Patent Vouchers as Innovation Incentives: Theory and Evidence from Europe*

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Abstract

A patent voucher grants the innovator a transferable right to extend market exclusivity. Although policy interest in such instruments is rising, little is known about their efficiency relative to conventional cash prizes. We develop a theoretical framework to compare the social cost of rewarding innovation with cash versus a voucher. Using comprehensive pharmaceutical sales data from 15 European countries, we provide the first empirical evaluation of voucher schemes. Our results show that in most countries, vouchers impose a lower cost on consumers than the incentive-equivalent cash transfers borne by taxpayers, largely because post-patent generic competition is imperfect. We also analyze cross-country heterogeneity, the risk of adverse selection, and design considerations such as voucher auctions. Overall, the findings suggest that, if carefully designed, patent vouchers can serve as a valuable complement to existing innovation incentives.

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Keywords: Patents, vouchers, prizes, pull mechanisms, burden sharing, drug prices.

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1 Introduction

Intellectual property rights remain the dominant tool for encouraging innovation, yet they fail to support viable business models in many "orphan markets": drugs for small populations or low-income countries, new antibiotics and vaccines that safeguard against pandemics, or green technologies that curb greenhouse gas emissions. These settings compound the familiar problem of unpriced knowledge spillovers with additional market failures—such as limited buyer solvency, free riding, and unpriced carbon externalities—strengthening the case for supplementary pull incentives. Prizes and advance market commitments have long been proposed to address these gaps. More recently, policymakers in the United States and Europe have explored *transferable exclusivity extensions (TEEs)*—commonly known as *patent vouchers*—which allow innovators, or the firms that purchase these rights, to extend the life of an existing patent.[1]

Are patent vouchers a good idea? At first glance, the extension of exclusivity appears less efficient than prizes, since it prolongs monopoly distortions. Yet this view overlooks an important nuance: the welfare gains from patent expiry are overstated when post-patent competition is weak. Generic drug prices, for example, remain above competitive levels when entry costs are high, brand loyalty is strong, firms collude, or regulators provide incentives to secure generics delivery. In such cases, the social benefit from patent expiration may be modest, and the innovator's ability to sell a patent voucher can substitute for large cash transfers, potentially saving substantial public funds.

Our analysis focuses on the form of the reward—cash versus vouchers—rather than its overall size, which depends on the elasticity of innovation supply.[2] We make both theoretical and empirical contributions. We develop a tractable model to compare the costs and benefits of vouchers, captured by their cost-over-reward ratio (a variant of the inverse marginal value of public funds). We then draw on comprehensive sales data from 15 European countries to quantify the conditions under which vouchers provide innovation incentives at lower social cost than direct cash payments. The results also highlight cross-country differences and the importance of voucher design in shaping outcomes.

[1] The impetus for a patent voucher was not based on a cost-benefit analysis, but rather built on the failure of previous European attempts at funding an ambitious pan-European antibiotic-innovation reward scheme. In Europe, fiscal decisions must be taken unanimously, so member states are able to stay out of the financing: Cash funding is ripe with free riding. In contrast, the European Medicines Agency can "tax" all member states: It can delay granting licenses to new generics for the molecule that has purchased the voucher, for a time period equal to its length, de facto enforcing the intellectual property rights associated with the voucher.

[2] Thus, the paper is not concerned with the incentive side and simply presumes that society has determined some level of reward for the innovation. Whether the reward is appropriate for the innovation is irrelevant for the structure study, for the social cost of providing the reward must be minimized whether the reward is well-picked or off-the-mark.

Theory. The cost-over-reward ratio captures, for each additional dollar of benefit granted to the innovator through a voucher, how many dollars of social surplus are lost. If the ratio exceeds one, vouchers are less efficient than an equivalent cash prize; put differently, cash is the cheaper currency. Notably, the duration of the exclusivity extension does not affect this ratio and is therefore irrelevant when comparing vouchers to direct payments.

A voucher raises the price of the drug to which exclusivity is extended. The resulting welfare loss depends on the price of generics, which in turn reflects their mode and intensity of competition and whether quasi-rents are dissipated by free entry.

To maintain tractability, our model cannot incorporate every nuance of national environments. Instead, we calculate the cost-over-reward ratio under two simplifying assumptions, which we later revisit. Firstly, after patent expiry, branded and generic molecules are imperfect substitutes: a country-specific fraction of consumers remain captive to the branded product, while the rest consider both branded and generic options. Secondly, the branded price during and past the exclusivity period is determined through Nash-bargaining with the regulator, who stands for the public or private entity in charge of negotiations with the owner of intellectual property. One natural interpretation is that negotiations can be reopened when one of the parties so desires (although they will not if the environment is stationary). While stylized, these assumptions allow us to derive a simple formula for the cost-over-reward ratio, that has broad empirical applicability.

We compute this ratio both for a single country and for a union of countries that jointly finance neglected drugs. Joint funding is often necessary to generate reward levels sufficient to spur innovation in areas lacking viable business models. It is therefore essential to compare the incidence of cash transfers and voucher schemes across participating countries.

Section 3 shows that a country is more likely to prefer a voucher scheme to a cash transfer when (i) its generic prices are high, (ii) the country's contribution share in a union-wide prize is high, and (iii) under natural conditions, when the country has a large market size for the drug.

Empirics. To the best of our knowledge, our paper is the first to estimate the costs and benefits of a voucher scheme. We assemble a comprehensive dataset covering all drugs sold in 15 European countries—including the largest economies—over the period 2002–2012 (Section 4). The data include sales volumes (in standard units) and values for each product, as well as the identity of the molecule and its status as branded or generic.

This structure allows us to measure, for each country, the share of consumers who remain loyal to the originator after generic entry and the extent of revenue preservation by the originator firm. Using these measures, we estimate the value of one-year vouchers and identify

their potential acquirers during the sample period. We then recover country-specific demand parameters and, exploiting observed prices before and after patent expiry, compute cost-over-reward ratios both at the national level and for a hypothetical union of the 15 countries. As we noted, this approach does not require assumptions about the determination of post-exclusivity prices. Nevertheless, earlier estimates that explicitly calibrated a bargaining framework yield results broadly consistent with our findings, reinforcing the robustness of the analysis.

We begin by investigating the efficiency of a voucher scheme relative to a prize scheme, at the single-country level and at the (15-country) union level. We first show that, if they lived in isolation and only chose between the two incentive schemes (the voucher and the prize) to raise funding, all 15 countries in the sample would unambiguously prefer a voucher scheme over a prize scheme. That is, a voucher scheme is more efficient than a prize scheme at the single-country level.

We next turn to union-level scheme (within the 15 countries in our sample), asking two main questions:

(a) *Is a union-wide voucher scheme more efficient than a union-wide prize scheme,* i.e., does there exist a contribution rule that achieves unanimity over all 15 countries in our data in favor of a voucher?

(b) Does a union-wide voucher scheme achieve a *qualified majority* (as defined by EU rules, i.e., 55% of Member States and 65% of the population) among the 15 countries in our data, given a budget contribution rule proportional to GDP (as is broadly the case in the EU)?

We note that the answer to question (a) is "yes": a union-wide voucher scheme is more efficient than a union-wide prize scheme (there exists a contribution rule that makes all countries strictly favor a voucher over a prize). Combined with our analysis of isolated countries, this result suggests that in our data, a voucher scheme is more efficient than a prize scheme both at the country level and at the union level. Moreover, we show that the answer to question (b) is "almost yes": a union-wide voucher scheme *almost achieves* a qualified majority among the 15 countries in our data, given a budget contribution rule proportional to GDP: consistently with our theoretical prediction, while the 8 largest countries favor a voucher, the smaller countries favor a prize. So, a union-wide voucher scheme gathers the support of 88% of the population in our data (well above the required 65%) and 53% of countries (slightly missing the 55% threshold).

As a caveat, our sample does not include all EU countries (but includes the UK): Since the missing countries are smaller countries and our analysis suggests that such countries are

less likely to favor a voucher, it may be that a voucher fails to achieve a qualified majority *in country count* by a larger margin when considering the whole set of EU Member States. By contrast, given the large dominance of the voucher scheme over the prize scheme in terms of union-wide efficiency, and its unanimous dominance in terms of country-wide efficiency, it is unlikely that considering the whole set of EU Member States would overturn the voucher's dominance in terms of efficiency.

Discussion. Finally, we examine two potential concerns that may limit the appeal of vouchers. First, market power in voucher auctions can raise the cost-over-reward ratio. However, once established, the rents accruing to voucher buyers themselves encourage innovation. Second, we consider the risk of adverse selection: Vouchers may be used disproportionately for drugs with particularly high cost-over-reward ratios. Our empirical analysis later estimates the magnitude of this effect and shows that our main results remain robust.

Successful implementation is critical. Poorly designed voucher schemes can generate high social costs. In Section 5, we discuss several pitfalls and propose remedies. A central issue is that current proposals specify a fixed voucher duration (e.g., one year), which creates uncertainty both about the developer's reward and about the total costs borne by patients and taxpayers. This uncertainty can be avoided by reversing the auction design: rather than fixing the voucher length, fix the reward to the innovator and let firms bid on the minimum exclusivity period they would accept in exchange. The winning bidder is the firm that offers the shortest extension, thereby minimizing the social cost of the voucher while ensuring a predictable reward for the innovator.

Policy proposals in the antibiotics space. While pull mechanisms usually take the form of prizes, possibly reinforced by extended patent lengths and expedited approval processes, it has lately been proposed that inventors of new antibiotics be rewarded with vouchers. In fact, such a voucher system has recently been adopted in Europe as part of the reform of the European pharmaceutical legislation, recently adopted by the European Commission and the European Parliament (December 2025). The new legislation grants an extra year of regulatory protection (amounting to market exclusivity) for companies that deliver functioning innovative therapies against multi-drug resistant infections.[3]

In the United States, an early draft of the bipartisan 2018 US REVAMP Act planned to introduce vouchers for drugs designated as priority antimicrobial products. Although a patent-voucher mechanism has yet to be implemented, a different form of vouchers, "priority

[3]See https://health.ec.europa.eu/medicinal-products/legal-framework-governing-medicinal-products-human-use-eu/reform-eu-pharmaceutical-legislation and https://www.europarl.europa.eu/news/en/press-room/20251209IPR32110/deal-on-comprehensive-reform-of-eu-pharmaceutical-legislation (accessed March 2026).

review vouchers", which were inspired by academic work (Ridley et al., 2006), have been used in the US since 2007. While they differ much economically from patent vouchers (see Appendix B), they share their spirit of rewarding innovation through tradable vouchers.

Related literature. From a methodological perspective, our cost-over-reward ratio approach is closely related to the marginal-value-of-public-funds (MVPF) approach (Hendren, 2016; Finkelstein and Hendren, 2020; Hendren and Sprung-Keyser, 2020). Indeed, defining the MVPF as the "ratio of the benefits that [a] policy provides to its recipients, divided by the policy's net cost to the government" (Hendren and Sprung-Keyser, 2022), the relevant ratio in our environment becomes the ratio of the incentive to innovate delivered by a policy over the policy's net cost to citizens, be they consumers (vouchers) or taxpayers (prize). For ease of interpretation and following the spirit of the MVPF approach, we take the inverse of that ratio to identify the "bang-for-the-buck" of a policy, i.e. the policy's social cost from providing \$1 of incentive to innovate.[4]

The public-health literature on transferable exclusivity extensions is still nascent.[5] Rome and Kesselheim (2020) provide an estimation based on US data (2007-2019) of the costs associated with one-year transferable exclusivity extension for fast-track drugs. Their analysis is limited to financial costs and does not consider user welfare. Moreover, while their focus on a fixed length for exclusivity extension is motivated by the proposed 2018 REVAMP Act (fixed one-year extensions), it could – and indeed should – 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 1997 FDA Pediatric Exclusivity Extension, which gave pharmaceutical manufacturers 6 additional months of market exclusivity for performing pediatric clinical trials of brand-name drugs widely used in adults.[6] 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 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 voucher schemes should be tailored, emphasizing that the length of the exclusivity

[4]There are differences between the two concepts. First, the MVPF allows for welfare weights. The concept of cost-over-reward ratio can be extended to allow for welfare weights if one can assign welfare weights along the demand curve. Second, Hendren and Sprung-Keyser (2020) compare the welfare impact per dollar of alternative policies. So, their concept does not require taking a stance on the cost of public funds. In contrast, the comparison of a prize and a voucher involves as we will see the shadow cost of public funds.

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

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

extension be adapted to the investment need of antibiotic development, as well as what guardrails should be set to prevent market abuse – e.g., sufficient advance notice of the exclusivity extension to generic manufacturers.[7] However their discussions remain mostly informal and consider only US markets. Imperfect tailoring and regulation of vouchers may significantly reduce their desirability. Yet, vouchers may be easier to implement, albeit imperfectly, than alternative incentive schemes such as direct cash transfers, due to budgetary rules and political constraints, both in the US and in Europe.

Lastly, another literature, pioneered by Ridley et al. (2006), investigates transferable "priority review vouchers" (PRVs). Gans and Ridley (2013) notably provide 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 Online Appendix A how our approach helps 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 for priority review vouchers on the one hand, and transferable patent extensions on the other hand differ significantly. We provide, again in Online 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 vouchers increases with it.

2 Vouchers vs prizes in a single country

As any incentive scheme must achieve a sufficiently large scale to be effective, the analysis in this Section applies to large countries, which are likely to be federal states, such as the United States and the European Union, provided that negotiated cross-country transfers enable the realization of Pareto improvements.[8]

The inventor who receives the voucher (e.g., for having developed a priority antibiotic) puts the voucher for sale in an auction.[9] This auction is assumed perfectly competitive. Hence, consider a firm owning a patent on, say, a drug, that is due to expire at horizon T.

[7] The voucher is problematic when used for a patent about to expire and 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 and interest charges during the exclusivity extension, or even renew its entry investment, is *per se* socially wasteful. We abstract away from such holdups in the following by assuming that sufficient prior notice of the identity of the acquirer of the exclusivity extension is given to generics companies.

[8] See Section 3 for the case of a multi-union countries and more details on the European Union.

[9] Keeping the voucher for one of its own drugs is optimal for the inventor only if the inventor owns the current blockbuster drug that would benefit the most from an exclusivity extension. This scenario is highly unlikely, in particular in the case of priority antibiotics as most R&D in the field is performed by highly specialized firms, and antibiotics are not among the most profitable drugs.

The firm's willingness-to-pay for the voucher, i.e., for an extension Δ of the protection length of the patent is

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

where π_E is the flow profit during the exclusivity period, π_{NE} the flow profit when exclusivity is lost (the molecule is off-patent), and r is the rate of interest.[10]

Observation 1. *The voucher is more valuable to its acquirer, the longer the exclusivity extension (Δ), and, all else being equal, also*

- *the shorter the time T remaining before the patent expires,*
- *the more profitable the patent (the higher π_E is),*
- *the less profitable the molecule once it is off-patent (the lower π_{NE} is).*

2.1 Comparing vouchers and prizes

Let us compare the respective costs of vouchers and prizes, assuming that both schemes deliver a given reward to the innovator. To develop our analysis, we make the following assumptions:

(i) Health expenditures. Drug expenditures are decided and paid by the regulator, be it a government or an insurance company (it is straightforward to adjust our formulae to alternative assumptions about drug coverage). Let the therapeutic benefit of the drug for a consumer of type θ be equal to θ, distributed according to cumulative distribution $F(\theta)$ on $[0, +\infty)$. Letting θ^* denote the marginal consumer to have access to the drug, the quantity consumed is $\sigma[1 - F(\theta^*)]$, where σ denotes the size of the market (say, the population susceptible to taking the drug). The regulator faces a shadow cost of funds $\lambda \geq 0$. Let $\phi(y, h)$ denote the representative consumer's utility of income y and health condition h.[11] So, letting

$$\gamma \equiv (1 + \lambda)\phi_y/\phi_h$$

denote the marginal rate of substitution between income and health, times the shadow cost of public funds, the optimal cutoff at a given price p satisfies:

$$\theta^* = \gamma p.$$

[10] **?** allow interests rate to differ for the government and the firm. This can be easily incorporated into the modeling below.

[11] See Appendix A for details (we take a Taylor expansion, assuming that the health benefit and the financial cost of the drug are small relative to h and y, respectively).

The demand at price p can thus be written:

$$D(\gamma p) \equiv \sigma[1 - F(\gamma p)] \tag{1}$$

Consequently, under exclusivity and price p_E, the social surplus in utils is:

$$\phi_h \sigma \int_{\gamma p_E}^{+\infty} [\theta - \gamma p_E] dF(\theta) = \phi_h \gamma \int_{p_E}^{+\infty} D(\gamma p) dp \equiv \phi_h \gamma S(p_E), \tag{2}$$

where $S(p_E)$ is the social surplus in monetary terms.

Let $\varepsilon(p) \equiv -pD'(p)/D(p)$ denote the elasticity of demand. We make the following standard assumption (familiar from mechanism design for instance):

Assumption 1. *Demand is strictly log-concave.*

Assumption 1 implies that the demand elasticity is weakly increasing in price ($\varepsilon'(p) \geq 0$).

The cost of the voucher policy is measured by the loss in social welfare induced by the drug's patent extension. Letting $X \equiv \int_T^{T+\Delta} e^{-r\tau} d\tau$, this social-welfare loss (in utils) is equal to $L^{\text{voucher}} \equiv \phi_h \gamma X (S_{NE} - S_E)$, where S_R is the consumer net surplus in monetary terms in regime $R \in \{E, NE\}$. The cost (in utils) of a cash prize Γ is $L^{\text{prize}} = \phi_y (1 + \lambda)\Gamma$. A voucher is preferred to a prize if and only if $L^{\text{voucher}} \leq L^{\text{prize}}$. Hence, equalizing the reward from the cash prize and the exclusivity extension, $\Gamma = X(\pi_E - \pi_{NE})$ where π_R is the drug producer's profit in regime $R \in \{E, NE\}$, a voucher is preferred to a prize if and only if:

$$\rho \equiv \frac{S_{NE} - S_E}{\pi_E - \pi_{NE}} \leq 1, \tag{3}$$

where ρ is the cost-over-reward ratio of the exclusivity extension.

The cost of public funds and the marginal rate of substitution between income and health thus affect the comparison between a prize and a voucher through the demand function $D(\gamma p)$. While the social costs (in therapeutical terms) of a prize and of the patent extension are both multiplied by γ, the voucher's cost involves both this mechanical increase in drug expenditures and a quantity adjustment, in which some consumers are denied consumption of the drug. Thus, unlike the cost of a prize, the cost of the voucher grows less than proportionally with γ.

(ii) *Voucher demand.* We assume that voucher buyers have no market power in the market for the voucher, that is, the winner of the auction disburses her willingness to pay for the

patent extension (market power is discussed in Section 5.1). The pharmaceutical company that buys the exclusivity extension faces a constant marginal cost of production, denoted by $c \geq 0$, for the drug to which it applies the exclusivity extension. Hence, for a given price p and under exclusivity, profit is $\pi_E(p) = (p-c)D(\gamma p)$, and is assumed to be strictly quasi-concave. Generics face the same constant marginal cost of production.

