \geq 1$ whenever $x \leq 1/2$. [An intuition is as follows: Generics cartel members trade off a share of the non-captive consumers (from $1/N$ to $1/(N+1)$, i.e. a loss proportional to $1/(N(N+1))$, in exchange of a higher price (from p to p^*, with p independent of N) on their remaining share (thus a gain proportional to $1/N$). Hence, for N sufficiently high, the gain more than compensates the loss.]

Correlation between captivity and WTP. For simplicity, we omit regulation (in the form of Nash-bargaining on prices), and hence we consider unregulated profit maximization by the firms. Suppose captive consumers have the highest WTPs. Let θ_x be given by $1 - F(\theta_x) = x$ (captive consumers are exactly the consumers with WTP $\theta \geq \theta_x$), where F is the c.d.f. of therapeutical needs for drug j, given (as before) by

$$F \ : \ \begin{cases} [0,m] \longrightarrow [0,1], \\ \theta \longmapsto 1 - \left(1 - \dfrac{\theta}{m}\right)^k. \end{cases}$$

We focus on parameter values such that $p \mapsto p[1-F(p)]$ is concave.

For collusion among generics only, the two conditions become:

$$\begin{cases} N \leq 1/(1-\delta) \\ p[x + F(\theta_x) - F(p)] \leq \max\limits_{p' \geq \theta_x} p'[1 - F(p')] \end{cases}$$

For collusion including the original branded drug company, the two conditions are

$$\begin{cases} N+1 \leq 1/(1-\delta) \\ p\Big(x + \dfrac{[F(\theta_x) - F(p)]}{N+1}\Big) \geq (1-\delta)\max\Big(\max\limits_{p\geq\theta_x} p[1-F(p)],\ \max\limits_{p\leq\theta_x} p(x+[F(\theta_x)-F(p)])\Big) \\ \qquad\qquad +\delta \max\limits_{p\geq\theta_x} p[1-F(p)] \end{cases}$$

Henceforth, we focus on the case in which x is sufficiently small that a monopolist sets a price strictly below θ_x. This case arises if and only if[26]

$$x \leq \left(\frac{k}{k+1}\right)^k$$

The second condition above then writes for $N+1 = 1/(1-\delta)$ as

$$\Big(x + (1-\delta)[F(\theta_x) - F(p)]\Big)p \geq (1-\delta)\max_{p'\leq\theta_x} p'\Big(x + [F(\theta_x) - F(p')]\Big) + \delta\theta_x[1-F(\theta_x)]$$

Letting p_x^m be the price that solves the maximum on the RHS, i.e. $p_x^m[1-F(p_x^m)] = \max\limits_{p'\leq\theta_x} p'(x+[F(\theta_x)-F(p')])$, the inequality rewrites as

$$0 \geq (1-\delta)\Big(p_x^m[1-F(p_x^m)] - p[1-F(p)]\Big) + \delta x(\theta_x - p),$$

which is a contradiction by definition of p_x^m and as $p \leq \theta_x$. Therefore, whenever x is sufficiently low, the generics cartel does not include the original branded drug company.

The generics-only cartel price $p^g < \theta_x$ is then given by:

$$p^g[1-F(p^g)] = \theta_x[1-F(\theta_x)],$$

while the original branded drug's price is given by θ_x.

C Heterogeneous national welfare functions

Let us denote by j the drug that may benefit from the exclusivity extension. Let y_i be country i's aggregate income, p_{ij} the price of drug j in country i, and h_i aggregate "health" of country i's inhabitants absent drug j. We write country i's objective as:

$$u(y_i, p_{ij}) = \phi\Big(y_i - p_{ij}\sigma_{ij}\frac{k_{ij}+1}{m_{ij}}[1-F_{ij}(\underline{\theta}(y_i,p_{ij}))],\ h_i + \sigma_{ij}\frac{k_{ij}+1}{m_{ij}}\int_{\underline{\theta}(y_i,p_{ij})}^{m_{ij}} \theta dF_{ij}(\theta)\Big)$$

[26] The RHS strictly decreases with $k \in (0,1)$, down from 1 for $k=0$ to 1/2 for $k=1$.

where $\phi : \mathbb{R}^3 \to \mathbb{R}$ is a function of:

