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Patent Purchase as a Policy for Pharmaceuticals *

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Abstract

The system of rewarding pharmaceutical innovations is frequently singled out for criticism for offering inadequate incentives for non-trivial developments, since rewards can be earned from innovations with little incremental value. Often similar drugs, labelled in the same class, enter the market sequentially showing similar efficacy but with prices well above production costs. We construct a life-cycle analysis of the welfare gains from a policy where society grants and purchases the patent of the first of a new class of drug (instead of purchasing the drug), awarding no further patents to runner-up drugs, and producing or licensing production with price set to maximise welfare subject to covering costs. We show that there are a wide range of circumstances under which such a policy could produce large welfare gains with more patients benefiting from new drugs at lower prices but without damaging the expected profits of the pharmaceutical firms.

Keywords: Patent Purchase; Pharmaceuticals; Life-Cycle; Welfare
JEL classification: D4; L5; O3

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1 Introduction

We consider the idea of a pharmaceutical patent purchase policy under which society grants and buys the patent of the first of a new class of drug, instead of purchasing the drug, and awards no further runner-up patents. Society produces or licenses production setting price to maximise welfare subject to covering costs. We show, within a drug life-cycle framework, that the proposed approach can yield large welfare improvements relative to what we stylise as current practice.

The gains associated with this policy come from avoiding cost-duplication from rival firms seeking to achieve follow-up patents but also because, after the winning firm has been compensated and the patent purchased, the price that can be charged to cover the associated costs is lower than would prevail in the market subsequent to the awarding of a runner-up rival patent. Throughout the paper we set compensation for the winning firm under the patent purchase policy so that it leaves expected profit unchanged. Other compensation rules, which are more or less generous, are also viable. However this assumption supports a degree of incentive neutrality in terms of R&D effort across the policy regimes allowing us to focus on the gains from redirecting existing "duplicative" R&D efforts to more productive ends rather than trying to incentivise new funding for R&D. The focus of this paper is mostly upon the gains in welfare that can be achieved via the patent purchase policy looking only at the life-cycle of a single drug and therefore taking a narrow partial equilibrium approach which ignores other possible benefits from the policy in terms of new drug development outside this drug's life-cycle. The results are generated based upon a number of stylised facts regarding R&D in the pharmaceutical industry.

Patent "buyouts" involve the government buying the patent from the innovating firm and placing it in the public domain, replacing Intellectual Property (IP) protection and associated profits with a prize for the innovator. Placing the innovation in the public domain, in theory, eradicates monopoly price distortions as well as disincentivising duplicative research. Although patent buyouts is not a new idea (e.g. the Daguerreotype photography patent was subject to a buyout by the French government in 1839) and the arguments relating to their potential benefits

have been documented for some time (e.g. Marshall, 1890; Wright, 1983), they have so far failed to become an established policy option. Practical barriers and difficulties associated with their implementation include funding operational costs, possible distortive rent seeking and lobbying concerns as well as considerations about which patents to buyout and the compensation for the innovator.

However, Kremer (1998), amongst others, identifies the buyout model as being particularly well suited to the pharmaceutical industry. The high mark-ups and low, and typically homogenous, production costs of a drug placed in the public domain are likely to result in large gains from buyouts to end users relative to *IP*. Furthermore, low levels of private information associated with pharmaceutical innovations, via clinical trials (which are a requirement for a drug to be registered), reduce the costs of identifying and valuing the innovation and therefore of operating an effective buyout regime. Hence, the screening role of market-based rewards is probably of lesser importance in this sector.[1] Weyl and Tirole (2012, pp. 1972) draw the following conclusion: 'Despite the extensive theoretical and policy interest in ... the prize system, many consider it simply impractical. Yet it is hard to see what, other than informational asymmetries, could be the source of such "impracticality."' It is not surprising, therefore, that the buyout model for pharmaceutical innovations has attracted particular support in the literature (e.g., Kremer, 1998, 2000a,b; Hollis, 2004). Guell and Fischbaum (1995) attempt to place an estimate on the welfare gains from buyouts in the US pharmaceutical sector with estimates varying from $3bn (based solely on static Harberger (1954) dead-weight loss type arguments), to $30bn (including rent seeking and marketing). They argue that in the low-end scenario the benefits are in line with the costs of implementing the regime, hence for most of the range of estimates, the buyout policy is cost-effective, and at the top end very heavily so.

Whilst most of the existing literature has sought to examine the welfare gains based on the static price distortion under an *IP* approach and/or the rent seeking associated with marketing expenditures, we seek to identify potential welfare gains from a drug life-cycle perspective.