(iii) Consumer loyalty. Generics can enter the market at the end of the exclusivity period, extended or not. They are perfect substitutes among themselves. We model the preference of consumers for generics relative to the branded drug as follows. A share $x \in [0,1)$ of "captive consumers" does not trust the generics and remains captive of the branded drug, while the non-captive consumers, in proportion $(1-x)$, buy from the seller offering the lowest price: Non-captive consumers face the full consideration set {branded drug, generics}, while captive ones consider only the branded drug. Whether the consumer is captive or not is independent of their willingness to pay for the drug, i.e. their therapeutical benefit from the drug. Hence, both the captive and non-captive markets have the same demand as a function of the prices, up to a factor x or $(1-x)$. The drug manufacturer cannot price-discriminate between captive and non-captive users.

The generics' price is denoted by $p_g \geq c$. If the non-captive market is perfectly competitive, $p_g = c$. In practice however, the generics' price p_g is usually higher than the marginal cost c, for example due to entry costs or imperfect competition. We model the outcome of price competition in the following reduced-form way (foundations will be developed in Section 2.2): The branded drug's price p_{NE} strictly exceeds the generics price, p_g. Accordingly, generics producers supply non-captive consumers, while the branded drug focuses on captive ones. The branded drug focuses on captive consumers and therefore sets price $p_{NE} = \bar{p}$, where $\bar{p} \leq p^m \equiv \arg\max(p-c)D(\gamma p)$ is the price cap negotiated between the regulator and the branded drug producer.

After patent expiry, captive consumers (non-captive ones) face price p_{NE} (resp. p_g). Therefore, the post-exclusivity social surplus is (in utils):

$$\phi_h \gamma \Big(xS(p_{NE}) + (1-x)S(p_g) \Big).$$

Finally, applying (3) yields the cost-over-reward ratio:

$$\rho = \frac{xS(p_{NE}) + (1-x)S(p_g) - S(p_E)}{\pi(p_E) - x\pi(p_{NE})} = \frac{x\int_{p_{NE}}^{p_E} D(\gamma p)dp + (1-x)\int_{p_g}^{p_E} D(\gamma p)dp}{(p_E - c)D(\gamma p_E) - x(p_{NE}-c)D(\gamma p_{NE})}. \qquad (4)$$

2.2 Endogenizing prices

The cost-over-reward ratio can be computed using (4), i.e., observed data on supply, demand and prices, without any further assumptions on the price determination. However, as a part of our theoretical analysis and to provide foundations for the presumed payoff functions, we derive prices from regulatory behavior and firms' strategic choices.

(1) Regulation in the exclusivity period. The price of the branded drug during the exclusivity period (including any extension) is determined via Nash bargaining with the regulator. The regulator maximizes the consumers' net surplus during the exclusivity period, while the producer of the branded drug maximizes profit during that same period. When bargaining with the regulator, the firm faces utility function $U(\pi_E + \Pi_0)$, where U is a twice-differentiable, strictly increasing and weakly concave function of profit,[12] and Π_0 denotes the firm's background profit (when choosing not to sell the drug to the regulator).[13] Letting α denote the regulator's bargaining power, the Nash-bargained[14] exclusivity price $p_E \leq p^m$ maximizes:

$$S(p)^{\alpha}\big[U\big((p-c)D(\gamma p) + \Pi_0\big) - U(\Pi_0)\big]^{1-\alpha}.$$

(2) Regulation in the post-exclusivity period. A cap $\bar{p} \leq p^m$ on the post-exclusivity price for the branded drug is negotiated between the regulator and the producer of the branded drug. Let n_g denote the number of active generics producers.[15] We restrict attention to pure pricing strategies.

The timing goes as follows: (1) Given cap $\bar{p}$, generics producers make their competitive choice. (2) After observing the generics' choices, the branded drug producer selects a price $p \leq \bar{p}$.[16]

We make the following general assumptions on the post-exclusivity market equilibrium – which are satisfied in the three prominent examples described below (perfect competition, Cournot competition and tacit collusion).

(a) The generics producers all charge a price $p_g = P_g(\bar{p}, x)$, where $P_g(\bar{p}, x) < \bar{p}$ is weakly

[12] In particular, U can be linear. A strictly concave U captures the assumption that the firm is credit-constrained, and immediately reinvests any income in new projects, which are independent from other projects (for simplicity, the firm cannot cross-pledge collateral across generations of projects). Our only result that requires strict concavity is the comparative static with respect to market size (see Proposition 3).

[13] Note that upon first introducing its drug on the market, the firm expects perfect competition in voucher auctions, and thus foresees a zero net profit from buying a voucher; while after having bought a voucher, the latter's price is sunk and plays no role in a subsequent bargaining with the regulator.

[14] As is well-known, Nash bargaining admits sequential-offer-bargaining microfoundations (Stahl, 1972; Rubinstein, 1982).

[15] For expositional simplicity, we take this number as fixed, but our results still hold when n_g is determined by a free-entry condition (see Appendix B).

[16] Sequential price setting ensures the existence of an equilibrium in pure strategies.

increasing in its two variables, and serve the non-captive consumers.

(b) The branded drug producer contents itself with selling to its captive market at price $p_{NE} = \bar{p}$ and does not undercut the generics' price to reap the non-captive market as well.

The theoretical analysis depends on whether $P_g(\bar{p}, x)$ is constrained by $\bar{p}$. Namely, we say that the captive and non-captive markets are *decoupled* if the price charged by generics producers is the same as if the branded molecule were not sold, and that they are *coupled* otherwise. Let $p_g^{\emptyset}$ be the generics' price when the branded drug is not in the market, and let $P^L(\bar{p}, x) < \bar{p}$ be the price such that the branded drug manufacturer is indifferent between focusing on the captive market at price $\bar{p}$ and undercutting the generics (where the superscript L stands for "limit price"):

$$x\pi_E(\bar{p}) \equiv \left[P^L(\bar{p}, x) - c\right] D(\gamma P^L(\bar{p}, x)). \tag{5}$$

Straightforward computations yield the following result.

Lemma 1. ***(Captive and non-captive markets: Coupling vs decoupling)*** *The generics equilibrium price is the minimum of $p_g^{\emptyset}$ (decoupling) and $P^L(\bar{p}, x)$ (coupling). The captive and non-captive markets are decoupled ($p_g < P^L(\bar{p}, x)$) if and only if*

(i) competition among generics is intense ($p_g^{\emptyset}$ is low),

(ii) the captive market is large (x is large),

(iii) regulation is weak (i.e. $\bar{p}$ is high).

Examples of generics' pricing

(1) Perfect competition. When generics are perfectly competitive ($p_g \equiv c$, a price that is independent of both $\bar{p}$ and x), the captive and non-captive markets are always decoupled.

(2) Cournot. Suppose that n_g generics producers set their production capacity[17] simultaneously. In the absence of the branded drug, the Cournot (generics) oligopoly would result in a Cournot price $p_g^{\emptyset} = P^C(n_g)$, a decreasing function of n_g.

If the "no-undercutting constraint" (5) is satisfied by the unconstrained Cournot price ($P^C(n_g) \leq P^L(\bar{p}, x)$), then the captive and non-captive markets are decoupled, and $P_g(\bar{p}, x) \equiv P^C(n_g)$ does not depend on $\bar{p}$ (but still depends on x whenever there is free entry in the generics market with a strictly positive entry cost, as n_g does). If $P^C(n_g) > P^L(\bar{p}, x)$, then the two markets are coupled, the generics oligopolists increase their capacity investments to

[17] We assume for simplicity that the branded drug manufacturer faces no capacity constraint.

avoid being undercut by the branded drug and $p_g \equiv P^L(\bar{p}, x)$ is strictly increasing in $(\bar{p}, x)$.[18]
(3) Tacit collusion. Suppose now that time is discrete, indexed after the loss of exclusivity by $t \in \{0, 1, ..\}$, and with discount factor δ. Each period, the n_g generics producers[19] (who face no capacity constraints) coordinate on a price – the branded drug producer is not part of the cartel, although this assumption can be relaxed (see Appendix B and Online Appendix B). The branded drug producer undercuts this price if this is beneficial in the period. Suppose in a first step that the generics producers ignore the threat of undercutting by the branded drug producer. As is well-known, tacit collusion is feasible if and only if the discount factor is high enough $(1 - \delta)n_g \leq 1$ (otherwise the Bertrand outcome of case (1) prevails). In that case, the cartel sets the highest price that does not lead the branded drug manufacturer to undercut, so $p_g \equiv P^L(\bar{p}, x)$. The captive and non-captive markets are always coupled if tacit collusion is feasible.

2.3 Discussion of assumptions

The model contains the two simplifying assumptions behind our empirical analysis: (1) Captive vs non-captive consumers. (2) Nash-bargaining over the exclusivity price (that is, we ignore any impact of the exclusivity price on the post-exclusivity variables).
(1) Captive vs. non-captive consumers. Our assumption of two different consideration sets is for simplicity only. More generally, consumers could differ continuously in their reluctance to use the generics (consumer ϑ would be willing to consume the generic if and only if $p_g + \vartheta \leq p_{NE}$, where $\vartheta \geq 0$ is smoothly distributed along $\mathbb{R}_+$, with possibly an atom at 0). Our two-groups-of-consumers model captures the basic competitive advantage of the branded drug, and exhibits the key properties of the smoother model in a straightforward manner.
(2) Exclusivity price. We assumed that Nash bargaining over the branded drug's price in the exclusivity period ignores the post-exclusivity period. Put differently, neither the regulator nor the branded drug producer account for the potential impact of their current contract on price setting after the patent expires. This neglect if fully rational if the post-exclusivity price is negotiated anew; this is the case in particular in the US, where pharmacy benefit managers and insurers renegotiate prices anew when generics enter. However, this neglect is less appealing when the legacy cap impacts the post-exclusivity one (as for instance in France and in our legacy modeling, with $\overline{p} = p_E$, in Online Appendices C.1 and D). A defense in this case is that discounting between the first negotiation and the determination of the

[18] The analysis is the same if there is free entry in the generics market (see Appendix B).
[19] As with the Cournot model, the same analysis applies when the number of generics producers is endogenized through a free-entry condition. See Appendix B for details.

branded drug's post-exclusivity price may be heavy.[20]

(3) Absence of generics' regulation. The absence of generics regulation is broadly a reasonable assumption. Even when generics' prices are regulated,[21] they most often largely exceed the (very small in our time sample) marginal production costs of generics. Such regulations may not alter our theoretical analysis, and in any case, they do not affect our empirical analysis of the cost-over-reward ratio, given our assumption of myopic Nash-bargaining over the exclusivity price.

3 Vouchers vs prizes in a multi-country union

Irrespectively of a country's preference for a voucher or a cash prize, a single country may not be able to achieve a reward large enough to incentivize the development of a new drug or technology. Or, even if it can, it may want to join forces with other countries to share the cost. In this Section, we thus assume in the case of a cash prize centralized funding by Member-States or States (with decentralized negotiations for drug prices). Our analysis thus applies notably to the EU.

Let us then consider a set of heterogeneous countries, indexed by $i \in \mathcal{I}$, within a union. We maintain our previous assumptions regarding sales, profits and surpluses under exclusivity and non-exclusivity, allowing all parameters except production costs to differ from one country to another. In addition, we rule out parallel trade: Patients in country i can access the drug only at country i's price.

The firm that uses the voucher to extend a patent derives a utility $U(\Pi)$ from its total profit Π in the country union (viewed at the country level, the income obtained on this drug in other countries thus acts as the firm's background income, due to decentralized drug price negotiations). Hence, denoting by $\Pi_i(p_i)$ its profit in country i from selling at price p_i, the firm's utility from its total profit in the country union is given by $U(\Pi) = U\big(\sum_{i\in\mathcal{I}} \Pi_i(p_i)\big)$.

Let γ_i denote the marginal rate of substitution between (national) income y_i and (national) therapeutic benefit for country $i \in \mathcal{I}$, times country i's shadow cost of public funds

[20] Besides, the net effect of foresight is ambiguous in general, depending on the determination of the post-exclusivity price and the generics' market competition. In particular, one can show that in the case of legacy regulation ($\overline{p} = p_E$), with a linear U, foresight raises the exclusivity price p_E (as the regulator foresees the surplus from generics and thus negotiates less agressively), while by contrast, for a sufficiently concave U, foresight lowers the exclusivity price (as the firm foresees the profits from captive consumers and thus negotiates less agressively).

[21] For instance, the French regulation secures a generics price in the year after the exclusivity loss equal to 60% of the branded drug's price ($p_g = 0.6p_E$), while the brand drug's price is reduced by 20% ($p_{NE} = 0.8p_E$). The goal is to secure supplies of the generic drug. In the UK, generics prices are unregulated, but the NHS' Drug Tariff sets a reference reimbursement price for many generics; branded drugs are subject to scheme-based controls (rebates, growth caps) that limit how much the NHS ultimately pays, but these schemes do not impose a formal, across-the-board "price cut" at patent expiry. In Germany, generics' prices are unregulated, but insurers set a reimbursement cap and negotiate discounts.

$(1+\lambda_i)$. As earlier, we assume that national expenditures on the drug are sufficiently low with respect to aggregate income, and the therapeutical benefits brought by the drug sufficiently low with respect to aggregate health that a first-order approximation is valid. For a given drug price p_i, the demand in country i is thus given by $D_i(\gamma_i p_i)$ (see equation (1)).

Suppose that countries compare a union-wide voucher and a union-wide cash prize, where country i's individual contribution to the total cash reward Γ is given by $s_i^{\mathcal{I}}\Gamma$, with $s_i^{\mathcal{I}} \in [0,1]$ and $\sum_{i\in\mathcal{I}} s_i^{\mathcal{I}} = 1$. We refer to the vector $(s_i^{\mathcal{I}})_{i\in\mathcal{I}}$ as the (union-wide) *contribution rule*. For example, the contributions could be determined from a set of (extensive) observables, $(y_i)_{i\in\mathcal{I}}$ (e.g., GDP, or population), as $s_i^{\mathcal{I}} = \frac{y_i}{\sum_{i'\in\mathcal{I}} y_{i'}}$.

Country i prefers the union-wide voucher to a union-wide cash prize with contribution rule $(s_i^{\mathcal{I}})_{i\in\mathcal{I}}$ if and only if

$$\left(\int_T^{T+\Delta} e^{-r\tau}d\tau\right)\left[x_i\int_{p_{i,NE}}^{p_{i,E}} D_i(\gamma_i p)dp + (1-x_i)\int_{p_{i,g}}^{p_{i,E}} D_i(\gamma_i p)dp\right] \leq s_i^{\mathcal{I}}\Gamma.$$

The two schemes – the union-wide voucher and the union-wide cash prize – deliver the same total reward to the innovator if and only if

$$\Gamma = \left(\int_T^{T+\Delta} e^{-r\tau}d\tau\right)\left[\sum_{i'\in\mathcal{I}}\left((p_{i',E}-c)D_{i'}(\gamma_{i'}p_{i',E}) - x_{i'}(p_{i',NE}-c)D_{i'}(\gamma_{i'}p_{i',NE})\right)\right].$$

Proposition 1 (**Union-wide schemes and unanimity rule**). *(i) Country i favors a voucher over a cash transfer at the union's level if and only if*

$$\rho_i^U \equiv \frac{x_i\int_{p_{i,NE}}^{p_{i,E}} D_i(\gamma_i p)dp + (1-x_i)\int_{p_{i,g}}^{p_{i,E}} D_i(\gamma_i p)dp}{\sum_{i'\in\mathcal{I}}\left((p_{i',E}-c)D_{i'}(\gamma_{i'}p_{i',E}) - x_{i'}(p_{i',NE}-c)D_{i'}(\gamma_{i'}p_{i',NE})\right)} \leq s_i^{\mathcal{I}}, \tag{6}$$

and the union-wide voucher is implemented under the unanimity rule if and only if (6) holds for all countries.

(ii) There exists a union-wide contribution rule $(\hat{s}_i^{\mathcal{I}})_{i\in\mathcal{I}}$ achieving unanimity in favor of the voucher scheme if and only if

$$\rho^U \equiv \sum_{i\in\mathcal{I}}\rho_i^U = \frac{\sum_{i\in\mathcal{I}}\left(x_i\int_{p_{i,NE}}^{p_{i,E}} D_i(\gamma_i p)dp + (1-x_i)\int_{p_{i,g}}^{p_{i,E}} D_i(\gamma_i p)dp\right)}{\sum_{i\in\mathcal{I}}\left((p_{i,E}-c)D_{i'}(\gamma_i p_{i,E}) - x_i(p_{i,NE}-c)D_i(\gamma_i p_{i,NE})\right)} \leq 1. \tag{7}$$

In part (i), the funding rule is fixed, and the unanimity rule creates as many veto powers as there are countries in the Union. In contrast, part (ii) allow countries to negotiate shares and so to accommodate a reluctant country.

3.1 Theoretical implications for the relative preference for vouchers over cash transfers

Before turning to the data, we identify several drivers of countries' relative preference for vouchers over cash transfers. Our result obtains from (6) using standard comparative-static techniques.

Proposition 2 (**Voucher scheme in a union of countries: Comparative statics**). *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. Then, all else being equal, the relative attractiveness of a voucher scheme is high if:*

- *country i's generics price $p_{i,g}$ is high, or*
- *its contribution share s_i to the cash prize is high.*

To isolate the impact of a country's market size on its relative preference for a voucher, we suppose that countries have the same Nash-bargaining weight α (no country is inherently better than another at bargaining with the monopoly firm). Let $\Pi_{-i} \equiv \sum_{i' \in \mathcal{I} \setminus \{i\}} \Pi_{i'}(p_{i'})$. Country i's Nash-bargaining exclusivity price $p_{i,E}$ is given by the solution to

$$\max_{p_i} \ \left[U(\Pi_{-i} + \Pi_i(p_i)) - U(\Pi_{-i})\right]^{1-\alpha} S_i(p_i)^{\alpha}.$$

Letting $R_i(p) \equiv [-S_i'(p)/S_i(p)]/[\Pi_i'(p)/\Pi_i(p)]$, the first-order condition is

$$\frac{\alpha}{1-\alpha} R_i(p_{i,E}) = \frac{U'(\Pi)(\Pi - \Pi_{-i})}{U(\Pi) - U(\Pi_{-i})} = \frac{U'(\Pi)\Pi_i}{U(\Pi) - U(\Pi_{-i})}$$

where $\Pi \equiv \sum_{i \in \mathcal{I}} \Pi_i(p_i)$

Under Assumption 1, the LHS is strictly increasing in p_i. If U is strictly concave, then the RHS is increasing in Π_{-i}. Suppose by contradiction that country i has a larger market size than country i', but negotiates a weakly higher price: $\sigma_i > \sigma_{i'}$, but $p_{i,E} \geq p_{i',E}$. As all bargained prices are below the monopoly price (otherwise the bilaterally bargained price would be Pareto-dominated), $\Pi_i > \Pi_{i'}$, implying that $\Pi_{-i} < \Pi_{-i'}$, and the first-order condition above implies that $p_i < p_{i'}$, a contradiction. The next comparative static follows from this observation, noting that the LHS in (6) is a strictly increasing function of the exclusivity price $p_{i,E}$ when $\rho_i^U < 1$.[22]

Proposition 3 (**Market size and relative preference for a voucher**). *Suppose the firm's profit utility U is strictly concave, and that Assumption 1 holds.*

[22] In fact, the LHS in (6) is a strictly increasing function of the exclusivity price $p_{i,E}$ when $\rho_i^U < 1/(1 - \varepsilon_i(\gamma_i p_{i,E})$ where $\varepsilon_i(\gamma_i p_{i,E}) \equiv -\gamma_i p_{i,E} D_i'(\gamma_i p_{i,E})/D_i(\gamma_i p_{i,E}) < 1$ is the demand elasticity.