- disposable aggregate income after expenditures on drug j, i.e. $y_i - p_{ij}\sigma_{ij}\frac{k_{ij}+1}{m_{ij}}[1 - F_{ij}(\underline{\theta}(y_i, p_{ij}))]$ where $\underline{\theta}(y_i, p_{ij})$ is the lowest therapeutical benefit from drug j that country i decides to cover when national revenue is y_i and drug price p_{ij} (more on this below), and F_{ij} is the c.d.f. of individuals' therapeutical benefits from drug j.[27]
- aggregate health of country i's inhabitants including the therapeutical benefits brought by usage of drug j, i.e. $\int_{\underline{\theta}(y_i,p_{ij})}^{m_{ij}} \theta dF_{ij}(\theta)$ times patients' population size, $\sigma_{ij}(k_{ij} + 1)/m_{ij}$,

We assume that ϕ strictly increases with each of its arguments, and is continuously differentiable.

We assume that expenditures on drug j are sufficiently low with respect to aggregate income, and the therapeutical benefits brought by drug j sufficiently low with respect to aggregate health that a first-order approximations are valid. Country i thus decides to buy the drug at price p_{ij} to give it to all its inhabitants with therapeutical need $\theta \in [\theta, \theta + d\theta]$ if and only if

$$\theta \geq \frac{\phi_y(y_i, h_i)}{\phi_h(y_i, h_i)} p_{ij} \equiv \underline{\theta}(y_i, p_{ij}).$$

where ϕ_y and ϕ_h denote the partial derivatives of ϕ with respect to its first and second arguments (we omit the arguments to alleviate the expressions).

Let $\gamma_i \equiv \phi_y/\phi_h$ be the ratio of *marginal utility of income* y_i for country i over the *marginal utility of therapeutical benefit* for country i from the drug benefiting from the exclusivity extension. Using a first-order approximation, country i's objective as a function of drug price p_{ij} thus writes as

$$\sigma_{ij}\frac{k_{ij}+1}{m_{ij}}\int_{\gamma_i p_{ij}}^{m_{ij}}(\theta - \gamma_i p_{ij})dF_{ij}(\theta) = \gamma_i\sigma_{ij}\frac{k_{ij}+1}{m_{ij}}\int_{p}^{m_{ij}/\gamma_i}\left(1 - \frac{\gamma_i\tilde{p}}{m_{ij}}\right)^{k_{ij}} d\tilde{p}$$

using an integration by parts. Therefore, the social surplus at price p_{ij} writes as

$$\gamma_i\sigma_{ij}\frac{k_{ij}+1}{m_{ij}}\int_{p_{ij}}^{m_{ij}/\gamma_i}\left(1 - \frac{\gamma_i\tilde{p}}{m_{ij}}\right)^{k_{ij}} d\tilde{p} = \sigma_{ij}\left(1 - \frac{\gamma_i p_{ij}}{m_{ij}}\right)^{k_{ij}+1}$$

[27] The c.d.f. of therapeutical needs for drug d is given (as before) by

$$F_{ij} \ : \ \begin{cases} [0, m_{ij}] \longrightarrow [0, 1], \\ \theta \longmapsto 1 - \left(1 - \dfrac{\theta}{m_{ij}}\right)^{k_{ij}} \end{cases}$$

D Proof of Proposition 1

We show claim (iv) of Proposition 1, i.e. the monotonicity of the cost-over-reward ratio with respect to k for $p_g = c$.

For $p_g = c$, the cost-over-reward ratio writes as the following function on $[0, 1]$:

$$\rho(k) = \frac{1 - \left(\frac{k+\alpha}{k+1}\right)^{k+1}}{(1-\alpha)\left(\frac{k+\alpha}{k+1}\right)^{k}}$$

We will show that the derivative with respect to k is positive on $(0, 1)$ (reminding that we always have $0 \leq \alpha < 1$).

Using automatic differentiation tools, we get:

$$\rho'(k) = \frac{\left(\frac{k+1}{k+\alpha}\right)^{k} \cdot \left[(k+1)^2(\alpha+k)\ln\left(\frac{k+\alpha}{k+1}\right) + (1-\alpha)\left(a\left(\frac{k+\alpha}{k+1}\right)^{k} + k\left(\frac{k+\alpha}{k+1}\right)^{k} + k + k^2\right)\right]}{(k+\alpha)(\alpha-1)(k+1)^2}$$

Let's define:

$$g(k) \equiv (k+\alpha)(\alpha-1)(k+1)^2 < 0$$

$$h(k) \equiv \left(\frac{k+\alpha}{k+1}\right)^{k} > 0$$

$$p(k) \equiv (k+1)^2(\alpha+k)\ln\left(\frac{k+\alpha}{k+1}\right)$$

$$l(k) \equiv \alpha\left(\frac{k+\alpha}{k+1}\right)^{k} + k\left(\frac{k+\alpha}{k+1}\right)^{k} + k + k^2$$

$$m(k) \equiv p(k) + (1-\alpha)l(k)$$

$$\hat{k}(k) \equiv \frac{p(k)}{1-\alpha}\ ; \qquad m(k) = (1-\alpha)\left[\hat{k}(k) + l(k)\right]$$

So that $\rho'(k) = \dfrac{p(k) + (1-\alpha)l(k)}{h(k)g(k)} = \dfrac{m(k)}{h(k)g(k)}$ and we know that $h(k)g(k) < 0$.

D.1 Case $0 \leq \alpha \leq 0.5$

D.1.1 Summand $l(k)$

We claim that (on the interval $[0, 1]$) $h(k) = \left(\dfrac{k+\alpha}{k+1}\right)^{k} \leq 1 - \dfrac{1}{2}(1-\alpha)k$. We will show that the right and left sides match for $k = 0$ and $k = 1$, and that the left side is convex, while the right side is linear. Hence, by property of convexity, the inequation will be proved.

Let us define LHS $= \left(\dfrac{k+\alpha}{k+1}\right)^{k}$ and RHS $= 1 - \dfrac{1}{2}(1-\alpha)k$.

Matching at both ends: For $k = 0$, we clearly get LHS $= 1$ and RHS $= 1$. For $k = 1$, we clearly get LHS $= \dfrac{\alpha+1}{2}$ and RHS $= \dfrac{1}{2} + \dfrac{\alpha}{2}$.

Convexity of $h(k)$ (LHS) We remember $h(k) = \left(\dfrac{k+\alpha}{k+1}\right)^k$ (the LHS above, also factor of ρ'). To show h is convex, we will show its second derivative is positive ($h''(k) > 0$ on $(0,1)$).

Using automatic differentiation tools, we get:

$$h'(k) = h(k) \cdot \left[\frac{(1-\alpha)x}{(k+\alpha)(k+1)} + \ln\left(\frac{k+\alpha}{k+1}\right)\right]$$

Let $\psi = \dfrac{(1-\alpha)x}{(k+\alpha)(k+1)} + \ln\left(\dfrac{k+\alpha}{k+1}\right)$, so that $h'(k) = h(k) \cdot \psi(k)$.

Now, $h''(k) = h(k) \cdot \psi'(k) + h'(k) \cdot \psi(k) = h(k) \cdot \left[\psi'(k) + \psi(k)^2\right]$. Using (again) automatic differentiation tools, we get: $\psi'(k) = \dfrac{(1-\alpha)\left[k(1+\alpha)+2\alpha\right]}{(k+\alpha)^2(k+1)^2}$. When $\alpha, k \in]0,1[$, it is trivial that $\psi'(k) > 0$; and, of course, $\psi(k)^2 \geq 0$.

Thus, we finally get $h''(k) > 0$, i.e. h is convex.

Final estimate for $l(k)$ Using $h(k) \leq 1 - \dfrac{1}{2}(1-\alpha)k$, we get:

$$l(k) < (\alpha + k)\left(1 - \frac{k}{2} + \frac{\alpha k}{2}\right) + k + k^2$$