(i) Larger countries negotiate lower exclusivity prices: If $\sigma_1 < ... < \sigma_{|\mathcal{I}|}$*, then* $p_1 > ... > p_{|\mathcal{I}|}$*. (ii) Assume that a union-wide voucher can achieve unanimity (i.e., (7) holds). Suppose that a country's contribution share* $s_i^{\mathcal{I}}$ *to a prize is proportional to its market size, that the post-exclusivity branded drug prices are equal to the exclusivity prices, and that the marginal cost of production is close to zero. Then, a larger market size increases the country's relative preference for a voucher.*

3.2 Politics: Efficiency, unanimity and qualified majority

The actual implementation of a voucher scheme in a union of countries depends on the union's collective decisionmaking process. We tailor our framework to encompass the European Union's procedures. In contrast to a prize scheme, which requires unanimity and a budget debate, a voucher scheme goes through the ordinary legislative procedure, and so only requires a simple majority in the European Parliament, and a *qualified majority* in the European Council (defined as a double majority of 55% of Member States and 65% of the EU population, and no blocking minority of at least 4 states representing over 35% of the population).[23] In a positive approach, we will thus adopt the above definition of a *qualified majority* in our empirical analysis.

Our empirical analysis at the union level will ask two main questions:

(a) *Is a voucher scheme more efficient than a prize scheme at the union level?* Does there exist a contribution rule that achieves unanimity over all countries in our data in favor of a voucher, i.e., does (7) hold?

(b) *Do vouchers achieve a qualified majority for a given contribution rule?* For a fixed union-wide contribution rule $(s_i^{\mathcal{I}})_{i\in\mathcal{I}}$, and comparing voucher and prize,[24] does a union-wide voucher achieve a qualified majority in our data, i.e., does (6) hold for a qualified majority? (We will in particular consider the case of contributions based on GDP shares.)

4 An Empirical Analysis on European Data

We now turn to an empirical estimation of the model on European data.

[23] The same procedural difference between vouchers and prizes exists in the US (with prizes requiring a budget debate and approval by the Congress, while vouchers do not, and was among the reasons why vouchers were considered in early drafts of the 2018 REVAMP Act.

[24] Note that we refrain from defining an extensive form for the decision process: We thus characterize countries' preferences, but do not predict what outcome(s) a given decision process would deliver given those preferences.

4.1 Data Sources

We utilize IMS (IQVIA) data on pharmaceutical sales across 15 European countries - Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Norway, Poland, Portugal, Spain, Sweden, Switzerland, and the United Kingdom - covering the period from 2002 to 2012. The dataset is available at a quarterly frequency and encompasses all prescription drugs. Quantities are measured in standard units, defined as the smallest available dose for each molecule. This data source has been previously employed by Dubois et al. (2015) to estimate the elasticity of innovation to market size in pharmaceutical markets, as well as in other studies analyzing specific drug markets (Dubois and Lasio (2018); Starc and Wollmann (2025) for example). The dataset provides manufacturer-level sales values in local currencies and sales volumes in standard units. We aggregate these data to compute total annual sales—both in value and volume—at the country and pan-European (15-country) levels by product. This aggregation accounts for variations in formats, dosages, strengths, and pack sizes of the same product, as well as generics of the same molecule. For countries with their own sovereign currency, we convert sales values into euros. In total, the dataset captures sales for over 5,000 distinct molecules.

4.2 Estimating the Value of a Voucher

We start by using these data to estimate the value of vouchers, had they been implemented during the data period of 2002-2012. Denoting by π_{ijt} the estimated profit (see below) for the original branded drug j in country i during year t, and $T(j)$ the year of exclusivity loss[25] 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 2011. 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. By attending to the country-specific median μ_i we focus on country-specific drivers of the relative revenue losses, and remain agnostic regarding molecule-specific drivers.[26] We thus assume that firms who consider

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

[26] As a robustness check, we compute the median of the ratios $\pi_{ijT(j)+1}/\pi_{ijT(j)-1}$ for the top 50 best-selling molecules in Europe and recompute the values of a one-year with it voucher (see below). Theoretically, molecule-specific drivers may push in opposite directions. For instance, blockbuster drugs, i.e. the most likely to benefit from exclusivity extensions, may have a stronger brand recognition and thus a larger share of captive consumers, which would imply lower relative revenue losses. However, blockbuster drugs may also

purchasing an exclusivity extension anticipate a revenue loss proportional to μ_i in country i.

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 the value of profits with exclusivity, minus the expected counterfactual value of profits in case of exclusivity loss: $\pi_{ijt} - \mu_i \pi_{ijt}$.[27] If the voucher is purchased in year t for extending the exclusivity of a drug j expiring in year $T(j) \geq t+1$, this value needs to be discounted and is given at t by

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

where $\{1, .., \mathcal{I}\}$ is the set of countries participating in the scheme 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 that $j^2(t)$ with the second highest value V_t^2, and iteratively, $j^n(t)$ with the n-th highest value V_t^n. With myopic bidders (or a single voucher for sale, more on this shortly), the buyer of an exclusivity extension in year t is then the one with the highest value among all drugs expiring in the future, i.e. V_t^1, if that buyer has not already purchased a voucher for the same drug.

In the data however, we observe revenues and not profits. As we do not observe directly the marginal costs, we compute both upper and lower bounds on these costs. We build an upper bound estimate of the marginal cost of each molecule by using the minimum price for this molecule observed in any of the 15 countries in our data set over all time periods. For older molecules (whose exclusivity ends during our time sample), the minimum price is typically a generics' price (we observe a generic version for 1,428 molecules of the 5,352 molecules in our sample). For more recent molecules, we do not observe generics yet, and the minimum (on-patent) price may then significantly overestimate the marginal cost. However, some countries in our data set have strong regulatory powers that enable them to negotiate prices close to marginal cost, so that the minimum (on-patent) price remains a reasonable upper bound on the true marginal cost.

At the other extreme, we take zero as a lower bound on marginal costs, hence using revenue as an upper bound on the true profits. A marginal cost close to 0 does not seem an unrealistic assumption for our sample (2002 to 2012). Most drugs were simple molecules whose marginal cost of production is generally very low. Biological drugs with larger marginal

be in more profitable markets, which may attract more generics entry and thus entail higher relative revenue losses.

[27] As the length of exclusivity extension does not affect the cost-over-reward ratio of vouchers, henceforth we focus on the value of a one-year extension.

costs appeared in the early 2000s but were not yet widespread in our sample period. The first biosimilar was approved in 2006 in Europe and the diffusion of biosimilars took a few years; so, they represent a small share of drugs in our sample. Therefore, most top selling drugs in Europe during that period were not biological drugs.[28]

We denote by $\underline{V}_t^n$ and $\bar{V}_t^n$ the lower and upper bounds on the true profits of the n^{th}-value drug, i.e. on the value of a one-year exclusivity extension to its buyer.

Table 1 reports the estimates of μ_i, i.e. the median of the ratios of the patent-holder's revenue 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. We assume that firms take these values as the anticipated relative decline of revenue after exclusivity loss in each country. Table 1 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. Table 1 also documents the number of exclusivity losses observed during 2002-2012, the variation across countries stemming from differences in available products. We also report the share of captive consumers x_i for country i, which we will use to compute the cost-over-reward ratio. These shares are estimated via the quantity share of a molecule sold in generic form one year after the branded drug's exclusivity loss.[29,30]

Table 2 reports the five largest values $\bar{V}_t^n$ from a one-year exclusivity extension delivered at the European (15-country) level in any year between 2002 and 2011, using our upper-bound estimates for values (i.e. assuming zero marginal cost). It also reports which drug corresponds to each value, and its year of exclusivity expiration (absent any extension). The values are discounted – e.g. Sanofi's willingness-to-pay for a one-year exclusivity extension for its Plavix patent expiring in 2008, thus reaches its maximum in the year of the patent expiration (2008), and decreases the further away the patent expiration.

Table 2 shows that the additional profits that a one-year exclusivity extension generates for its buyer vary substantially depending on the buyer and the year of purchase. Moreover, these additional profits exhibit a strong path-dependence as the identity of the buyer in a

[28] See Scott-Morton et al. (2018) for a comparison of the slower adoption of biosimilars in the US compared to Europe and some statistics and figures showing biosimilars were not very important until the end of the 2000s.

[29] To avoid timing issues when a generic entry enters at the end of a year, we consider that 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.

[30] Our theoretical analysis predicts that μ_i should be equal to x_i. Our modeling is of course a simplification of reality. In practice, a reason for $\mu_i < x_i$ is that captive consumers are not completely captive, so that after exclusivity loss, the original branded drug actually decreases its price to retain its "captive" consumers. Alternatively, the post-exclusivity price may be capped below the exclusivity price like in France. On the other hand, a reason for $\mu_i > x_i$ in the estimation in Table 1 may be the timing (as mentioned above): the share of captive consumers is estimated once generics have entered, while preservation revenue stems from profit the year after exclusivity loss and generics may not have entered yet.

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	14	0.594	0.515
BELGIUM	15	0.571	0.578
FINLAND	14	0.422	0.442
FRANCE	21	0.630	0.350
GERMANY	115	0.464	0.374
GREECE	14	0.922	0.595
IRELAND	10	0.785	0.518
ITALY	29	0.556	0.538
NORWAY	25	0.323	0.393
POLAND	25	0.806	0.170
PORTUGAL	17	0.785	0.421
SPAIN	19	0.702	0.499
SWEDEN	36	0.583	0.504
SWITZERLAND	12	0.574	0.465
UK	14	0.517	0.261

Notes: Second column is the number of drugs on patent that lost exclusivity during 2003-2012. The third column is the mean μ_i of ratios $\frac{\pi_{ijT(j)+1}}{\pi_{ijT(j)-1}}$ across all products j whose exclusivity loss year $T(j)$ is between 2003 and 2012. The fourth column is the mean of the share of captive users of a molecule across all molecules.

given year depends on the history of past vouchers sold, which itself depends on the realized innovations awarded vouchers, as well as on the strategic behaviors of potential buyers. As an illustration, if a voucher had been granted in 2002 and bought by Sanofi for Plavix, Sanofi would not have competed for another voucher in the following year, which could then have been purchased by Pfizer for Lipitor (the second largest value in 2003). Suppose for the sake of illustration that each drug-maker buys at most one voucher per drug. Then, Table 2 indicates that if a one-year voucher had been awarded each year between 2002 and 2006 and bought by the firm with the highest value for it in that given year, the value of such vouchers to their buyers would have varied substantially, from 473 million euros down to 298 million euros.[31]

However, the likely buyers of vouchers may face demand curves and especially revenue preservation parameters, that differ from those of the average molecules. As a robustness check, we use the mean preservation revenue for the top 50 best-selling molecules in Europe to recompute the values of a one-year voucher – see Table 5 in Online Appendix E.1.

[31]Taken literally, Table 2 further suggests that whether or not an additional one-year voucher had been awarded in 2007 and 2010, a one-year voucher awarded in 2011 and bought by the firm with the highest value for it in that given year would have had a value of only 150 million euros to its buyer (owner of Zometa). However, this may be an artifact of our data sample as we do not observe sales after 2012, and we thereby understate the value of future discounted profits from drugs with patent expiration in 2013 or later.

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

Year	V_t^1	V_t^2	V_t^3	V_t^4	V_t^5
2002	PLAVIX (2008)	LIPITOR (2011)	ZOCOR (2002)	NORVASC (2003)	PANTOZOL (2008)
	506,430	502,799	479,518	372,335	305,154
2003	PLAVIX (2008)	LIPITOR (2011)	NORVASC (2003)	PANTOZOL (2008)	ZYPREXA (2010)
	522,093	518,349	383,851	314,591	302,019
2004	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	SEROQUEL (2011)
	538,240	534,380	324,321	311,360	296,476
2005	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	SEROQUEL (2011)
	554,886	550,908	334,352	320,989	305,646
2006	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	SEROQUEL (2011)
	572,048	567,946	344,692	330,917	315,099
2007	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	SEROQUEL (2011)
	589,740	585,511	355,353	341,151	324,844
2008	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	SEROQUEL (2011)
	607,980	603,620	366,343	351,702	334,891
2009	LIPITOR (2011)	ZYPREXA (2010)	SEROQUEL (2011)	NEXIUM (2010)	TAXOTERE (2010)
	622,289	362,580	345,248	322,412	303,353
2010	LIPITOR (2011)	ZYPREXA (2010)	SEROQUEL (2011)	NEXIUM (2010)	TAXOTERE (2010)
	641,535	373,794	355,926	332,383	312,735
2011	LIPITOR (2011)	SEROQUEL (2011)	CODIOVAN (2011)	EBIXA (2012)	CERAZETTE (2012)
	661,376	366,934	149,081	107,167	49,433

Notes: Voucher values $\bar{V}_t$ for one year voucher, 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 we thus lack observations for drugs whose exclusivity stops in or after 2012.

In addition, Table 6 in Online Appendix E.2 reports the same quantities as Table 2 using the lower-bound estimates $\underline{V}_t^n$. Notably (and as discussed above), these lower-bound estimates turn out to be close to the upper-bound estimates in Table 2, and to yield the same ranking for the five highest values each year as the upper-bound estimates.

4.3 An Empirical Estimation of the Cost-Over-Reward Ratio of a voucher

We are interested in the costs and benefits of a voucher scheme, were the 15 European countries in our data set to implement a union-wide voucher scheme. To estimate the social cost of such a voucher 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 estimate the demand using the variation over time of prices and quantities per molecule. Following our theoretical model, for each country i, we assume that the demand in year t for molecule j is given by:

$$D_{ijt}(\gamma_i p_{ijt}) = \sigma_{ijt}\left(1 - \frac{\gamma_i p_{ijt}}{m_{ic(j)}}\right)^{k_{c(j)}}$$

where $\sigma_{ijt} = \sigma_{ic(j)} \exp(\epsilon_{ijt})$ is country i's date-t size of the market, and ϵ_{ijt} is a demand shock, $c(j)$ is the class of drug j, $m_{ic(j)}$ a parameter capturing the maximum therapeutical benefit for drugs in class c in country i, and $k_{c(j)}$ a parameter that affects the shape of

demand in country i. Put differently, we assume that the shape of demand (as a function of the price normalized by the maximum willingness to pay) is determined by country-drug class specific effects – e.g. related to population characteristics, lifestyle, environment, etc. –, up to a multiplicative factor σ_{ijt}.

We take the log of the demand and use a first-order Taylor expansion after approximating m_{ic} for any country i and drug class $c \in \{1, ..., C\}$ by the maximum price observed for a molecule belonging to the class: $m_{ic} = \max_{\{j,t|c(j)=c\}} \{p_{ijt}\}$.

We thus obtain the following linear regression for country i:

$$\log D_{ijt} = \log(\sigma_{ic(j)}) - (k_{c(j)}\gamma_i)\left(\frac{p_{ijt}}{m_{ic(j)}}\right) + \epsilon_{ijt}. \tag{8}$$

We can thus identify $(k_c\gamma_i)$ using the price coefficient $\beta_{ic} \equiv k_c\gamma_i$.

As the error term ϵ_{ijt} may be correlated with the price p_{ijt}, creating an endogeneity problem in this equation, we use instrumental variables for price. The instruments for p_{ijt} are the means of prices of the same product j in other countries than i in year t, and the number of products in the same Anatomical Therapeutical Chemical (ATC) class. Both instruments are likely to be correlated with the price in country i but not with the demand shock in country i. Estimation of these demand equations by country are reported in Table 10 in Appendix E.4.

Having identified the price coefficient β_{ic}, we then find all k_c, γ_i as solution of

$$\begin{aligned} \min_{\{k_c,\gamma_i\}_{i,c}} \quad & \textstyle\sum_{i,c} (\beta_{ic} - k_c\gamma_i)^2 \\ \text{s.t.} \quad & 0 < \gamma_i \leq \min_{\{j,t\}} \{\frac{m_{ic(j)}}{p_{ijt}}\} \end{aligned} \tag{9}$$

where the constraint on γ_i stems from the demand form (as $1 - \gamma_i p_{ijt}/m_{ic(j)}$ must be weakly positive for all j, t)[32].

However, parameters are not identified up to a scale effect as any set of solutions $\{k_c, \gamma_i\}$ implies that $\{\xi k_c, \gamma_i/\xi\}$ for $\xi \geq 1$ is also a solution (as well as for any $\xi \in (0, 1)$ if none of the constraint on γ_i is binding).

Thus, instead of choosing an ad-hoc normalization for one parameter k_c, we use another implication of our model due to the price setting of branded drugs during their exclusivity period. We specify the firms preference U as $U(t) = t^\chi$ with $0 < \chi < 1$, and derive the relationship between χ, the regulated price, the marginal cost, and the bargaining parameter

[32] In practice, we reparameterize the problem using $\gamma_i \equiv \frac{1}{1+\tilde{\gamma}_i^2} \min_{\{j,t\}} \{\frac{m_{ic(j)}}{p_{ijt}}\}$ and minimizing:

$$\min_{\{k_c,\tilde{\gamma}_i\}_{i,c}} \sum_{i,c} (\log \beta_{ic} - \log k_c - \log \frac{1}{1+\tilde{\gamma}_i^2} - \log(\min_{\{j,t\}} \{\frac{m_{ic(j)}}{p_{ijt}}\}))^2$$

$\alpha \in (0,1)$ that each branded drug j regulated price should satisfy using the bargaining model of Section 2 for the exclusivity period.

Substituting profit and surplus function in $R_i(p_{ijt}) \equiv [-S_i'(p)/S_i(p)]/[\Pi_i'(p)/\Pi_i(p)]$ using our demand specification, we obtain:

$$R_i(p_{ijt}) = \frac{\frac{(k_{c(j)}+1)\gamma_i}{m_{ic(j)}}(p_{ijt} - c_{ij})}{1 - \frac{\gamma_i}{m_{ic(j)}}p_{ijt} - k_{c(j)}\frac{\gamma_i}{m_{ic(j)}}(p_{ijt} - c_{ij})}.$$

Then, the first-order condition for the Nash-bargaining is

$$\frac{\alpha}{1-\alpha}R_i(p) = \frac{U'(\Pi)\Pi_i}{U(\Pi) - U(\Pi_{-i})} = \frac{\chi(\Pi)^{\chi-1}\Pi_i}{(\Pi)^{\chi} - (\Pi_{-i})^{\chi}}$$

and so

$$\frac{\alpha}{1-\alpha}\frac{\frac{(k_{c(j)}+1)\gamma_i}{m_{ic(j)}}(p_{ijt} - c_{ij})}{1 - \frac{\gamma_i}{m_{ic(j)}}p_{ijt} - k_{c(j)}\frac{\gamma_i}{m_{ic(j)}}(p_{ijt} - c_{ij})} = \frac{\chi\frac{\Pi_i}{\Pi}}{1 - (1 - \frac{\Pi_i}{\Pi})^{\chi}} \tag{10}$$

We then estimate k_c, χ, minimizing the lack of fit of this equation across all branded drugs prices.