D.1.2 Summand $p(k)$

We remark that $\left(\dfrac{k+\alpha}{k+1}\right) - 1 = \dfrac{\alpha-1}{k+1}$; And $0 \leq \left(\dfrac{k+\alpha}{k+1}\right) \leq 1$. Thus, using the four terms Taylor expansion of $\ln(u)$ at $u = 1$, and the fact that all remaining terms of the Taylor expansion are negative (if $u \in [0,1]$), we have:

$$\ln(u) \leq (u-1) - \frac{(u-1)^2}{2} + \frac{(u-1)^3}{3} - \frac{(u-1)^4}{4}$$

$$\text{i.e.} \quad \ln\left(\frac{k+\alpha}{k+1}\right) \leq -\left(\frac{1-\alpha}{k+1}\right) - \frac{1}{2}\left(\frac{1-\alpha}{k+1}\right)^2 - \frac{1}{3}\left(\frac{1-\alpha}{k+1}\right)^3 - \frac{1}{4}\left(\frac{1-\alpha}{k+1}\right)^4$$

multiplying by $(k+1)^2(\alpha+k)$ and dividing by $(1-\alpha)$:

$$\hat{k}(k) \leq (k+\alpha)\left[-(k+1) - \frac{1}{2}(1-\alpha)^2 - \frac{1}{3}\frac{(1-\alpha)^3}{k+1} - \frac{1}{4}\frac{(1-\alpha)^4}{(k+1)^2}\right]$$

now, we use the following lower bounds:

$$(1-\alpha)^2 \geq 1 - 2\alpha$$

$$(1-\alpha)^3 \geq 1-3\alpha$$

$$\frac{1}{k+1} \geq 1-k+k^2-k^3$$

$$\frac{1}{k+1} \geq 1-k \text{ so } \frac{1}{(k+1)^2} \geq (1-k)^2$$

to obtain:

$$\hat{k}(k) \leq (k+\alpha)\left[-(k+1)-\frac{1}{2}(1-\alpha)-\frac{1}{3}(1-2\alpha)(1-k+k^2-k^3)-\frac{1}{4}(1-3a)(1-2k+k^2)\right]$$

D.1.3 Factor $m(k)$

We have $m(k) = (1-\alpha)\left(\hat{k}(k)+l(k)\right)$, so letting $\hat{m}(k) = \dfrac{m(k)}{1-\alpha}$ and using the estimates above:

$$\hat{m}(k) \leq (k+\alpha)\left(-(k+1)-\frac{1}{2}(1-\alpha)-\frac{1}{3}(1-2\alpha)(1-k+k^2-k^3)-\frac{1}{4}(1-3\alpha)(1-2k+k^2)\right) + (\alpha+k)\left(1-\frac{k}{2}+\frac{\alpha k}{2}\right)+k+k^2$$

after expanding, simplifying[28]:

$$12\cdot\hat{m}(k) \leq -8\alpha^2k^3+17\alpha^2k^2-20\alpha^2k+23\alpha^2-8\alpha k^4+21\alpha k^3-27\alpha k^2+15\alpha k-13\alpha+4k^4-7k^3+4k^2-k$$

Now, we let:

$$p_1(k) = -k+4k^2-7k^3+4k^4$$

$$p_2(k) = -1+15k-27k^2+21k^3-8k^4$$

$$p_3(k) = -20k+17k^2-8k^3$$

so that $12\cdot\hat{m}(k) \leq -12\alpha+23\alpha^2+p_1(k)+\alpha p_2(k)+\alpha^2 p_3(k)$. One may check that $p_1(k) < 0$ for $x < 1$, $p_2(k) < 0$ and $p_3(k) < 0$. When $\alpha \leq 0.5$, we also have $-11\alpha + 23\alpha^2 < 0$. Therefore, we finally have $m(k) < 0$, which implies $\rho'(k) > 0$ in the case $\alpha \leq 0.5$.

D.2 Case $0.5 \leq \alpha < 1$

D.2.1 Summand $l(k)$

Since we proved (on the interval $[0,1]$) $h(k) = \left(\dfrac{k+\alpha}{k+1}\right)^k \leq 1-\dfrac{1}{2}(1-\alpha)k$, so we in fact have $h(k) \geq \dfrac{1}{2}$ on this interval. Thus, $l(k) \leq \dfrac{\alpha}{2}+\dfrac{k}{2}+k+k^2$.

[28] We used SymPy to avoid errors and multiplied by 12 to avoid having fractions in coefficients.