Then, once one parameter k_c and χ are identified through this bargaining equation (we use one ATC class in France), we get identification of all k_c ,γ_i using (9).

The estimates of parameters k_c are varying between 0.10 and 0.73 according to Table 3. It shows that the class of anticancer drugs (ATC class L) is the less elastic, followed by hormones (ATC H), antibiotics (ATC J), sensory organs (ATC S) and blood drugs (ATC B). The more elastic class is the one of cardiovascular system (ATC C) as well as nervous system drugs (ATC N).

Denoting $p_{ij,E}$ the branded drug's exclusivity price (observed before patent expiration) in country i, $p_{ij,NE}$ its post-exclusivity price (observed after patent expiration), and $p_{ij,g}$ the generics' price (observed), the cost-over-reward ratio for a nation-wide voucher scheme is then given for each drug by

$$\rho_{ij} \equiv \left(\frac{m_{ic(j)}}{\gamma_i(k_{c(j)}+1)}\right)\frac{x_i\left(1 - \frac{\gamma_i p_{ij,NE}}{m_{ic(j)}}\right)^{k_{c(j)}+1} + (1-x_i)\left(1 - \frac{\gamma_i p_{ij,g}}{m_{ic(j)}}\right)^{k_{c(j)}+1} - \left(1 - \frac{\gamma_i p_{ij,E}}{m_{ic(j)}}\right)^{k_{c(j)}+1}}{(p_{ij,E} - c_{ij})\left(1 - \frac{\gamma_i p_{ij,E}}{m_{ic(j)}}\right)^{k_{c(j)}} - x_i(p_{ij,NE} - c_{ij})\left(1 - \frac{\gamma_i p_{ij,NE}}{m_{ic(j)}}\right)^{k_{c(j)}}},$$

Similarly, the cost-over-reward ratio for a country i participating in a union-wide voucher

Table 3: Calibration of parameters χ, k_c

ATC Class	Label	k_c
A	Alimentary tract and metabolism	0.194
B	Blood and blood forming organs	0.143
C	Cardiovascular system	0.731
D	Dermatologicals	0.304
G	Genito urinary system and sex hormones	0.468
H	Systemic hormonal preparations, excl. sex hormones and insulins	0.099
J	Antiinfectives for systemic use	0.122
L	Antineoplastic and immunomodulating agents	0.035
M	Musculo-skeletal system	0.299
N	Nervous system	0.718
R	Respiratory system	0.375
S	Sensory organs	0.112
Bargaining parameter χ		0.952

scheme is given by

$$\rho_{ij}^U \equiv \left(\frac{\sigma_i m_{ic(j)}}{\gamma_i(k_{c(j)}+1)}\right) \frac{x_i\left(1-\frac{\gamma_i p_{ij,NE}}{m_{ic(j)}}\right)^{k_{c(j)}+1} + (1-x_i)\left(1-\frac{\gamma_i p_{ij,g}}{m_{ic(j)}}\right)^{k_{c(j)}+1} - \left(1-\frac{\gamma_i p_{ij,E}}{m_{ic(j)}}\right)^{k_{c(j)}+1}}{\sum_{i'}\sigma_{i'}m_{i'c(j)}\left[(p_{i'j,E}-c_{i'j})\left(1-\frac{\gamma_{i'}p_{i'j,E}}{m_{i'c(j)}}\right)^{k_{c(j)}} - x_{i'}(p_{i'j,NE}-c_{i'j})\left(1-\frac{\gamma_{i'}p_{i'j,NE}}{m_{i'c(j)}}\right)^{k_{c(j)}}\right]}$$

We denote ρ_i the average of ρ_{ij} over drugs in country i and ρ_i^U the average over drugs in country i of ρ_{ij}^U.

Moreover, a sharing rule will lead all countries to prefer a TEE over a cash transfer as soon as its required share of the total reward, s_i, is above a threshold $\underline{s}_i^*$ defined as

$$\underline{s}_i^* \equiv \frac{\int_{p_{i,NE}}^{p_{i,E}} D_i(\gamma_i p)dp + (1-x_i)\int_{p_{i,g}}^{p_{i,NE}} D_i(\gamma_i p)dp}{\sum_{i'\in U}(p_{i',E}-c)D_{i'}(\gamma_{i'}p_{i',E}) - x_{i'}(p_{i',NE}-c)D_{i'}(\gamma_{i'}p_{i',NE})} \tag{11}$$

Thus, if $\sum_{i\in U}\underline{s}_i^* \leq 1$, there always exist sharing rules that make the TEE preferable over a cash transfer at unanimity in the union, for example with $s_i^{U*} = \frac{\underline{s}_i^*}{\sum_{i'\in U}\underline{s}_{i'}^*}$. However, if $\sum_{i\in U}\underline{s}_i^* > 1$, there is no sharing rule that allows unanimity preference of a TEE over a cash transfer.

Table 4 also shows this sharing rule (s_i^{U*}) that can achieve unanimity.

Table 4 reports the estimated cost-over-reward ratios for country-level voucher (ρ_i). The corresponding demand parameters and characteristics are in Table 9 in appendix E.4. Table 4 shows that these cost over ratio vary between .29 for Ireland and go up to .95 for Italy but are all below one demonstrating that each country prefers to finance innovation using a transferable exclusivity extension voucher rather than a direct cash transfer. This is an

Table 4: Cost-over-reward ratios (top 10 drugs)

Country	(1) ρ_i	(2) s_i^{gdp}	(3) s_i^{pop}	(4) s_i^{U*}	(5) $\frac{\rho_i^U}{s_i^{gdp}}$	(6) $\frac{\rho_i^U}{s_i^{pop}}$
AUSTRIA	0.82	0.06	0.05	0.06	0.81	0.95
BELGIUM	0.87	0.03	0.02	0.07	1.86	2.05
FINLAND	0.83	0.01	0.01	0.09	5.20	5.64
FRANCE	0.68	0.15	0.15	0.08	0.42	0.42
GERMANY	0.81	0.21	0.19	0.13	0.46	0.51
GREECE	0.47	0.02	0.03	0.02	0.79	0.63
IRELAND	0.29	0.01	0.01	0.02	1.02	1.30
ITALY	0.95	0.14	0.14	0.07	0.42	0.42
NORWAY	0.85	0.02	0.01	0.05	2.19	3.50
POLAND	0.66	0.05	0.09	0.05	0.90	0.46
PORTUGAL	0.67	0.02	0.02	0.05	2.20	1.64
SPAIN	0.64	0.09	0.10	0.05	0.43	0.39
SWEDEN	0.49	0.02	0.02	0.07	2.03	2.39
SWITZERLAND	0.78	0.03	0.02	0.10	2.86	4.23
UK	0.69	0.15	0.14	0.09	0.47	0.50
Nb favorable countries (total share)	15				8 (.859)	8 (.879)
ρ^U	0.76					

Notes: s_i^{gdp} denotes the GDP share of country i in the union, s_i^{pop} the population share of country i in the union. s_i^{U*} is a sharing rule achieving unanimity. The total share in parenthesis represents the share of GDP or population of countries that prefer the TEE over the cash transfer.

important result regarding the optimality of using one of these two mechanisms for public finance. Then, we show in this same Table the cost over reward ratio of a union level transferable exclusivity extension, ρ^U, which is equal to 0.76 showing that it is 24% cheaper to finance an innovation through a union level exclusivity extension rather than using a cash transfer. However, this preference for a union level TEE aggregates all countries surplus loss due to the exclusivity extension and does not depend on any sharing across countries of the alternative of a cash transfer. In practice, the preference for a union-level TEE voucher will depend on the share of the cash prize that each country will be required to pay and the country specific burden of the exclusivity extension on social surplus. As shown before, each country i will then prefer a TEE voucher over a cash transfer if the sharing rule implies a too large cash contribution which means that the share s_i is larger than the parameter ρ_i^U (as shown by condition (6)). Table 4 shows the ratios $\frac{\rho_i^U}{s_i}$ for each country using first the GDP share of each country as a basis for its cash contribution and then its population share. Using the GDP share over the union of 15 countries used here, we find that 8 countries over the 15 would prefer a TEE voucher and that these 8 countries represent 86% of the union GDP. Indeed we find that Finland, Switzerland, Norway, Sweden, Portugal, Belgium would clearly prefer a cash transfer over a TEE while Ireland marginally prefers a cash transfer

but can be almost considered as indifferent as $\frac{\rho_i^U}{s_i} = 1.002$ for Ireland. Using the population share, we also find that 8 countries representing 88% of the population of these countries prefer the TEE voucher to the cash transfer.

In order to account for the possible selection bias in cost-over-reward ratios that could be different across drugs and correlated with their revenues hence with their probabilities to be benefiting from exclusivity extensions, we compute those with different subsample, reducing the average to the higher revenue drugs. Results are similar for top 30, top 20 or top 10 drugs and Table 4 show the results for the top 10 drugs.

5 Discussion

5.1 Market power and adverse selection in the voucher market

This section addresses two concerns about vouchers. First, the buyer may enjoy market power in the voucher market. Second, there is "adverse selection" from the point of view of society if the auction for the voucher scheme tends to select drugs with high cost-over-reward ratios. These questions are distinct as adverse selection may occur in the absence of market power.

5.1.1 Market power in voucher auctions

Competition in the voucher market may be imperfect because the top-earning drugs may be unequally profitable, or unequally close to patent expiration. For a given reward accruing to the neglected disease drug developer (Γ), let us phrase the argument in the framework of the auction mechanism we propose in Section 5.2. The latter requires auction participants to bid the lowest extension length for which they are willing to pay Γ (see motivation and details in Section 5.2). However, with imperfect competition, the voucher's buyer (the auction winner) receives an exclusivity extension at the second-lowest bidden length, and thus reaps a socially costly rent.[33] Put differently, while the (flow) social cost of the voucher stems from a higher price for the drug of the voucher's buyer, the profits accruing to the latter correspond to the (exclusivity) profits that the second-lowest bidder would have made – hence, the numerator of the cost-over-reward ratio remains unchanged, while its denominator decreases. Therefore, the cost-over-reward ratio of a voucher scheme increases.

Admittedly, once the voucher scheme is established, the buyers' rent (difference between

[33] If the same firm owns the two blockbuster molecules that would benefit the most from an extension (an unlikely event), the second-lowest bidden length corresponds to the third-highest WTP.

own WTP and second-highest one) may provide an additional incentive to develop a (blockbuster) innovation in the first place.

Observation 2. *Market power in the voucher market increases the cost-over-reward ratio of vouchers. When the existence of the voucher market is anticipated, though, the increase may be (eventually) mitigated by more innovators entering the innovation market.*

Let us mention a last caveat about market power in the voucher market (buyers' side). 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 occurs when blockbuster drugs turn off-patent and are replaced by generics or when they have already acquired a voucher – which also depends on the supply of vouchers, 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 vouchers may then arise. As a consequence, voucher schemes may involve in practice a higher uncertainty than in our simple benchmark, which may reduce their desirability.

5.1.2 Adverse selection

Adverse selection arises if the drugs that generate the highest additional profits from an exclusivity extension are also the ones with the highest cost-over-reward ratios. In fact, our comparative statics indicate that whenever the generics' price strictly increases with the share of captive users – which is in particular the case whenever generics form a cartel (see Appendix B) –, both the additional profit from an exclusivity extension and the cost-over-reward ratio decrease with the share of captive users x. The same comparative static holds with respect to the intensity of competition among generics. While the social planner would prefer exclusivity extensions to be purchased and used for drugs with low cost-over-reward ratios (i.e, low social costs), such drugs are thus unlikely to be the ones for which an exclusivity extension is most profitable. In fact, exclusivity extensions are most likely to be purchased and used for drugs with high cost-over-reward ratios.[34]

This adverse selection would hamper the desirability of vouchers with respect to cash prizes. It motivates our focusing in our empirical analysis on the drugs with the highest willingnesses-to-pay for an exclusivity extension (see Sections 4.2-4.3): Our main specification is thus already robust to adverse selection.

[34] Adding market power in the voucher auction (so that the winning bid is determined by the second-highest WTP), the question of adverse selection becomes: When are a drug-maker's additional profits from an exclusivity extension and the social loss from the exclusivity of that drug being extended, positively correlated? In fact, both the drug-maker's (j) additional profits and the country's (i) social loss increase when time to patent expiration T_j decreases, when market size σ_{ij} increases, when the share of captive users x_{ij} decreases (with $p_{i,gj}$ independent of, or increasing with x_{ij}), and with our empirical specification, when the highest therapeutical benefit m_{ij} from drug j in country i increases.

To empirically test for the presence of adverse selection and validate our methodology, we further conduct a robustness check by computing the cost-over-reward ratio for all drugs rather than only the bestselling ones, and show that the data reveals the existence of (limited) adverse selection.

5.2 Concerns and implementation: Doing vouchers right

Our assessment methodology presumes that the voucher scheme is implemented properly. If not, the voucher scheme will be less attractive. Many criticisms have indeed been leveled at the existing voucher proposals.

Questions orthogonal to prize-voucher comparison. Some of these criticisms can be easily discarded as they touch on aspects that are orthogonal to the question of how to reward the innovation, the focus of the voucher vs. prize comparison. Some observers are concerned about a reward that exceeds what is strictly needed to incentivize the innovation, a possibility which arises equally under both schemes (see discussion below). Similarly, in the context of antibiotics, some complain about the absence of stewardship in the description of the scheme. But stewardship must be added regardless of whether a voucher or prize mechanism is being considered.[35] As a final example of an orthogonal question, many observers are concerned that vouchers would not ensure that products are accessible and available for an agreed-upon time period; however the availability issue occurs under any scheme and requires that the producer be given enough skin in the game (through contractual purchase prices and penalties for non-delivery); for example in the case of a voucher and assuming that the inventor is also the ex-post supplier of the drug, some of the voucher voucher-sale proceeds could be put into an escrow in order to ensure future compliance.

Could it hurt the generics competitors? A second line of criticism is that the voucher scheme could stifle innovation from competitors and delay the introduction of generics and biosimilars of the very profitable products that benefit from an extension. This criticism has been addressed in the literature, as noted in the literature review. There is no question that the stranding of generics investments through a surprise purchase of a voucher by the originator is undesirable. This is why the voucher purchase (or final purchase if the voucher changes hand several times) should not intervene too close to the expiration date of the patent; a length of advance notice to the generic industry in the form of a floor on candidate buyers' remaining patent horizon would avoid such stranding.[36]

[35] One can apply the same concern for other neglected diseases. For example, the (important) drug delivery question arises under any reward scheme.

[36] Table 2 then suggests that such a regulatio forbidding a drug-maker from buying a voucher for a drug whose patent expires, say, the next year, would not always prevent the drug-maker with the highest value for a voucher from buying it – the highest value at a given time does not always stem from the closest patent expiration date.

Predictability of voucher value. Thirdly, a voucher that specifies a length of extension (say 6 months or a year) raises the possibility of randomness in the reward that is unrelated to the quality of the neglected-disease innovation and stems from current conditions in the voucher market. Indeed, we assumed that the length of a voucher 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 voucher requires information on the buyer's profit. While domestic prices and quantities may be observable, production costs and profits abroad 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 voucher and eliminate this uncertainty, one can let the voucher buyers bid in terms of extension length.[37] Namely, fix a reward Γ for the antibiotic developer, the same as the one the antibiotic developer would receive under a cash transfer (a prize). For each potential drug j that could benefit from an exclusivity extension in each country i, let Δ_j be implicitly defined by

$$\Gamma = \sum_i [\pi_{E,ij} - \pi_{NE,ij}] \int_{T_j}^{T_j+\Delta_j} e^{-r\tau} d\tau \equiv [\pi_{E,j} - \pi_{NE,j}] \int_{T_j}^{T_j+\Delta_j} e^{-r\tau} d\tau,$$

where $\pi_{E,j} = \sum_i \pi_{E,ij}$ and $\pi_{NE,j} = \sum_i \pi_{NE,ij}$, then the holder of patent j is willing to pay Γ in exchange of any extension of the exclusivity length $\Delta \geq \Delta_j$. The winner of the auction is the one announcing the lowest extension length against cash transfer Γ.

For example, in a Vickrey auction,[38] and for demanded lengths $\Delta_1 \leq \Delta_2 \leq \Delta_3$..., the bidder demanding length Δ_1 obtains a voucher of length Δ_2. Such an auction is optimal under the usual assumptions (independent draws of valuations from a symmetric distribution with monotone hazard rate, appropriately chosen reserve price).

Observation 3. *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.*

Could the inventor keep the voucher? We recommend that the auction format allow the inventing entity to bid and therefore give it the possibility to use it on one of existing patents. The inventor, who would be willing to get an extension of length (no less than) Δ_0 at price Γ will bid $\hat{\Delta}_0 = \Delta_0$. Indeed, let $R(\Delta_0) = \Sigma_i [\pi_{E,i0} - \pi_{NE,i0}] \int_{T_0}^{T_0+\Delta} e^{-r\tau} d\tau$. Then, if $\Delta_0 \leq \Delta_1$,

[37] 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. (2001), 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.

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

$R(\Delta_0) \geq \Gamma$ and so bidding truthfully is optimal. Similarly, if $\Delta_0 > \Delta_1$, $R(\Delta_1) < \Gamma$ and so bidding truthfully remains optimal. Hence, the presence of the inventor in the auction increases the incentive to innovate (strictly so when $\Delta_0 < \Delta_1$), and lowers the rents left to the holder of patent 1 (strictly so when $\Delta_1 \leq \Delta_0 < \Delta_2$).

6 Conclusion

This paper offers the first theoretical and empirical assessments of patent vouchers as an innovation incentive. It develops a cost-over-reward framework to compare vouchers with cash prizes and apply it to pharmaceutical sales data from 15 European countries.

Our results indicate that, in our environment, vouchers deliver rewards to innovators at lower social cost than equivalent cash transfers. This reflects the limited competitiveness of generic markets, which reduces the welfare gains from patent expiration and creates scope for financing innovation through extended exclusivity. At the national level, all 15 countries in our sample would prefer a voucher to a prize. At the union level, vouchers are preferred by the largest countries when contributions are allocated in proportions to GDP, and by all countries if contribution shares are properly selected.

Yet vouchers also carry risks. Market power in voucher auctions, adverse selection, and poorly specified voucher lengths can all increase social costs. We highlight design features—such as auctions based on extension length—that mitigate these problems and enhance efficiency.

More broadly, the analysis underscores that innovation incentives must be judged not only by the rewards they generate, but also by the distribution and incidence of their costs. Patent vouchers may thus serve as a valuable addition to the policy toolbox. Their scalability, applicability beyond pharmaceuticals, and interaction with the broader patent system remain important questions for future research. While much of this broader perspective lies beyond our present scope, the findings suggest implications well beyond the pharmaceutical sector and provide a foundation for further policy debate.

Is the scheme scalable? Our conclusions, while robust, require validation with other datasets and in other industries. Still, both the empirical results and the underlying theory suggest a compelling logic: careful adjustments to patent design may provide relatively inexpensive sources of public funding.

The scalability of voucher schemes warrants caution.[39] The rents accruing to infra-

[39]To illustrate this point in a simple way, consider a static environment in which there are m vouchers for sale. Rank potential buyers so that their willingnesses to pay for a one-year extension, V_j (that is, $V_j \equiv [\pi_{E,j} - \pi_{NE,j}]e^{-rT_j}$) for buyer j, satisfy $V_1 \geq V_2 \geq ....$ As earlier, they bid over the extension length Δ_j that they demand and the m lowest extensions win. In a Vickrey auction, they obtain extension length $\Delta_{m+1} = \Gamma/V_{m+1}$. The rent of buyer $j \leq m$ is therefore $(V_j - V_m)\Gamma/V_m$.

marginal buyers of vouchers grow as more vouchers are issued—substantially so, unless the demand curve is unusually flat, which our data suggest is unlikely. Expanding the scheme therefore raises the cost-over-reward ratio, ρ, and may be undesirable if vouchers are introduced unexpectedly. In a steady-state regime, where vouchers are anticipated, some of this inefficiency is offset by the additional incentive to innovate. One way to avoid "running down the demand curve" too quickly would be to allow a given drug to acquire multiple successive vouchers. The qualifier is important: generics firms would find it difficult to enter a market characterized by intermittent reversion to exclusivity. Selling vouchers in clusters could be another solution, though this would likely require regulators to provide liquidity to innovators awaiting the next auction round.

Beyond pharmaceuticals. Vouchers could also be awarded for patent extensions outside the pharmaceutical sector, potentially lowering the cost of scaling up the program. However, nothing guarantees that cost-over-reward ratios in other industries would resemble those in pharma. Where entry is easy after the expiration of an intellectual property right – whether a patent or copyright – these ratios are likely to be high. Extending the type of exercise we conduct here to other industries, provided the data are available, would therefore be a valuable avenue for future work.

Patent system reform. More broadly, our analysis connects to the design of intellectual property itself. Public policies often operate with inconsistent instruments whose shadow costs of achieving the same objective—say, a transfer to a target population or a reduction in emissions—can differ widely. Intellectual property is only one among many push and pull mechanisms intended to stimulate innovation, and it is a relatively crude one. Patent length, for example, is applied with little discrimination across technologies, and instruments to encourage patenting or renewal are limited. While theoretical research has begun to explore refinements, further theoretical and empirical work is needed to understand how intellectual property might be redesigned to provide sharper, more cost-effective incentives for innovation.

Bibliography

Boyer, B., Kroetsch, A., and Ridley, D. (2022). "Design of a Transferable Exclusivity Voucher Program". Duke Margolis Center for Health Policy white paper.

Dubois, P., de Mouzon, O., Scott-Morton, F., and Seabright, P. (2015). "Market Size and Pharmaceutical Innovation". Rand Journal of Economics, 46(4):844–871.

Dubois, P. and Lasio, L. (2018). Identifying industry margins with price constraints: Structural estimation on pharmaceuticals. American Economic Review, 108(12):3685–3724.

Engel, E., Fischer, R., and Galetovic, A. (2001). "Least-Present-Value-of-Revenue Auctions and Highway Franchising". Journal of Political Economy, 109(5):993–1020.

Finkelstein, A. and Hendren, N. (2020). "Welfare Analysis Meets Causal Inference". Journal of Economic Perspectives, 34(4):146–167.

Gans, J. S. and Ridley, D. B. (2013). "Innovation Incentives under Transferable Fast-Track Regulatory Review". The Journal of Industrial Economics, 61(3):789–816.

Hendren, N. (2016). "The Policy Elasticity". Tax Policy and the Economy, 30.

Hendren, N. and Sprung-Keyser, B. (2020). "A Unified Welfare Analysis of Government Policies". Quarterly Journal of Economics, 135(3):1209–1318.

Hendren, N. and Sprung-Keyser, B. (2022). The case for using the mvpf in empirical welfare analysis. Working Paper 30029, National Bureau of Economic Research.

Lakdawalla, D. N. (2018). "Economics of the Pharmaceutical Industry". Journal of Economic Literature, 56:397–449.

Outterson, K. and McDonnell, A. (2016). "Funding Antibiotic Innovation with Vouchers: Recommendations on how to Strengthen a Flawed Incentive Policy". Health Affairs, 35(5):784–790.

Ridley, D. B., Grabowski, H. G., and Moe, J. L. (2006). "Developing Drugs For Developing Countries". Health Affairs, 25(2):313–324.

Rome, B. N. and Kesselheim, A. S. (2020). "Transferrable Market Exclusivity Extensions to Promote Antibiotic Development: An Economic Analysis". Clin Infect Dis., 71(7):1671–1675.

Rubinstein, A. (1982). "Perfect Equilibrium in a Bargaining Model". Econometrica, 50(1):97–109.

Scott-Morton, F., Stern, A. D., and Stern, S. (2018). "The Impact of the Entry of Biosimilars: Evidence from Europe". Review of Industrial Organization, 53(1):173–210.

Sinha, M. S., Najafzadeh, M., Rajasingh, E. K., Love, J., and Kesselheim, A. S. (2018). "Labeling Changes and Costs for Clinical Trials Performed Under the US Food and Drug Administration Pediatric Exclusivity Extension, 2007 to 2012". JAMA Intern. Med., 178(11):1458–1466.

Stahl, I. (1972). Bargaining Theory. Stockholm School of Economics.

Starc, A. and Wollmann, T. G. (2025). Does entry remedy collusion? evidence from the generic prescription drug cartel. American Economic Review, 115(5):1400–1438.

Appendix

A 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, $p_{ij,C}$ and $p_{ij,NC}$ the prices of drug j in country i for captive consumers ("C"), resp. non-captive consumers ("NC"), and h_i aggregate "health" of country i's inhabitants absent drug j. Hence, during the exclusivity period, $p_{ij,C} = p_{ij,NC} = p_{ij,E}$, while during the post-exclusivity period, $p_{ij,C} = p_{ij,NE}$ and $p_{ij,NC} = p_{ij,g}$ (as we assume that non-captive consumers then purchase generics).

For simplicity, we first assume away time considerations and focus on flow surpluses and costs. Let $\lambda_i \geq 0$ denote the shadow cost of public funds in country i. We thus write country i's (flow) objective as:[40]

$$\phi\Big(y_i - (1+\lambda_i)p_{ij,C}q_{ij,C}(p_{ij,C}) - (1+\lambda_i)p_{ij,NC}q_{ij,NC}(p_{ij,NC}),\ h_i + \omega_{ij}(p_{ij,C}, p_{ij,NC})\Big),$$

where $\phi : \mathbb{R}^3 \to \mathbb{R}$ is a strictly increasing and continuously differentiable function of its two arguments:

- disposable aggregate income after expenditures on drug j, $y_i - (1+\lambda_i)p_{ij,C}q_{ij,C}(p_{ij,C}) - (1+\lambda_i)p_{ij,NC}q_{ij,NC}(p_{ij,NC})$. Letting $F_{ij}(\cdot)$ be the c.d.f. of therapeutical needs for drug j in country i, $\sigma_{ij} > 0$ the market size parameter, and $\theta^*_{ij}(p_{ij,X})$ the lowest therapeutical need for consumers $X \in \{C, NC\}$ from drug j that is covered in country i when drug j's price is $p_{ij,X}$ (more on this below),

$$q_{ij,C}(p_{ij,C}) = x_i\sigma_{ij,C}[1 - F_{ij,C}(\theta^*(p_{ij,C}))],$$
$$q_{ij,NC}(p_{ij,NC}) = (1-x_i)\sigma_{ij,NC}[1 - F_{ij,NC}(\theta^*(p_{ij,NC}))].$$

- aggregate health of country i's inhabitants including the therapeutical benefits brought by usage of drug j, where

$$\omega_{ij}(y_i, p_{ij,C}, p_{ij,NC}) = x_i\sigma_{ij}\int_{\theta^*_{ij}(p_{ij,C})}^{\infty}\theta dF_{ij}(\theta) + (1-x_i)\sigma_{ij}\int_{\theta^*_{ij}(p_{ij,NC})}^{\infty}\theta dF_{ij}(\theta).$$

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 approximation is valid. Country i thus decides to buy

[40] We omit the dependence of the function ϕ on the country, i, to alleviate the notation.

the drug at price $p_{ij,X}$ to give it to all its inhabitants $X \in \{C, NC\}$ with therapeutical need $\theta \in [\theta, \theta + d\theta]$ if and only if

$$\theta \geq (1 + \lambda_i) \frac{\phi_y(y_i, h_i)}{\phi_h(y_i, h_i)} p_{ij,X} = \theta^*_{ij}(p_{ij,X}).$$

where ϕ_y and ϕ_h denote the partial derivatives of ϕ with respect to its first and second arguments.

Let $\gamma_{ij} \equiv (1+\lambda_i)\phi_y/\phi_h$ be the product of the shadow cost of public funds, $(1+\lambda_i)$, and 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. We assume that the expenditures and benefits for any drug that may benefit from an exclusivity extension are sufficiently low with respect to y_i and h_i that γ_{ij} does not depend on j, but only on i. Country i's demand from consumers $X \in \{C, NC\}$ for drug j at price p_{ij} is thus given by

$$\begin{aligned} D_{ij,C}(\gamma_i p_{ij,C}) &= x_i \sigma_{ij} \big[1 - F_{ij}(\gamma_i p_{ij,C})\big] = x_i D_{ij}(\gamma_i p_{ij,C}), \\ D_{ij,NC}(\gamma_i p_{ij,NC}) &= (1 - x_i) \sigma_{ij} \big[1 - F_{ij}(\gamma_i p_{ij,NC})\big] = (1 - x_i) D_{ij}(\gamma_i p_{ij,NC}). \end{aligned}$$

Hence, using a first-order approximation, country i's objective as a function of drug price p_{ij} writes as

$$\begin{aligned} & - \gamma_i p_{ij,C} D_{ij}(\gamma_i p_{ij,C}) - \gamma_i p_{ij,NC} D_{ij}(\gamma_i p_{ij,NC}) + \omega(p_{ij,C}, p_{ij,NC}) \\ &= x_i \sigma_{ij} \int_{\gamma_i p_{ij,C}}^{\infty} (\theta - \gamma_i p_{ij,C}) dF_{ij}(\theta) + (1 - x_i) \sigma_{ij} \int_{\gamma_i p_{ij,NC}}^{\infty} (\theta - \gamma_i p_{ij,NC}) dF_{ij}(\theta) \\ &= \gamma_i \sigma_{ij} \bigg(x_i \int_{p_{ij,C}}^{\infty} \big[1 - F_{ij}(\gamma_i p)\big] dp + (1 - x_i) \int_{p_{ij,NC}}^{\infty} \big[1 - F_{ij}(\gamma_i p)\big] dp \bigg) \\ &= \gamma_i \bigg(x_i \int_{p_{ij,C}}^{\infty} D_{ij}(\gamma_i p) dp + (1 - x_i) \int_{p_{ij,NC}}^{\infty} D_{ij}(\gamma_i p) dp \bigg) \end{aligned}$$

using an integration by parts. Therefore, the social surplus at prices $p_{ij,C}, p_{ij,NC}$ writes as

$$\gamma_i \bigg(x_i \int_{p_{ij,C}}^{\infty} D_{ij}(\gamma_i p) dp + (1 - x_i) \int_{p_{ij,NC}}^{\infty} D_{ij}(\gamma_i p) dp \bigg).$$

In our empirical specification, the c.d.f. of therapeutical needs for drug j is given by

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

while the market size is equal to σ_{ij}. Hence, with our empirical specification, country i's social surplus at price p_{ij} is given by

$$\gamma_i\sigma_{ij}\Big(x_i\int_{p_{ij,C}}^{m_{ij}/\gamma_i}\Big(1-\frac{\gamma_i p}{m_{ij}}\Big)^{k_j}dp+(1-x_i)\int_{p_{ij,NC}}^{m_{ij}/\gamma_i}\Big(1-\frac{\gamma_i p}{m_{ij}}\Big)^{k_j}dp\Big)$$
$$=\frac{\sigma_{ij}m_{ij}}{k_j+1}\Big[x_i\Big(1-\frac{\gamma_i p_{ij,C}}{m_{ij}}\Big)^{k_j+1}+(1-x_i)\Big(1-\frac{\gamma_i p_{ij,NC}}{m_{ij}}\Big)^{k_j+1}\Big].$$

Comparing exclusivity extensions and cash transfers. Let us reintroduce time and denote by T the date of patent expiration (absent an exclusivity extension). With the above linearization of the country's objective, the date-T value of the country's objective with an exclusivity extension of length Δ writes as

$$\gamma_i\int_0^\Delta e^{-r\tau}d\tau\Big(\int_{p_{ij,E}}^\infty D_{ij}(\gamma_i p)dp\Big)+\gamma_i\int_\Delta^\infty e^{-r\tau}d\tau\Big(x_i\int_{p_{ij,NE}}^\infty D_{ij}(\gamma_i p)dp+(1-x_i)\int_{p_{ij,g}}^\infty D_{ij}(\gamma_i p)dp\Big)$$

with $p_{ij,E}$, resp. $p_{ij,NE}$ the price of the branded drug under exclusivity, resp. after the exclusivity loss, and $p_{ij,g}$ the generics' price. With a cash transfer of date-T value Γ, the date-T value of the country's objective writes as

$$-\gamma_i\Gamma_i+\gamma_i\int_0^\infty e^{-r\tau}d\tau\Big(x_i\int_{p_{ij,NE}}^\infty D_{ij}(\gamma_i p)dp+(1-x_i)\int_{p_{ij,g}}^\infty D_{ij}(\gamma_i p)dp\Big)$$

As a consequence, country i favors a voucher over a cash transfer if and only if

$$\int_0^\Delta e^{-r\tau}d\tau\Big(\int_{p_{ij,E}}^\infty D_{ij}(\gamma_i p)dp\Big)+\Gamma_i$$
$$\geq\int_0^\Delta e^{-r\tau}d\tau\Big(x_i\int_{p_{ij,NE}}^\infty D_{ij}(\gamma_i p)dp+(1-x_i)\int_{p_{ij,g}}^\infty D_{ij}(\gamma_i p)dp\Big),$$

i.e., if and only if

$$\Big(\int_0^\Delta e^{-r\tau}d\tau\Big)\Big[x_i\int_{p_{ij,NE}}^{p_{ij,E}}D_{ij}(\gamma_i p)dp+(1-x_i)\int_{p_{ij,g}}^{p_{ij,E}}D_{ij}(\gamma_i p)dp\Big]\leq\Gamma_i.$$

B Imperfect competition under free entry in the generics market

Setting aside any regulation of the generics' price (e.g. aimed at guaranteeing a continuous, diversified supply), we investigate several possible causes of imperfect competition in the generics market. We focus on the two standard models of industrial economics already considered in the main text: Cournot competition (understand: competition in production

capacities) and price collusion.[41] For simplicity, we here restrict attention to a linear utility function U for the branded drug producer (and for the generics producers).

We consider free entry, and suppose that an entering generics company must sink an investment cost $I > 0$. (For simplicity, we ignore integer constraints on the number of generics entrants.) Let n_g denote the number of generics entrants. Both Cournot competition and price collusion exhibit testable relations between the number of active generics producers, the investment cost I and the share of captive consumers x. 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.

Cournot competition. Let us solve explicitly for the outcome of symmetric Cournot competition among $n_g \geq 1$ generics producers.[42] Each generics producer chooses its capacity to maximize its profit subject to the constraint that the originator does not find it profitable to undercut the generics' price $P(Q^C)$ with Q^C the total generics supply:

$$x\pi_E(\bar{p}) \geq [P(Q^C) - c]Q^C. \tag{12}$$

Hence, assuming that demand is quasi-concave (and thus $Q \mapsto (P(Q) - c)Q$ is concave), a candidate symmetric equilibrium is described by a total supply Q^C where

$$P(Q^C) = c - \frac{P'(Q^C)Q^C}{n_g}, \tag{13}$$

if the undercutting constraint (12) is not binding, and by (12) with equality if it does.

Such quantity choices form an equilibrium with free entry if the resulting profits for generics match their investment cost:

$$(1 - x)[P(Q^C) - c]Q^C = n_g I. \tag{14}$$

Observation 4. ***(Generics' Cournot competition)*** *Assume that demand is quasi-concave. If there is free entry and generics compete à la Cournot,*

(i) The number of generics active in equilibrium is first increasing then decreasing in $x \in (0, 1)$, and decreasing in $I > 0$. It is given by (ignoring integer constraints):

- *(14) and (13), as long as (12) holds strictly;*

[41] Bertrand competition between (horizontally and/or vertically) differentiated generics also yields prices above marginal cost and its characterization follows that of Cournot competition.

[42] We assume that the originator, who served the entire market under exclusivity, faces no capacity constraint.

- *(14) and (12) with equality, otherwise. In this case, the generics' equilibrium price is equal to* $P_g^L(\bar{p}, x)$.

(ii) The generics' equilibrium price increases with $x \in (0, 1)$ *and* $I > 0$.

Price collusion. Let us turn to price collusion. Suppose there are n_g active generics companies (this number will be endogenous). We assume that generics companies are no longer constrained by capacities but can form a cartel charging the same price p_g.[43] Let δ denote the discount factor. The highest price that can be sustained by the cartel is the no-undercutting price $P_g^L(\bar{p}, x)$, which is given by

$$x\pi_E(\bar{p}) = (P_g^L(\bar{p}, x) - c)D(\gamma P_g^L(\bar{p}, x)),$$

where $\bar{p}$ is the branded drug's post-exclusivity price, and thus $\bar{p} = p_E$ with legacy regulation. The price $P_g^L(\bar{p}, x)$ is strictly increasing in x (and strictly convex in x if $p \mapsto (p-c)D(\gamma p)$ is concave).

With legacy pricing for the branded drug, the ratio of the welfare gain from patent expiration over the profit loss is

$$\rho = \frac{S_{NE} - S_E}{\pi_E - \pi_{NE}} = \frac{(1-x)\int_{P_g^L(\bar{p},x)}^{p_E} D(\gamma p)dp}{(1-x)\pi_E(\bar{p})} = \frac{\int_{P_g^L(\bar{p},x)}^{p_E} D(\gamma p)dp}{(p_E - c)D(\gamma p_E)}$$

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 voucher scheme in a single country depends on the share of captive consumers of the original branded drug x, and a voucher 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. The level of entry is determined by a free-entry condition:

$$(1-x)(p(x) - c)D(\gamma p(x)) = n_g I,$$

as long as $n_g \leq \bar{N}_g$, where $\bar{N}_g$ is the maximum number of firms that allows generics producers

[43] We discuss in Online Appendix B the possibility that the original branded drug company joins the cartel. We further study in Online Appendix B a case of correlation between consumers' willingness to pay for the drug and captivity from the originating brand.

to sustain the collusive equilibrium:

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

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

Observation 5. ***(Generics' cartel)*** *The generics' cartel price is given by the no-undercutting price $P_g^L(\bar{p}, x)$, 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:*

$$n_g = \min \left\{ \frac{x(1-x)\pi_E(\bar{p})}{I}, \frac{1}{1-\delta} \right\},$$

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

Consistently with our theoretical analysis, in our data the generics' price increases with the share of captive consumers x.[44]

[44]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.