D.2.2 Summand $p(k)$

We proceed similarly as above, using only the first term of the expansion ($\ln(u) \leq 1 - u$ if $u \in]0, 1]$):

$$\ln\left(\frac{k+\alpha}{k+1}\right) \leq \left(\frac{\alpha-1}{k+1}\right)$$

This leads to:

$$p(k) \leq (k+1)(\alpha+k)(\alpha-1)$$

$$\text{so } \hat{k}(k) \leq -(k+1)(\alpha+k)$$

D.2.3 Factor $m(k)$

We have $m(k) = (1-\alpha)\left(\hat{k}(k) + l(k)\right)$, so:

$$m(k) \leq (1-\alpha) \cdot \left(-\alpha - \alpha k + \frac{\alpha}{2} + \frac{k}{2}\right)$$

Now, if $\alpha \geq \frac{1}{2}$, clearly $m(k) < 0$; this again implies $\rho'(k) > 0$.

E Data Appendix

E.1 Lower Bound Values of one year voucher by year

Table 5: Lower Bound Values of one year voucher by year (in 1000 €)

Year	$\underline{V}_t^1$	$\underline{V}_t^2$	$\underline{V}_t^3$	$\underline{V}_t^4$	$\underline{V}_t^5$
2002	PLAVIX (2008)	ZOCOR (2002)	LIPITOR (2011)	NORVASC (2003)	PANTOZOL (2008)
	440,359	452,902	424,550	345,259	270,056
2003	PLAVIX (2008)	LIPITOR (2011)	NORVASC (2003)	PANTOZOL (2008)	ZYPREXA (2010)
	453,979	437,681	355,937	278,409	274,375
2004	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	SEROQUEL (2011)
	468,019	451,217	287,019	282,861	257,219
2005	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	SEROQUEL (2011)
	482,494	465,172	295,896	291,609	265,174
2006	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	SEROQUEL (2011)
	497,417	479,559	305,048	300,628	273,376
2007	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	SEROQUEL (2011)
	512,801	494,391	314,482	309,926	281,830
2008	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	SEROQUEL (2011)
	528,661	509,681	324,208	319,511	290,547
2009	LIPITOR (2011)	ZYPREXA (2010)	SEROQUEL (2011)	NEXIUM (2010)	TAXOTERE (2010)
	525,445	329,393	299,533	244,140	274,358
2010	LIPITOR (2011)	ZYPREXA (2010)	SEROQUEL (2011)	NEXIUM (2010)	TAXOTERE (2010)
	541,695	339,580	308,797	251,691	282,843
2011	LIPITOR (2011)	SEROQUEL (2011)	ZOMETA (2012)	SINGULAIR (2012)	VIAGRA (2012)
	558,449	318,347	89,707	131,425	114,167

Notes: Voucher values $\underline{V}_t$ for one year TEE, in 1000 Euros, with yearly discount factor $\delta = 0.97$ for vouchers purchased in a given year for extending the exclusivity several years ahead. As we rank values using the upper bound $\bar{V}_t$, it can happen that $\underline{V}_t^m < \underline{V}_t^n$ for $m < n$ while upper bounds are ordered. The values for the end of sample, particularly 2010 and 2011 are not reliable because our sample stops in 2012 and thus once we lack observation of other drugs whose exclusivity stops in or after 2012.

E.2 Calibration removing unwilling countries

Table 6: Union level TEE cost over fixed reward ratio by country - removing unwilling country

Country	(1) $\tilde{\rho}_i$	(2) $\tilde{\rho}_i^{gen}$	(3) $\frac{\gamma_i y_i^{gdp}}{\sum_j y_j^{gdp}}$	(4) $\frac{(1)}{(3)}$	(5) $\frac{(2)}{(3)}$	(6) $1+\lambda_i$	(7) $\frac{pop_i}{\sum_j pop_j}$	(8) $\frac{y_i^{ph}}{\sum_j y_j^{ph}}$	(9) $\frac{y_i^{gdp}}{\sum_j y_j^{gdp}}$
AUSTRIA	0.962	0.541	1.865	0.52	0.29	1.82	0.049	0.022	0.058
BELGIUM	1.311	0.803	0.773	1.70	1.04	1.98	0.025	0.031	0.028
FRANCE	8.097	4.244	5.423	1.49	0.78	2.41	0.149	0.205	0.151
GERMANY	6.726	5.812	8.250	0.82	0.70	1.96	0.191	0.206	0.212
GREECE	0.776	0.063	0.518	1.50	0.12	1.59	0.026	0.026	0.021
IRELAND	0.293	0.053	0.181	1.62	0.29	1.33	0.010	0.011	0.013
ITALY	3.686	2.767	4.513	0.82	0.61	1.68	0.137	0.145	0.137
NORWAY	0.145	0.151	0.289	0.50	0.52	1.2	0.011	0.009	0.018
POLAND	0.765	0.175	1.088	0.70	0.16	1.63	0.089	0.027	0.047
PORTUGAL	0.603	0.169	0.311	1.94	0.54	1.82	0.025	0.021	0.018
SPAIN	2.847	1.328	2.362	1.21	0.56	1.79	0.105	0.117	0.094
SWEDEN	0.860	0.861	0.482	1.78	1.79	2.06	0.022	0.023	0.025
SWITZERLAND	0.324	0.192	0.454	0.71	0.42	1	0.018	0.021	0.027
UK	8.366	6.316	8.323	1.01	0.76	1.81	0.144	0.135	0.151

Notes: We also report the share of each country population, pharmaceutical manufactures revenue as well as the share of GDP.

E.3 Alternative calibration

Table 7 shows the estimated parameters when we add a molecule fixed effect in the demand equation (1) in which case we estimate

$$\log q_{ijt} \approx \log(\sigma_{ij}\frac{k_i+1}{m_i}) - k_i\gamma_i\frac{p_{ijt}}{m_i} + \epsilon_{ijt}$$

where the parameter σ_i reported is $\sigma_i \equiv \frac{1}{J(i)}\sum_j \sigma_{ij}$.

Table 7: Demand, Bargaining parameters and cost over reward ratio by country

Country	α_i	k_i	γ_i	ρ_i	ρ_i^{gen}	$\mathcal{E}_i$	$\frac{y_i^{ph}}{\sum_j y_j^{ph}}$	$\frac{y_i^{gdp}}{\sum_j y_j^{gdp}}$	$\frac{\frac{\sigma_i(k_i+1)}{m_i}}{\sum_j \frac{\sigma_j(k_j+1)}{m_j}}$
AUSTRIA	0.9140	0.8898	12.00	1.0212	0.5852	-0.058	0.022	0.058	0.034
BELGIUM	0.9725	0.9030	4.00	1.0066	0.6279	-0.020	0.030	0.027	0.049
FINLAND	0.9474	0.9147	4.00	1.0129	0.8222	-0.037	0.013	0.013	0.031
FRANCE	0.9450	0.8559	11.00	1.0130	0.5406	-0.040	0.202	0.149	0.120
GERMANY	0.9783	0.7244	7.00	1.0046	0.8719	-0.015	0.203	0.209	0.102
GREECE	0.9360	0.8604	11.00	1.0153	0.0845	-0.049	0.026	0.020	0.068
IRELAND	0.9291	0.8633	5.00	1.0171	0.1900	-0.051	0.011	0.013	0.030
ITALY	0.9776	0.8283	6.00	1.0051	0.7599	-0.018	0.143	0.135	0.120
NORWAY	0.9554	0.8716	5.00	1.0106	1.0499	-0.035	0.009	0.018	0.014
POLAND	0.9116	0.9112	11.00	1.0221	0.2388	-0.074	0.027	0.047	0.065
PORTUGAL	0.9487	0.8701	7.00	1.0123	0.2876	-0.038	0.021	0.018	0.077
SPAIN	0.9515	0.9251	7.00	1.0120	0.4809	-0.042	0.115	0.093	0.132
SWEDEN	0.8978	0.9243	7.00	1.0259	1.0280	-0.072	0.023	0.025	0.034
SWITZERLAND	0.9215	0.9435	8.00	1.0198	0.6083	-0.058	0.021	0.026	0.030
UK	0.9852	0.8174	8.00	1.0033	0.7622	-0.011	0.133	0.149	0.094

Notes: Adding molecule fixed effect in demand. We also report each country's share of union pharmaceutical expenses, share of union GDP, and share of union market size.