Online Appendix

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

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

The additional social surplus (in therapeutical terms) brought by a priority review is equal to

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

Suppose that the authority incurs the additional social cost $\varphi(\Delta)$ of expediting the review. Let us compare a PRV to a prize. Under a PRV, to achieve a reward Γ, the reduction of review time must satisfy:

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

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

$$\rho^{PRV} \leq 1,$$

where

$$\rho^{PRV} \equiv \frac{\varphi(\Delta(\bar{p},x)) - (e^{-r(T_R-\Delta(\bar{p},x))} - e^{-rT_R})\left(\frac{1-e^{-rT}}{r}S(p_E) + \frac{e^{-rT}}{r}\left[xS(p_{NE}) + (1-x)S(p_g)\right]\right)}{(e^{-r(T_R-\Delta(\bar{p},x))} - e^{-rT_R})\left(\frac{1-e^{-rT}}{r}\pi_E + \frac{e^{-rT}}{r}\pi_{NE}\right)}.$$

Observation 6. *In contrast with a patent voucher, the cost-over-reward ratio of priority review vouchers increases with the generics' price. Put differently, priority review vouchers are more desirable the more competitive the generics market, whereas patent vouchers are more desirable the less competitive the generics market.*

This observation suggests reversed preferences for countries with respect to both schemes (against cash transfers): the strongest supporters of patent vouchers (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 patent vouchers may still prefer cash transfers.]

B Market power in the supply of generics

We investigate in more details the generics' optimal cartel. Let us first take generics entry as given, and denoted by N the number of generics who enter the market once the exclusivity expires. The n_g 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 (as in the text) that a consumer's captivity (or lack thereof) to the original branded drug is independent of her WTP, hence both the demand of captive and non-captive consumers is given by $D(\cdot)$, 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 $n_g \leq 1/(1-\delta)$ with δ the firms' (common) discount factor. The original branded drug company is unwilling to undercut the cartel's price $p \leq \bar{p}$ if and only if

$$x\pi^* \geq (p-c)D(p),$$

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

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

$$\begin{cases} n_g \leq 1/(1-\delta) \\ (p-c)D(p) \leq x\pi^* \end{cases}$$

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. Can all producers collude on some price p? The no-deviation condition for generics writes as $n_g + 1 \leq 1/(1-\delta)$. The

no-deviation condition for the original branded drug company writes as

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

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

$$(p-c)D(p) \geq \pi^*.$$

Together with $p \leq \bar{p}$, this implies that $p = \bar{p}$ (the cartel sustains the regulated monopoly price). Each generic, resp. the original branded drug company, then makes a profit

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

which decreases, resp. increases, with x.

Do generics coopt the original branded drug company in their cartel?[45] 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

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

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

Generics entry in equilibrium. Let us now consider generics entry in equilibrium, i.e. endogenize the number of generics n_g.[46] (We ignore integer constraints on n_g for the sake of exposition.) Let $I > 0$ denote the entry cost.

- Case (I): $I \leq (1-\delta)x(1-x)\pi^*$. Then, a member of a generics-only cartel with size $1/(1-\delta)$ covers its entry cost. As a consequence, $N = 1/(1-\delta)$ generics enter. Therefore, as $n_g > \delta/(1-\delta)$, the generics cartel does not include the original branded drug.

[45] More precisely, we consider the following timing. Upon patent expiration, generics simultaneously decide whether to enter the market. Then, the generics who have entered decide whether to collude, and how. As a consequence, the number of generics n_g is fixed during the collusive stage.

[46] Our timing is thus as follows: (1) The regulator sets a regulated price $\bar{p}$, (2) generics decide whether to enter (we denote by n_g the number of generics who do enter), (3) generics who have entered collude and coordinate on the most profitable equilibrium for them. We restrict our attention to pure strategies for entry.

- Case (II): $(1-\delta)x(1-x)\pi^* < I \leq (1-\delta)(1-x)\pi^*$. Then, a member of a generics-only cartel with size $1/(1-\delta)$ does not cover the entry cost, whereas a member of a cartel including $\delta/(1-\delta)$ generics and the original branded drug covers it. (No cartel can have strictly more than $\delta/(1-\delta)$ generics and include the original branded drug.) Hence, the number of generics who enter is equal to

$$n_g = \max\left\{\frac{\delta}{1-\delta}, \frac{x(1-x)\pi^*}{I}\right\}.$$

Whether their cartel includes the original branded drug depends on the following inequality:

(II.a) If $\delta/(1-\delta) < x(1-x)\pi^*/I$, i.e. if $I < (1-\delta)x(1-x)\pi^*/\delta$, then the generics cartel does not include the original branded drug.

(II.b) If $I \geq (1-\delta)x(1-x)\pi^*/\delta$ (which thus requires $x \leq \delta$), then the generics cartel includes the original branded drug.

- Case (III): $(1-\delta)(1-x)\pi^* < I$. Then the number of generics who enter is equal to

$$n_g = \max\left\{\frac{x(1-x)\pi^*}{I}, \frac{(1-x)\pi^*}{I} - 1\right\}$$

Whether their cartel includes the original branded drug depends on the following inequality:

(III.a) If $x(1-x)\pi^*/I \leq (1-x)\pi^*/I - 1$, i.e. $I \leq (1-x)^2\pi^*$ (which thus requires $x \leq \delta$), the generics cartel includes the original branded drug (indifference if equality).

(III.b) If $I > (1-x)^2\pi^*$, the generics cartel does not include the original branded drug.

Correlation between captivity and WTP. To alleviate the expressions, suppose the marginal cost of production c is equal to zero. For simplicity, we omit regulation (in the form of Nash-bargaining on prices), and hence we consider unregulated profit maximization by the firms. Suppose N generics have entered the market.[47] 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.

[47] For the sake of brevity, we do not endogenize n_g later on, as this paragraph is only meant to illustrate how correlation between captivity and WTP affects the generics' incentive to include the original branded drug in their cartel.

As an illustration, with our flexible specification for demand,

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

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

For collusion among generics only, the two conditions become:

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

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

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

Henceforth, we focus on the case in which x is sufficiently small that a monopolist sets a price strictly below θ_x. As an illustration, for our flexible specification, this case arises if and only if[48]

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

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

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

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 Examples of post-exclusivity price determination.

C.1 Legacy post-exclusivity cap for the branded drug

Suppose that after the loss of exclusivity, the price of the branded drug is still regulated at the exclusivity level $\bar{p} = p_E$: the existing regulation is prolonged. We call this case "legacy price regulation". [We study the case in which the branded drug's price is renegotiated at the end of the exclusivity period in Online Appendix C.2.]

Proposition C.1. ***(Prices and cost-over-reward ratio with legacy price regulation)***

(i) When the captive and non-captive markets are decoupled ($P_g(p_E, x) = p_g^{\emptyset} < P^L(p_E, x)$), the generics' price is independent of the branded drug's price p_E^* and locally independent of the fraction x of captive consumers.[49]

(ii) When the two markets are coupled ($P_g(p_E, x) = P^L(p_E, x) \geq p_g^{\emptyset}$), the price of generics is a strictly increasing function of x and p_E^*.

Whether markets are coupled or decoupled, the cost-over-reward ratio is given by

$$\rho = \frac{S(P_g(p_E, x)) - S(p_E)}{\pi_E(p_E)}. \tag{15}$$

Remark: Distortion vs redistribution. A voucher distorts consumers' demand by maintaining a higher price. Yet, unless the generics' price is equal to the marginal cost, a voucher also induces some redistribution from the generics' quasi-rents to the original branded drug (in the limit case where $p_g = \bar{p}$, a voucher would be pure redistribution and entail no social cost, i.e. $\rho = 0$). Which effect dominates determines whether ρ is greater or smaller than 1.

Online Appendix D derives further theoretical properties of the cost-over-reward ratio in the legacy case, with our empirical demand specification.

[49] If the captive and non-captive markets are decoupled and generics compete à la Cournot with free entry, then with a concave demand, the generics' price strictly increases with x.

C.2 Post-exclusivity renegotiation of the branded drug's price

Suppose now that upon exclusivity loss, the regulator renegotiates the branded drug's price (with the same bargaining power α). The timing starting at the date of exclusivity loss is now as follows: (i) The branded drug price is renegotiated between the regulator and the IP owner, and a new price cap $\bar{p}$ is agreed upon. If no agreement on a price $\bar{p}$ is reached, the branded drug is taken off the market. (ii) Generics producers make their competitive choice (as described above). (iii) The branded drug producer selects a price $p \leq \bar{p}$.

For simplicity, we here restrict attention to a linear utility function U for the branded drug producer. The post-exclusivity branded drug price $\bar{p}$ is renegotiated to solve:

$$\max_p \ \big[x(p-c)D(\gamma p)\big]^{1-\alpha}\big[xS(p)+(1-x)\big(S(P_g(p,x))-S(p_g^{\emptyset})\big)\big]^{\alpha},$$

where, as before, $p_g^{\emptyset}$ is the generics price that prevails when there is no agreement with the branded drug manufacturer (and so the latter is not allowed to sell its drug anymore).[50] The captive and non-captive markets are decoupled if and only if $p_g^{\emptyset} \leq P_g^L(\bar{p},x)$. As in the legacy case, either the optimum is in the region in which the no-undercutting constraint is not binding and markets are decoupled, or the no-undercutting constraint is binding and the markets are coupled. In contrast to legacy regulation, whether coupling or decoupling obtains is now endogenously determined via the post-exclusivity renegotiation.

As the branded drug's price exerts a downward pressure on the generics' price, renegotiation introduces two new effects:

(i) *Competition effect:* The regulator has a heightened interest in a low branded-drug price to squeeze the generics' price, and thus bargains more aggressively,

(ii) *Reliance effect:* The regulator is more eager to strike a deal with the branded drug manufacturer to avoid generics choosing a high price, and it thus renegotiates from a weaker bargaining position.

The competition effect captures the regulator's gains from a low branded drug price, while

[50] For all $x \in (0,1)$, letting $W(p,p_g^{\emptyset})$ denote the log of the Nash-bargain objective $W(p,p_g^{\emptyset}) = W_D(p,p_g^{\emptyset}) + W_g(p,p_g^{\emptyset})$, where $W_D(p,p_g^{\emptyset}) \equiv \log\left(\big[x(p-c)D(\gamma p)\big]^{1-\alpha}\big[S(p)\big]^{\alpha}\right)$ is continuously differentiable and concave in p, with a maximum at p_E, and $W_g(p,p_g^{\emptyset}) \equiv \alpha\log\left(x+(1-x)\dfrac{S(P_g(p,x))-S(p_g^{\emptyset})}{S(p)}\right)$. By construction, $W_g(p,p_g^{\emptyset}) = S(P_g^L(p,x))-S(p_g^{\emptyset})$ if there is coupling ($p_g^{\emptyset} \leq P_g^L(p,x)$), and $W_g(p,p_g^{\emptyset}) = 0$ otherwise. For any p such that $p_g^{\emptyset} < P_g^L(p,x)$, $W_g(\cdot,p_g^{\emptyset})$ is continuously differentiable in a neighborhood of p and

$$\frac{\partial W_g}{\partial p}(p,p_g^{\emptyset}) = \alpha(1-x)\frac{S'(P_g^L(p,x))\dfrac{\partial P_g^L}{\partial p}(p,x) - S'(p)\dfrac{S(P_g(p,x))-S(p_g^{\emptyset})}{S(p)}}{xS(p)+(1-x)S(P_g(p,x))-S(p_g^{\emptyset})\big)}.$$

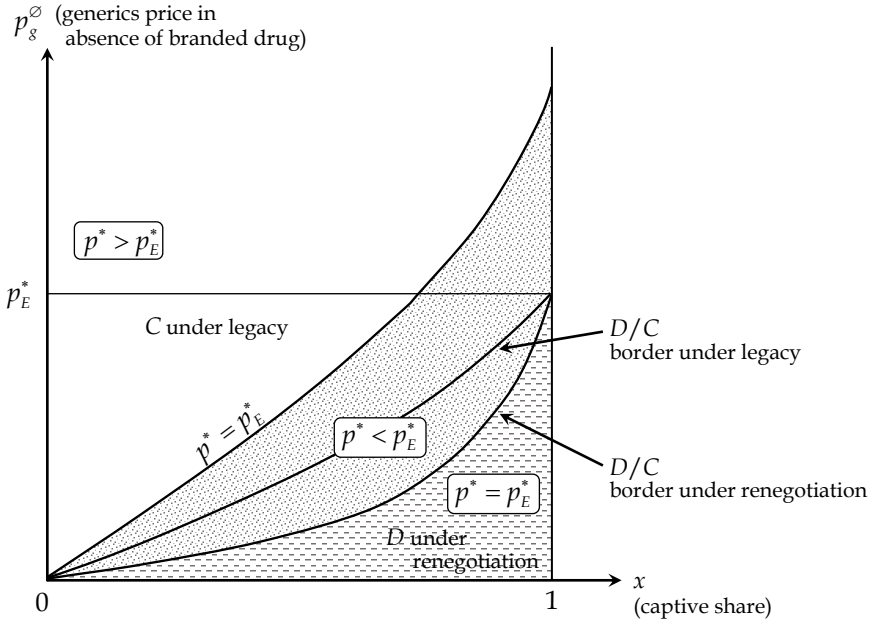


Figure 1: Coupling and decoupling regions with legacy regulation and renegotiation.

the reliance effect captures its loss from a bargaining breakdown. Which effect dominates depends in particular on the share of captive consumers x and the generics' price absent the branded drug $p_g^{\emptyset}$, as the next Proposition shows.[51]

An interesting observation is thus that post-exclusivity renegotiation does not necessarily lead to a lower price than legacy price-regulation. This observation is empirically supported in our data.

Proposition C.2. ***(Generics pricing: Post-exclusivity price renegotiation)*** *Let $\bar{p}$ denote the renegotiated branded drug price.*
(i) The generics' equilibrium price $P_g(\bar{p}, x) = \min\{p_g^{\emptyset}, P^L(\bar{p}, x)\} < \bar{p}$ is weakly increasing in its two arguments, strictly so whenever the captive and non-captive markets are coupled ($P_g(\bar{p}, x) = P^L(\bar{p}, x)$). The cost-over-reward ratio is given by

$$\rho = \frac{xS(\bar{p}) + (1-x)S(P_g(\bar{p}, x)) - S(p_E)}{\pi_E(p_E) - x\pi_E(\bar{p})}. \tag{16}$$

(ii) Under perfect competition among generics, and more generally if decoupling prevails, the renegotiated post-exclusivity price is equal to the exclusivity price, $\bar{p} = p_E$.

[51] Following on the previous footnote, the competition effect dominates the reliance effect at price $\bar{p}$ if and only if

$$D(\gamma P^L(\bar{p}, x))\frac{\partial P^L}{\partial p}(\bar{p}, x) \geq D(\gamma\bar{p})\frac{S(P_g(\bar{p}, x)) - S(p_g^{\emptyset})}{S(\bar{p})}.$$

As intuitive, the impact of the competition effect is proportional to the slope of P^L, $\partial P^L/\partial p$, while the one of the reliance effect is proportional to the surplus loss in case of bargaining breakdown, $S(P_g(\bar{p}, x)) - S(p_g^{\emptyset})$.

(iii) If competition is imperfect,

- *the post-exclusivity renegotiated price $\bar{p}$ is strictly higher than p_E for x in a neighborhood of 0, or for $p_g^\emptyset$ sufficiently high and x not too close to 1.*
- *fixing $p_g^\emptyset$, there exists $x_r \in (0,1)$ such that the post-exclusivity renegotiated price $\bar{p}$ is lower than p_E for any $x > x_r$, and in particular strictly so over a non-empty open interval. Similarly, fixing $x \in (0,1)$, there exists $p_r^\emptyset$ such that $\bar{p} \leq p_E$ for any $p_g^\emptyset \in (0, p_r^\emptyset)$, strictly so over a non-empty open interval.*

Proof. Claims (i) and (ii) derive from the above discussion, while claim (iii) is established in Online Appendix C.3. □

As intuitive, the coupling region (in the parameter space $\{x, p_g^\emptyset\}$) expands with renegotiation relative to legacy pricing, strictly so with imperfect generics competition. For, the regulator's interest in renegotiating the branded drug's price stems from the latter's downward pressure on the generics' price.

Corollary C.3. ***(Coupling and decoupling regions under imperfect generics competition)*** *Under imperfect generics competition, for any $x \in (0,1)$, the set of generics' prices in the absence of the branded drug, $p_g^\emptyset$, such that there is coupling with legacy pricing is a strict subset of the one such that there is coupling with renegotiation.*

Whether the cost-over-reward ratio ρ is higher or lower under post-exclusivity renegotiation than under legacy pricing is ambiguous in general.

Legacy pricing as default regulation. Suppose alternatively that in the case of renegotiation failure, the branded drug's price cap remains equal to p_E. Then, the post-exclusivity price $\bar{p}$ is always equal to p_E. Intuitively, during the post-exclusivity bargain, the branded drug always asks for a price weakly above p_E, while the regulator always asks for a price weakly below p_E.

C.3 Proof of Proposition C.2 and Corollary C.3

C.3.1 Proof of Proposition C.2

Let us show claim (iii). Let $p_g^\emptyset$ be fixed. Let $\underline{x}$ be the cutoff between the "coupling" and "decoupling" region with legacy pricing p_E^*, i.e. $\underline{x}$ is given by $P_g^L(p_E^*, \underline{x}) = p_g^\emptyset$.

Step 1: For any $x > \underline{x}$, $\bar{p}(x) \leq p_E^*$. Indeed, let us break the bargaining program solved by the post-exclusivity branded drug price in two: the maximum over $p \leq p_E^*$, and the maximum over $p \geq p_E^*$. For any $x > \underline{x}$, $P_g^L(p_E^*, x) > p_g^\emptyset$, and thus for any $p \geq p_E^*$, $P_g(p, x) = p_g^\emptyset$. As a consequence, the sub-program for $p \geq p_E^*$ reaches its maximum for p_E^*. (If $\underline{x}$ sufficiently

high, see additional monotonicity argument in Section C.3.3.)

Step 2: For any x in a neighborhood of 0, $\bar{p}(x) > p_E^*$. Indeed, for any x in a neighborhood of 0, $P_g^L(p,x) < p_g^\emptyset$ for any p in a relevant range (e.g. $[0, p^m]$), and hence $P_g(p,x) = P_g^L(p,x)$. The rest of the argument is in Section C.3.3 below.