Table 8: Union level TEE cost over fixed reward ratio by country - removing unwilling country

Country	(1) $\tilde{\rho}_i$	(2) $\tilde{\rho}_i^{gen}$	(3) $\frac{\gamma_i y_i^{gdp}}{\sum_j y_j^{gdp}}$	(4) $\frac{(1)}{(3)}$	(5) $\frac{(2)}{(3)}$	(6) $1+\lambda_i$	(7) $\frac{pop_i}{\sum_j pop_j}$	(8) $\frac{y_i^{ph}}{\sum_j y_j^{ph}}$	(9) $\frac{y_i^{gdp}}{\sum_j y_j^{gdp}}$
AUSTRIA	0.335	0.192	0.690	0.48	0.28	1.82	0.049	0.022	0.058
BELGIUM	0.173	0.108	0.109	1.59	0.99	1.98	0.025	0.030	0.027
FINLAND	0.137	0.111	0.053	2.57	2.09	1.61	0.012	0.013	0.013
FRANCE	2.302	1.228	1.635	1.41	0.75	2.41	0.147	0.202	0.149
GERMANY	1.125	0.977	1.461	0.77	0.67	1.96	0.189	0.203	0.209
GREECE	0.321	0.027	0.225	1.43	0.12	1.59	0.025	0.026	0.020
IRELAND	0.098	0.018	0.064	1.53	0.29	1.33	0.010	0.011	0.013
ITALY	0.627	0.474	0.810	0.77	0.59	1.68	0.136	0.143	0.135
NORWAY	0.043	0.044	0.089	0.48	0.50	1.2	0.011	0.009	0.018
POLAND	0.344	0.080	0.513	0.67	0.16	1.63	0.088	0.027	0.047
PORTUGAL	0.234	0.066	0.126	1.85	0.53	1.82	0.024	0.021	0.018
SPAIN	0.745	0.354	0.652	1.14	0.54	1.79	0.103	0.115	0.093
SWEDEN	0.293	0.294	0.175	1.67	1.67	2.06	0.021	0.023	0.025
SWITZERLAND	0.143	0.086	0.211	0.68	0.41	1	0.018	0.021	0.026
UK	1.140	0.866	1.195	0.95	0.72	1.81	0.142	0.133	0.149

Notes: Adding molecule fixed effect in demand. We also report the share of each country population, pharmaceutical manufactures revenue as well as the share of GDP.

Table 9: Union level TEE cost over fixed reward ratio by country - removing unwilling country

Country	(1) $\tilde{\rho}_i$	(2) $\tilde{\rho}_i{}^{gen}$	(3) $\frac{\gamma_i y_i^{gdp}}{\sum_j y_j^{gdp}}$	(4) $\frac{(1)}{(3)}$	(5) $\frac{(2)}{(3)}$	(6) $1+\lambda_i$	(7) $\frac{pop_i}{\sum_j pop_j}$	(8) $\frac{y_i^{ph}}{\sum_j y_j^{ph}}$	(9) $\frac{y_i^{gdp}}{\sum_j y_j^{gdp}}$
AUSTRIA	0.346	0.198	0.700	0.50	0.28	1.82	0.049	0.022	0.058
BELGIUM	0.179	0.112	0.110	1.62	1.01	1.98	0.025	0.031	0.028
FRANCE	2.382	1.271	1.657	1.44	0.77	2.41	0.149	0.205	0.151
GERMANY	1.165	1.011	1.481	0.79	0.68	1.96	0.191	0.206	0.212
GREECE	0.332	0.028	0.228	1.46	0.12	1.59	0.026	0.026	0.021
IRELAND	0.101	0.019	0.065	1.56	0.29	1.33	0.010	0.011	0.013
ITALY	0.649	0.491	0.820	0.79	0.60	1.68	0.137	0.145	0.137
NORWAY	0.044	0.046	0.090	0.49	0.51	1.2	0.011	0.009	0.018
POLAND	0.356	0.083	0.520	0.68	0.16	1.63	0.089	0.027	0.047
PORTUGAL	0.242	0.069	0.128	1.89	0.54	1.82	0.025	0.021	0.018
SPAIN	0.771	0.366	0.661	1.17	0.55	1.79	0.105	0.117	0.094
SWEDEN	0.303	0.304	0.178	1.71	1.71	2.06	0.022	0.023	0.025
SWITZERLAND	0.148	0.089	0.214	0.69	0.41	1	0.018	0.021	0.027
UK	1.179	0.896	1.211	0.97	0.74	1.81	0.144	0.135	0.151

Notes: Adding molecule fixed effect in demand. We also report the share of each country population, pharmaceutical manufactures revenue as well as the share of GDP.