Step 3: For any $x < \underline{x}$ in a neighborhood of $\underline{x}$, $\bar{p} < p_E^*$. Indeed, suppose by contradiction that there exists $x < \underline{x}$ arbitrarily close to $\underline{x}$ such that $\bar{p}(x) \geq p_E^*$. This implies that $P_g^L(\bar{p}(x), x) < p_g^\emptyset$,[52] and that this same inequality holds strictly for all p in a neighborhood of $\bar{p}(x)$. Hence, for $x < \underline{x}$ arbitrarily close to $\underline{x}$,

$$\frac{S'(\bar{p}(x)) + \frac{(1-x)}{x} S'(P_g^L(\bar{p}(x),x)) \frac{\partial P_g^L(\bar{p}(x),x)}{\partial \bar{p}}}{S(\bar{p}(x)) + \frac{(1-x)}{x}[S(P_g^L(\bar{p}(x),x)) - S(p_g^\emptyset)]}$$
$$= \frac{S'(\bar{p}(\underline{x})) + \frac{(1-\underline{x})}{\underline{x}} S'(P_g^L(\bar{p}(\underline{x}),\underline{x})) \frac{\partial P_g^L(\bar{p}(\underline{x}),\underline{x})}{\partial \bar{p}}}{S(\bar{p}(\underline{x}))} + O(\underline{x} - x)$$

and hence,

$$-\frac{1-\alpha}{\alpha} \frac{\pi_E'(\bar{p}(\underline{x}))}{\pi_E(\bar{p}(\underline{x}))} < \frac{S'(\bar{p}(\underline{x}))}{S(\bar{p}(\underline{x}))},$$

which, assuming the local concavity of the bargaining objective, implies that $\bar{p}(\underline{x}) < p_E^*$, a contradiction.

The same arguments apply when fixing x and varying $p_g^\emptyset$. Yet, as $p_g^\emptyset$ is constrained above by the monopoly price p^m, the region with $p_g^\emptyset$ sufficiently high such that $\bar{p} > p_E^*$ may be empty for x close to 1.

C.3.2 Proof of Corollary C.3

We begin with the following observation, used to derive Figure 1.

Lemma C.4. ***(Coupling regions)*** *Consider a given post-exclusivity regulation, either legacy pricing or price renegotiation. If there is coupling for a given couple $(x, p_g^\emptyset)$ of share of captive $x \in (0,1)$ and generics' price absent the branded drug $p_g^\emptyset \in (0, p_m)$, then, for any $x' \leq x$ and $p_g^{\emptyset\prime} \leq p_g^\emptyset$, there is coupling for $(x', p_g^{\emptyset\prime})$.*

Proof. The result with legacy pricing stems from the monotonicity of P_g^L. Consider price renegotiation. Suppose there exists $(x, p_g^\emptyset)$ such that there is coupling, and suppose by contradiction that there exists $x' \leq x$ and $p_g^{\emptyset\prime} \geq p_g^\emptyset$ such that decoupling prevails for $(x', p_g^{\emptyset\prime})$. Then, $P_g^L(p_E^*, x') > p_g^{\emptyset\prime}$, and thus $\bar{p}(p_g^\emptyset, x) < p_E^*$. Moreover, for any p such that $P_g^L(p,x') \leq$

[52] Indeed, a necessary condition for any $\bar{p}(x) > p_E^*$ to be a solution to the post-exclusivity Nash-bargaining is that $P_g^L(\bar{p}(x),x) < p_g^\emptyset$. Lastly, if $\bar{p}(x) = p_E^*$, then as $P_g^L(\cdot,\cdot)$ strictly increases with x, $P_g^L(\bar{p}(x),x) < p_g^\emptyset$ for $x < \underline{x}$.

$p_g^{\emptyset'}$, and thus in particular for any p such that $P_g^L(p,x) \leq p_g^\emptyset$,

$$\begin{aligned}\pi_E(p_E^*)^{1-\alpha}S(p_E^*)^\alpha &\geq \pi_E(p)^{1-\alpha}\left(S(p) + \frac{1-x'}{x'}\left[S(P_g^L(p,x')) - S(p_g^{\emptyset'})\right]\right)^\alpha \\ &> \pi_E(p)^{1-\alpha}\left(S(p) + \frac{1-x}{x}\left[S(P_g^L(p,x)) - S(p_g^\emptyset)\right]\right)^\alpha\end{aligned}$$

as $x' \leq x$ and $p_g^{\emptyset'} \geq p_g^\emptyset$, with at least one of the two inequalities strict. Yet, since there is coupling for $p_g^\emptyset$, $P_g^L(\bar{p}(p_g^\emptyset, x), x) \leq p_g^\emptyset$ and

$$\pi_E(\bar{p}(p_g^\emptyset,x))^{1-\alpha}\left(S(\bar{p}(p_g^\emptyset,x)) + \frac{1-x}{x}\left[S(P_g^L(\bar{p}(p_g^\emptyset,x),x)) - S(p_g^\emptyset)\right]\right)^\alpha \geq \pi_E(p_E^*)^{1-\alpha}S(p_E^*)^\alpha,$$

a contradiction. □

We now show Corollary C.3. Fix $x \in (0,1)$.

A) Suppose there exists $p_g^\emptyset$ such that there is coupling with legacy, but not with renegotiation. If there is no coupling with renegotiation, then the principal bargains $\bar{p} = p_E^*$, and hence there should be coupling, a contradiction.

Hence, the set of prices $p_g^\emptyset$ such that coupling happens is weakly larger with renegotiation than with legacy.

B) Let $\underline{p}_g^\emptyset$ be the infimum of the set of prices $p_g^\emptyset$ such that there is coupling with renegotiation. Let us denote $p_{lim}^* \equiv \lim_{p_g^\emptyset \to \underline{p}_g^\emptyset,\ p_g^\emptyset \geq \underline{p}_g^\emptyset} \bar{p}(p_g^\emptyset, x)$, the right limit of $\bar{p}(p_g^\emptyset, x)$ as $p_g^\emptyset$ decreases down to $\underline{p}_g^\emptyset$. Therefore, at $\underline{p}_g^\emptyset$, the renegotiated price is given by $\bar{p}(\underline{p}_g^\emptyset, x) = p_{lim}^*$ if there is coupling at $\underline{p}_g^\emptyset$, and $\bar{p}(\underline{p}_g^\emptyset, x) = p_E^*$ otherwise. Moreover, by monotonicity and continuity of $P_g^L(\cdot, x)$,

$$\underline{p}_g^\emptyset = P_g^L(p_{lim}^*, x). \tag{17}$$

Suppose by contradiction that $p_{lim}^* > p_E^*$. Then, there exists $p_g^{\emptyset'}$ such that $P_g^L(p_E^*, x) < p_g^{\emptyset'} < P_g^L(p_{lim}^*, x) = \underline{p}_g^\emptyset$. However, by A), there is coupling with renegotiation for $p_g^{\emptyset'}$. But then, $p_g^{\emptyset'} < \underline{p}_g^\emptyset$ contradicts the definition of $p_g^\emptyset$. Consequently, $p_{lim}^* \leq p_E^*$.

Consider now a sequence of prices $p_g^\emptyset$ such that there is coupling with renegotiation, and converging (down) to $\underline{p}_g^\emptyset$. Using the FOC of the post-exclusivity Nash-bargain, continuity yields that:

$$-\frac{1-\alpha}{\alpha}\frac{\pi'(p_{lim}^*)}{\pi(p_{lim}^*)} = \frac{S'(p_{lim}^*) + \frac{1-x}{x}S'(\underline{p}_g^\emptyset)\frac{\partial}{\partial p}P_g^L(p_{lim}^*, x)}{S(p_{lim}^*)},$$

By definition of p_E^* and as $S'(\cdot) < 0$ and $\partial P_g^L(\cdot)/\partial p > 0$, we know that for any $p_g^\emptyset$ in that sequence,

$$-\frac{1-\alpha}{\alpha}\frac{\pi'(p_E^*)}{\pi(p_E^*)} = \frac{S'(p_E^*)}{S(p_E^*)} > \frac{S'(p_E^*) + \frac{1-x}{x}S'(\underline{p}^\emptyset)\frac{\partial}{\partial p}P_g^L(p_E^*, x)}{S(p_E^*)}.$$

Suppose by contradiction that $p_{lim}^* = p_E^*$. Then, $S'(P_g^L(p_E^*, x)) = S'(p_g^\emptyset)$ and $S(P_g^L(p_E^*, x) = S(p_g^\emptyset)$. As a consequence,

$$-\frac{1-\alpha}{\alpha}\frac{\pi'(p_E^*)}{\pi(p_E^*)} > \frac{S'(p_{lim}^*) + \frac{1-x}{x}S'(\underline{p}_g^\emptyset)\frac{\partial}{\partial p}P_g^L(\bar{p}, x)}{S(p_{lim}^*)} = -\frac{1-\alpha}{\alpha}\frac{\pi'(p_{lim}^*)}{\pi(p_{lim}^*)}.$$

Therefore, by concavity of the profit function, $p_E^* > p_{lim}^*$, a contradiction.

Hence, $p_{lim}^* < p_E^*$, and thus, for any $\varepsilon > 0$ sufficiently small,

$$P_g^L(p_E^*, x) > \underline{p}_g^\emptyset + \varepsilon \geq P_g^L(\bar{p}(\underline{p}_g^\emptyset + \varepsilon, x), x)$$

where the first inequality stems from (17) and the second from the definition of $\underline{p}_g^\emptyset$ together with the monotonicity result of Lemma C.4.

Consequently, the set of prices $p_g^\emptyset$ such that coupling happens is strictly larger with renegotiation than with legacy.

C.3.3 Monotonicity in the coupling region

Let us consider the case in which there is coupling, i.e. the generics' price is equal to $P_g^L(\bar{p}, x)$, and thus a strictly increasing function of $\bar{p}$ and x (coupling case).[53]

Then, by concavity of $\pi_E(\cdot)$ and Nash-bargaining, the renegotiated price $\bar{p}$ satisfies $\bar{p} > p_E^*$ if and only if

$$-\frac{(1-\alpha)}{\alpha}\frac{\pi_E'(p^*)}{\pi_E(p^*)} = \frac{S'(p^*) + \frac{(1-x)}{x}S'(P_g^L(p^*, x))\frac{\partial P_g^L(p^*, x)}{\partial p^*}}{S(p^*) + \frac{(1-x)}{x}[S(P_g^L(p^*, x)) - S(p_g^\emptyset)]} > \frac{S'(p_E^*)}{S(p_E^*)} = -\frac{(1-\alpha)}{\alpha}\frac{\pi_E'(p_E^*)}{\pi_E(p_E^*)},$$

and $\bar{p} < p_E^*$ if the opposite inequality holds.

[53] As $P_g^L(p, x)$ is given by the no-undercutting constraint (5),

$$\frac{\partial}{\partial x}P_g^L(p, x) = \frac{\pi_E(p)}{\pi_E'(P_g(p, x))},$$

and thus, $\partial P_g^L/\partial x$ strictly increases with p and with x.

For x in a neighborhood of 0,

$$\frac{S'(p^*) + \frac{(1-x)}{x} S'(P_g^L(p^*,x)) \frac{\partial P_g^L(p^*,x)}{\partial \bar{p}}}{S(p^*) + \frac{(1-x)}{x}[S(P_g^L(p^*,x)) - S(p_g^\emptyset)]} = \frac{x\left(S'(p^*) + S'(c)\frac{\pi_E'(\bar{p})}{\pi_E'(c)}\right)}{S(c) - S(p_g^\emptyset)} + o(x) > \frac{S'(p_E^*)}{S(p_E^*)},$$

and hence, $\bar{p} > p_E^*$ for x in a neighborhood of 0, and by the same argument, $\bar{p}(x)$ goes to p^m as x goes to 0.

Let us now define the function ψ such that

$$\psi : \begin{cases} \mathbb{R}_+ \times (0,1) \longrightarrow \mathbb{R}, \\ (p,x) \longmapsto [(p-c)D(\gamma p)]^{1-\alpha}\left[S(p) + \frac{1-x}{x}(S(P_g^L(p,x)) - S(p_g^\emptyset))\right]^\alpha. \end{cases}$$

We assume that ψ is strictly concave. Note that $S(p_g^\emptyset) > S(P_g^L(p,x))$ for all p, x, and that $\lim_{x\to 0} P_g^L(p,x) = c$ and $\lim_{x\to 1} P_g^L(p,x) = p$ for all p. Moreover, the exclusivity negotiated price p_E^* maximizes $\psi(\cdot, 1)$ (and thus $\bar{p}(1) = p_E^*$).

Using Milgrom-Shannon's (1994) monotonicity theorem, if for all $p' > p$ and $x' > x$,

$$\psi(p', x) \geq \psi(p, x) \implies \psi(p', x') > \psi(p, x') \tag{18}$$

then the post-exclusivity negotiated price $\bar{p}(x)$ strictly increases with x, whereas if if for all $p' > p$ and $x' > x$,

$$\psi(p', x) \geq \psi(p, x) \implies \psi(p', x') < \psi(p, x') \tag{19}$$

then the post-exclusivity negotiated price $\bar{p}(x)$ strictly decreases with x. Hence, if (18), resp. (19), holds for all $p' > p$ and $x' > x$, then $\bar{p} < p_E^*$, resp. $\bar{p} > p_E^*$.

Inequality (18), resp. (19), holds for all $p' > p$ and $x' > x$ if and only if for all $p' > p$, the function φ defined by

$$\varphi : \begin{cases} (0,1) \longrightarrow \mathbb{R}, \\ x \longmapsto \frac{S(p') + \frac{1-x}{x}(S(P_g^L(p',x)) - S(p_g^\emptyset))}{S(p) + \frac{1-x}{x}(S(P_g^L(p,x)) - S(p_g^\emptyset))}, \end{cases}$$

is strictly increasing, resp. strictly decreasing. The sign of $\psi'(x)$ is given by the sign of

$$
\begin{aligned}
&-\left(\frac{S(P_g^L(p',x))-S(p_g^\emptyset)}{x^2}+\frac{1-x}{x}D(\gamma P_g^L(p',x))\frac{\partial}{\partial x}P_g^L(p',x)\right)\left[S(p)+\frac{1-x}{x}(S(P_g^L(p,x))-S(p_g^\emptyset))\right]\\
&+\left(\frac{S(P_g^L(p,x))-S(p_g^\emptyset)}{x^2}+\frac{1-x}{x}D(\gamma P_g^L(p,x))\frac{\partial}{\partial x}P_g^L(p,x)\right)\left[S(p')+\frac{1-x}{x}(S(P_g^L(p',x))-S(p_g^\emptyset))\right]\\
&\equiv A(x).
\end{aligned}
$$

For x in a neighborhood of 1,

$$
A(x)=-\Big(S(p')-S(p_g^\emptyset)+o(1)\Big)\Big(S(p)+o(1)\Big)+\Big(S(p)-S(p_g^\emptyset)+o(1)\Big)\Big(S(p')+o(1)\Big),
$$

and hence for x in a neighborhood of 1, $A(x)>0$. Therefore, $\bar{p}$ increases with x in a neighborhood of 1, and thus $\bar{p}(x)<p_E^*$ for any $x<1$ in a neighborhood of 1.

For x in a neighborhood of 0,

$$
\begin{aligned}
A(x)=&-\frac{1}{x^3}\Big(S(c)-S(p_g^\emptyset)+o(x)\Big)\Big(S(c)-S(p_g^\emptyset)-xD(\gamma c)\frac{\pi_E(p)}{\pi_E'(c)}+xS(p)+o(x)\Big)\\
&+\frac{1}{x^3}\Big(S(c)-S(p_g^\emptyset)+o(x)\Big)\Big(S(c)-S(p_g^\emptyset)-xD(\gamma c)\frac{\pi_E(p')}{\pi_E'(c)}+xS(p')+o(x)\Big),
\end{aligned}
$$

and hence for x in a neighborhood of 0, $A(x)<0$. Therefore, $\bar{p}$ decreases with x in a neighborhood of 0.

D Properties of a national voucher in the legacy case

We specify a flexible demand for the drug that will benefit from the voucher as follows: for any $p\leq m/\gamma$,

$$
D(\gamma p)=\sigma\Big(1-\gamma\frac{p}{m}\Big)^k,
$$

where σ is market size, i.e. the size of the population of individuals who potentially benefit from the drug, m a measure of quality (m γ is the highest WTP in the population, with $m\gamma\geq c$ to ensure there is a market for the drug), and $k\geq 0$ a parameter governing the curvature of demand.[54]

[54]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.

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

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

(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 (in monetary terms) is given by

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

The elasticity of demand at a given price p, $\frac{kp}{(m/\gamma)-p}$ decreases with m and increases with p, γ and k.

Proposition D.1. ***(Empirical specification: Legacy case)*** *Suppose that the branded drug's post-exclusivity price remains equal to its exclusivity price, $\bar{p} = p_E^*$ (legacy case), and that the branded drug producer's utility U is linear. Let p_g denote the generics' price.*
(i) The cost-over-reward ratio of a voucher writes as:[55]

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

(ii) The cost-over-reward ratio decreases with the generics' price p_g. Moreover, the cost-over-reward ratio depends on the fraction of captive users (x) and on the scale of demand (σ) only via the generics' price.[56] *For a perfectly competitive generics market, the cost-over-reward ratio is independent from γ, from the marginal cost of production c and the drug quality m, and it decreases with the regulator's bargaining power α and increases with k.*[57]
(iii) The cost-over-reward ratio of a voucher scheme is greater than 1 if and only if the

[55] When the generics market is perfectly competitive ($p_g = c$), the less elastic the demand is, the lower the cost-over-reward ratio.

[56] Hence, when the generics' price increases with x, e.g. because it is constrained by the originator's ability to undercut (or if generics compete à la Cournot with free entry, a strictly positive entry cost and a concave demand), the cost-over-reward ratio of a voucher decreases with the share of captive users x. Similarly, when the generics' price p_g is independent of the scale of demand, e.g. because of price competition, the cost-over-reward ratio of a voucher is independent from the scale of demand. Other comparative statics depend on the demand specification and the shape of p_g as a function of the parameters. As another illustration, if because of regulation, the price of generics is an exogenous fraction $y \leq 1$ of the exclusivity price ($p_g = y\bar{p}$), the cost-over-reward ratio decreases with the exclusivity price $\bar{p}$ for any y sufficiently close to 1. Whenever this condition holds, the cost-over-reward ratio thus *increases* with the regulator's bargaining power α.

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

generics' price p_g is sufficiently low.[58] *For a perfectly competitive generics market ($p_g = c$), the cost-over-reward ratio of a voucher scheme is greater than* 1, *strictly so unless the regulator has full bargaining power ($\alpha = 1$) or demand is inelastic ($k = 0$, i.e. all patients have the highest WTP for the drug, m).*

Proof. The results derive from straightforward computations, except claim (iii'), for which we provide details in Online Appendix D.1. □

D.1 Proof of Proposition D.1

The (Nash-bargained) under-exclusivity and, with decoupling, post-exclusivity price maximizes:

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

and is thus given by

$$\gamma\frac{\bar{p}}{m} = \frac{1-\alpha}{k+1} + \frac{k+\alpha}{k+1}\gamma\frac{c}{m}.$$

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

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

while the social cost, per unit of time, of buying the original branded drug at the exclusivity price p_E^* instead of generics at price p_g because of the exclusivity extension, is given by

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

The expression for the cost-over-reward ratio follows.

D.1.1 Proof of claim (ii) in Proposition D.1

We now show claim (ii) of Proposition D.1, specifically the monotonicity of the cost-over-reward ratio with respect to k for $p_g = c$.

[58] Namely,

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

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.1.2 Case $0 \leq \alpha \leq 0.5$

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:

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

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:

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

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[59]:

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

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.1.3 Case $0.5 \leq \alpha < 1$

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, $l(k) \leq \dfrac{\alpha}{2} + \dfrac{k}{2} + k + k^2$.

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:

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

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

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

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 Value of one-year vouchers for top 50 bestselling molecules (in k€)

Table 5: Value of One-Year Voucher by Year - Using mean preservation revenue parameter μ_i from top 50 bestselling molecules (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)	LIPITOR (2011)	ZOCOR (2002)	NORVASC (2003)	PANTOZOL (2008)
	617,182	609,379	558,813	432,611	353,208
2003	PLAVIX (2008)	LIPITOR (2011)	NORVASC (2003)	PANTOZOL (2008)	PRAVACHOL (2003)
	636,270	628,226	445,990	364,132	350,847
2004	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	NEXIUM (2010)
	655,949	647,655	375,394	361,190	345,946
2005	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	NEXIUM (2010)
	676,236	667,686	387,004	372,361	356,646
2006	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	NEXIUM (2010)
	697,150	688,336	398,973	383,878	367,676
2007	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	NEXIUM (2010)
	718,712	709,625	411,313	395,750	379,048
2008	PLAVIX (2008)	LIPITOR (2011)	PANTOZOL (2008)	ZYPREXA (2010)	NEXIUM (2010)
	740,940	731,572	424,034	407,990	390,771
2009	LIPITOR (2011)	ZYPREXA (2010)	NEXIUM (2010)	SEROQUEL (2011)	TAXOTERE (2010)
	754,198	420,608	402,856	380,990	356,516
2010	LIPITOR (2011)	ZYPREXA (2010)	NEXIUM (2010)	SEROQUEL (2011)	TAXOTERE (2010)
	777,524	433,617	415,316	392,773	367,542
2011	LIPITOR (2011)	SEROQUEL (2011)	SINGULAIR (2012)	ZOMETA (2012)	VIAGRA (2012)
	801,571	404,921	190,567	183,176	156,587

Notes: Voucher values $\bar{V}_t$ for one year voucher, 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 we thus lack observations for drugs whose exclusivity stops in or after 2012.

E.2 Lower-bound values of one-year vouchers, by year

Table 6: Lower Bound Values of one year voucher by year (in k€)

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 voucher, 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 $\overline{V}_t$, 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 we thus lack observation of other drugs whose exclusivity stops in or after 2012.

E.3 Robustness checks Tables

E.4 Demand models

Table 7: Cost-over-reward ratios (top 30 drugs)

Country	(1) ρ_i	(2) s_i^{gdp}	(3) s_i^{pop}	(4) s_i^{U*}	(5) $\frac{\rho_i^U}{s_i^{gdp}}$	(6) $\frac{\rho_i^U}{s_i^{pop}}$
AUSTRIA	0.83	0.06	0.05	0.05	0.65	0.77
BELGIUM	0.84	0.03	0.02	0.11	3.02	3.34
FINLAND	0.86	0.01	0.01	0.08	4.44	4.81
FRANCE	0.70	0.15	0.15	0.09	0.48	0.48
GERMANY	0.75	0.21	0.19	0.10	0.38	0.42
GREECE	0.52	0.02	0.03	0.02	0.58	0.46
IRELAND	0.41	0.01	0.01	0.03	1.80	2.30
ITALY	0.80	0.14	0.14	0.05	0.30	0.30
NORWAY	0.91	0.02	0.01	0.04	1.54	2.46
POLAND	0.73	0.05	0.09	0.05	0.82	0.42
PORTUGAL	0.75	0.02	0.02	0.04	1.53	1.14
SPAIN	0.60	0.09	0.10	0.04	0.37	0.33
SWEDEN	0.67	0.02	0.02	0.09	2.87	3.38
SWITZERLAND	0.80	0.03	0.02	0.11	3.19	4.73
UK	0.72	0.15	0.14	0.11	0.56	0.59
Nb favorable countries (total share)	15				8 (.859)	8 (.879)
ρ^U	0.76					

Notes: s_i^{gdp} denotes the GDP share of country i in the union, s_i^{pop} the population share of country i in the union. s_i^{U*} is a sharing rule achieving unanimity. The total share in parenthesis represents the share of GDP or population of countries that prefer the TEE over the cash transfer.

Table 8: Cost-over-reward ratios (top 100 drugs)

Country	(1) ρ_i	(2) s_i^{gdp}	(3) s_i^{pop}	(4) s_i^{U*}	(5) $\frac{\rho_i^U}{s_i^{gdp}}$	(6) $\frac{\rho_i^U}{s_i^{pop}}$
AUSTRIA	0.80	0.06	0.05	0.06	0.83	0.98
BELGIUM	0.86	0.03	0.02	0.08	2.25	2.49
FINLAND	0.85	0.01	0.01	0.07	4.32	4.69
FRANCE	0.71	0.15	0.15	0.07	0.34	0.34
GERMANY	0.73	0.21	0.19	0.12	0.44	0.49
GREECE	0.58	0.02	0.03	0.02	0.75	0.60
IRELAND	0.52	0.01	0.01	0.03	1.83	2.34
ITALY	0.85	0.14	0.14	0.07	0.43	0.43
NORWAY	0.83	0.02	0.01	0.05	2.09	3.33
POLAND	0.73	0.05	0.09	0.06	0.99	0.51
PORTUGAL	0.72	0.02	0.02	0.05	2.35	1.75
SPAIN	0.56	0.09	0.10	0.03	0.29	0.26
SWEDEN	0.75	0.02	0.02	0.11	3.46	4.07
SWITZERLAND	0.82	0.03	0.02	0.08	2.26	3.35
UK	0.66	0.15	0.14	0.10	0.50	0.53
Nb favorable countries (total share)	15				8 (.859)	8 (.879)
ρ^U	0.77					

Notes: s_i^{gdp} denotes the GDP share of country i in the union, s_i^{pop} the population share of country i in the union. s_i^{U*} is a sharing rule achieving unanimity. The total share in parenthesis represents the share of GDP or population of countries that prefer the TEE over the cash transfer.

Table 9: Demand parameters

Country	(1) γ_i	(2) $\mathcal{E}_i$	(3) x_i	(4) σ_i
AUSTRIA	199.80	-0.02	0.58	6.15
BELGIUM	143.90	-0.01	0.77	6.58
FINLAND	163.39	-0.02	0.14	6.00
FRANCE	160.61	-0.01	0.24	7.52
GERMANY	258.83	-0.01	0.30	7.27
GREECE	153.97	-0.02	0.79	7.00
IRELAND	66.61	-0.02	0.51	5.93
ITALY	173.07	-0.01	0.78	7.54
NORWAY	70.80	-0.00	0.29	5.29
POLAND	157.38	-0.03	0.16	6.47
PORTUGAL	86.78	-0.01	0.43	6.85
SPAIN	94.78	-0.01	0.56	7.52
SWEDEN	63.09	-0.01	0.56	5.93
SWITZERLAND	83.14	-0.02	0.37	5.96
UK	487.17	-0.01	0.29	6.91

Notes: $\mathcal{E}_i = \sum_{j=1}^{J(i)} \mathcal{E}_{ij}/J(i)$, s_i denotes the GDP share of country i in the union. $\underline{s}_i^*$ is the threshold below which i does not favor a voucher (with $\lambda_i = 0$).

Table 10: Demand Regressions

	POLAND	AUSTRIA	BELGIUM	FINLAND	FRANCE	GERMANY	GREECE	IRELAND	ITALY	NORWAY	PORTUGAL	SPAIN	SWEDEN	SWITZERLAND	UK
price ATC A	-332.510**	-65.065**	-47.170**	-342.363**	-24.967**	-40.448**	-311.972**	-145.755**	-30.629**	-10.130**	-9.030**	-17.833**	-12.672**	-21.906**	-92.605**
	(26.509)	(6.608)	(3.589)	(22.835)	(2.036)	(2.655)	(20.507)	(10.266)	(1.856)	(2.541)	(0.848)	(1.167)	(1.264)	(5.736)	(6.127)
price ATC B	-33.473**	-58.146**	-29.960**	-19.862**	-34.220**	-69.844**	-56.754**	-36.215**	-48.584**	-17.509**	-23.061**	-32.266**	-11.123**	-47.284**	-106.243**
	(2.930)	(3.801)	(2.145)	(1.688)	(2.802)	(3.854)	(4.673)	(3.684)	(3.127)	(1.624)	(2.170)	(1.778)	(0.854)	(3.665)	(8.010)
price ATC C	-434.895**	-46.818**	-629.170**	-30.272**	-140.150**	-1045.538**	-335.069**	-138.175**	-87.645**	-174.637**	-158.507**	-69.982**	-33.765**	-252.533**	-2340.747**
	(50.000)	(4.802)	(50.365)	(2.949)	(23.099)	(99.595)	(27.208)	(13.130)	(7.816)	(29.391)	(21.551)	(6.132)	(3.473)	(21.405)	(183.019)
price ATC D	-1108.244**	-3438.538**	-15.739**	-1434.324**	-18.119**	-23.854**	-7.513**	-52.032**	-23.295**	-46.972**	-702.007**	-9.183**	-56.482**	-58.706**	-50.812**
	(167.025)	(571.416)	(6.536)	(284.099)	(4.470)	(4.386)	(1.952)	(13.194)	(5.710)	(14.567)	(116.411)	(1.973)	(12.841)	(18.671)	(11.066)
price ATC G	-165.533**	-186.781**	-156.613**	-56.465**	-218.770**	-402.315**	-58.081**	-26.555**	-258.647**	-50.317**	-59.572**	-125.670**	-56.700**	-77.870**	-695.891**
	(19.917)	(18.111)	(12.911)	(4.696)	(33.578)	(35.087)	(7.037)	(2.487)	(38.077)	(5.813)	(5.037)	(15.762)	(4.937)	(5.760)	(69.354)
price ATC H	-4.568*	-59.117**	-25.695**	-18.438**	-35.788**	-58.793**	-33.324**	-11.528**	-48.892**	-17.724*	-28.677**	-22.227**	-10.143**	-19.381**	-79.152**
	(2.559)	(7.777)	(5.481)	(4.263)	(9.302)	(8.952)	(6.260)	(3.335)	(10.387)	(9.527)	(4.487)	(4.531)	(2.797)	(3.607)	(20.455)
price ATC J	-20.645**	-27.126**	-37.879**	-22.360**	-63.106**	-93.036**	-20.124**	-8.010**	-66.891**	-23.593**	-15.184**	-30.734**	-16.538**	-21.781**	-160.955**
	(2.335)	(2.932)	(4.137)	(2.571)	(7.508)	(9.852)	(2.749)	(1.277)	(6.278)	(3.520)	(1.872)	(3.501)	(2.235)	(2.575)	(17.590)
price ATC L	-7.613**	-11.567**	-12.956**	-6.131**	-9.769**	-12.819**	-13.721**	-3.750**	-13.366**	-5.814**	-4.499**	-9.593**	-6.348**	-5.388**	-29.178**
	(1.057)	(1.314)	(1.509)	(0.860)	(1.535)	(1.580)	(1.498)	(0.484)	(1.345)	(1.060)	(0.826)	(0.873)	(0.839)	(0.672)	(3.941)
price ATC M	-61.016**	-84.268**	-106.524**	-42.459**	-172.935**	-183.011**	-58.622**	-23.983**	-144.056**	-33.449**	-62.308**	-111.955**	-33.670**	-29.108**	-390.841**
	(6.827)	(8.339)	(9.503)	(4.743)	(16.149)	(18.269)	(5.774)	(2.903)	(14.277)	(5.203)	(7.705)	(10.143)	(5.187)	(3.664)	(40.463)
price ATC N	-204.190**	-125.354**	-165.187**	-270.939**	-597.642**	-258.294**	-1849.872**	-65.090**	-238.388**	-64.102**	-54.610**	-108.679**	-107.424**	-53.567**	-609.410**
	(21.398)	(21.929)	(23.901)	(22.490)	(65.577)	(36.700)	(110.655)	(8.251)	(35.573)	(9.364)	(10.833)	(19.249)	(13.000)	(7.594)	(77.140)
price ATC R	-39.479**	-117.895**	-92.996**	-908.234**	-93.456**	-242.305**	-59.853**	-27.819**	-193.903**	-48.352**	-33.153**	-87.086**	-66.466**	-40.606**	-361.505**
	(4.571)	(19.726)	(14.403)	(77.676)	(9.542)	(21.835)	(8.034)	(3.533)	(16.267)	(8.336)	(6.787)	(8.359)	(7.760)	(7.603)	(29.447)
price ATC S	-14.941**	-31.270**	-35.380**	-16.693**	-59.119**	-80.612**	-23.311**	-10.216**	-64.091**	-17.463**	-12.130**	-33.075**	-20.676**	-12.860**	-139.182**
	(2.723)	(3.217)	(4.480)	(5.381)	(6.096)	(9.254)	(5.413)	(1.503)	(4.878)	(3.283)	(2.218)	(3.000)	(2.478)	(1.639)	(15.263)
ATC A	-0.488**	-0.907**	-0.514**	-0.559**	-1.200**	-1.532**	-0.476**	-0.627**	-0.644**	-1.707**	-0.456**	-1.531**	-0.857**	-1.536**	-1.067**
	(0.161)	(0.127)	(0.137)	(0.149)	(0.133)	(0.117)	(0.138)	(0.142)	(0.097)	(0.153)	(0.127)	(0.109)	(0.156)	(0.111)	(0.140)
ATC B	-1.862**	-1.074**	-2.014**	-1.835**	-1.942**	-2.149**	-1.076**	-1.287**	-1.753**	-1.397**	-0.793**	-1.737**	-2.142**	-1.092**	-2.507**
	(0.216)	(0.168)	(0.166)	(0.188)	(0.177)	(0.149)	(0.174)	(0.214)	(0.128)	(0.207)	(0.181)	(0.148)	(0.185)	(0.170)	(0.176)
ATC C	-0.320**	-0.178	0.463**	-0.042	0.564**	-0.219**	0.002	-0.203	0.516**	-0.097	0.670**	-0.081	-0.375**	-0.176	-0.413**
	(0.156)	(0.123)	(0.123)	(0.136)	(0.129)	(0.109)	(0.130)	(0.129)	(0.094)	(0.151)	(0.122)	(0.107)	(0.152)	(0.107)	(0.133)
ATC D	-1.054**	-0.879**	-1.591**	-0.784**	-2.003**	-1.708**	-1.342**	-1.004**	-0.899**	-1.191**	-0.979**	-1.560**	-1.480**	-1.443**	-0.991**
	(0.212)	(0.157)	(0.161)	(0.200)	(0.157)	(0.125)	(0.161)	(0.165)	(0.128)	(0.198)	(0.155)	(0.126)	(0.196)	(0.127)	(0.158)
ATC G	-1.496**	-1.532**	-1.396**	-1.432**	-1.190**	-1.428**	-2.014**	-1.615**	-1.336**	-1.434**	-1.435**	-1.751**	-1.618**	-1.485**	-1.367**
	(0.181)	(0.144)	(0.146)	(0.158)	(0.160)	(0.137)	(0.163)	(0.155)	(0.124)	(0.181)	(0.143)	(0.137)	(0.175)	(0.134)	(0.158)
ATC H	-3.913**	-2.289**	-2.763**	-2.699**	-2.231**	-2.350**	-2.709**	-3.099**	-2.415**	-2.579**	-2.176**	-2.846**	-3.104**	-2.559**	-3.300**
	(0.285)	(0.220)	(0.221)	(0.230)	(0.214)	(0.172)	(0.249)	(0.220)	(0.193)	(0.268)	(0.242)	(0.192)	(0.221)	(0.196)	(0.213)
ATC J	-3.131**	-2.890**	-2.641**	-3.036**	-1.961**	-2.591**	-3.450**	-3.121**	-2.165**	-2.512**	-2.373**	-2.880**	-3.230**	-2.534**	-2.811**
	(0.160)	(0.129)	(0.129)	(0.140)	(0.138)	(0.116)	(0.143)	(0.144)	(0.098)	(0.156)	(0.136)	(0.115)	(0.154)	(0.115)	(0.140)
ATC L	-3.585**	-3.250**	-3.068**	-3.461**	-3.326**	-3.765**	-3.942**	-3.126**	-3.273**	-2.919**	-3.283**	-3.559**	-3.376**	-3.051**	-3.704**
	(0.174)	(0.143)	(0.139)	(0.154)	(0.143)	(0.122)	(0.158)	(0.152)	(0.112)	(0.168)	(0.168)	(0.125)	(0.163)	(0.128)	(0.146)
ATC M	-1.385**	-1.217**	-1.143**	-1.551**	-0.432**	-1.718**	-1.699**	-1.804**	-1.255**	-1.583**	-0.331**	-1.445**	-2.001**	-1.525**	-1.352**
	(0.201)	(0.145)	(0.154)	(0.158)	(0.160)	(0.137)	(0.165)	(0.160)	(0.125)	(0.180)	(0.156)	(0.132)	(0.173)	(0.141)	(0.159)
ATC N	-1.598**	-0.685**	-0.274**	-0.360**	0.238*	-0.460**	-0.389**	-0.770**	-0.025	-0.698**	0.077	-0.593**	-0.805**	-0.333**	-0.797**
	(0.151)	(0.123)	(0.120)	(0.134)	(0.131)	(0.110)	(0.138)	(0.128)	(0.095)	(0.145)	(0.123)	(0.107)	(0.147)	(0.106)	(0.132)
ATC R	-0.053	-0.038	0.188	0.441**	0.288*	-0.315**	0.173	0.109	0.172	0.292	-0.213	-1.295**	0.224	-0.633**	0.351*
	(0.186)	(0.147)	(0.145)	(0.157)	(0.153)	(0.144)	(0.164)	(0.164)	(0.120)	(0.187)	(0.151)	(0.122)	(0.180)	(0.141)	(0.180)
Log gdp	0.366**	-0.212*	0.016	-0.224	-0.403**	0.037	1.382**	-0.078	0.425**	-0.332**	-0.965**	0.310**	-1.306**	0.324**	-1.219**
	(0.125)	(0.116)	(0.162)	(0.171)	(0.186)	(0.163)	(0.269)	(0.173)	(0.201)	(0.125)	(0.228)	(0.146)	(0.161)	(0.105)	(0.211)
Constant	3.058*	10.239**	7.370**	9.936**	14.290**	8.117**	-9.223**	8.058**	2.257	10.705**	19.490**	4.560**	24.201**	2.999**	26.147**
	(1.673)	(1.588)	(2.096)	(2.088)	(2.707)	(2.427)	(3.384)	(2.105)	(2.909)	(1.558)	(2.838)	(2.064)	(2.071)	(1.354)	(3.082)
N	6691	9304	7897	6482	11228	11878	7337	6157	11584	6888	7324	11650	6913	9094	9161

Notes: Estimates by Two Stage Least Squares. Price coefficients correspond to $(k_c\gamma_i)/m_{ic}$ in equation (8) for each country i and ATC class c.