[1]Market-based rewards can help elicit those opportunities which justify the associated development costs, as emphasised by Smith (1762), and without which it may be difficult for the government to value and select the most worthy innovations for a buy-out type approach.

Hence, we are interested in understanding how patent purchase will impact on costs and benefits from the development stage of a drug through to its obsolescence, which necessarily captures additional benefits such as the avoidance of duplicatory R&D.[2] The aim is to demonstrate that in cases where clinical trials suggest runner-up drugs are unlikely to generate benefits in terms of value-added or price competition then awarding and purchasing the winning firm's patent and allowing no market access to other runner-up drugs (demonstrating insignificant improvements) may offer substantial benefits to society.

Section 2 introduces and analyses a simple drug life-cycle model under policy A (current practice) and the patent purchase policy B. Section 3 reports simulations of possible gains in welfare available under policy B relative to A for different hypothetical parameterisations of the basic model. Section 4 explores the implications for these gains from relaxing some of the earlier modelling assumptions including the introduction of horizontal differentiation, production and marketing costs and general equilibrium considerations. Section 5 is a conclusion.

2 Simple Model

Our game has three players: a welfare maximising World Government, WG, and two identical profit-maximising multinational pharmaceutical companies. We assume that WG is the only government in the jurisdiction with the exclusive authority to control the patenting of pharmaceuticals globally. All players are risk neutral. The game is one of complete and full information. For simplicity there are no production costs and there is no discounting.[3]

WG chooses between a *Laissez Faire* policy, A, and a patent purchase policy, B. Under policy A all successful innovations are awarded patents and firms are free to set prices.[4] Under

[2]Much of the literature on pharmaceutical R&D has been concerned with pricing mechanisms, in particular, to bring about efficient R&D investment (see, Gravelle, 1998; Kremer, 1998), which often involve subsidies from taxation. However, we are not concerned so much with finding an optimal pricing rule as identifying scope for welfare gains largely treating the rate of R&D investment as a constant and without the need for subsidies or harming expected profits.

[3]Including time discounting would complicate the model considerably without offering much value in terms of added understanding. Amongst other things, policy B is weakly welfare superior to policy A in all periods of the drug life-cycle in most scenarios in the paper. However, even in the exceptional cases, i.e. with aggressive price competition and product differentiation, policy B is only inferior to A in the final period of the game.

[4]What is meant here by "patent" is in practice "authorisation to market".

policy B a patent is awarded only to the winning firm and purchased by WG. WG then produces or licenses production, recouping the revenue to pay for the patent purchase from the winning firm. The "prize" for the winning firm is paid on a "pay-as-you-go" basis in line with sales and the patented drug is priced to maximise social welfare subject to covering compensation to the winning firm in such a way that the expected profit for the firms is the same as under policy A.

The game is played over three periods each determined exogenously and lasting T_k ($k \in \{1, 2, 3\}$). In period 1 the firms compete to develop a new drug, X, each incurring an R&D cost of c per unit time. We treat c as constant and determined exogenously, for simplicity and with some justification based on the "stylised fact" that pharmaceutical firms invest in R&D at a fixed rate per period representing maximum capacity.[5] The constancy of this cost and the rate of investment of the firms across regimes (policies A and B) is also supported in this paper due to the assumptions of risk neutrality and the reward system under B generating an identical expected profit for the firms as under policy A. Hence, each firm incurs an R&D cost of cT_1 in period 1. Period 1 ends when one of the firms wins the race to develop X and is awarded a patent, with Nature determining the winner with probability $\frac{1}{2}$.[6] We label the winning firm, w, and the runner-up or laggard, r. Under policy A, the winning firm enjoys a monopoly for the duration of period 2, whilst the laggard, should they continue to undertake R&D in an attempt to develop their own version of the drug X, continues to incur c per unit time. Period 2 under policy A ends when the laggard firm is successful in developing its version of X and is awarded a patent and the two firms co-exist as suppliers in the market for the new drug for the duration of period 3.[7] Period 3 ends when the new drug becomes obsolete due to the development of

[5]Hence, our model departs from the standard model of innovation (e.g. Nordhaus, 1969) where R&D investments and associated success rates increase with the expected size of the prize. Although in this paper we are also careful to ensure that the size of the expected prize is constant across regimes.

[6]One might expect an association between relative firm size and the probability of success - posing a question about the usefulness of the assumptions of firm symmetry and equal ex ante chances of success. However, one sees many small companies come out as winners in the development process such as Gilead with their hepatitis C drug and Celgene with their blood cancer drug and a number of biotechnology companies who have been successful in beating "big Pharma" such as in the launch of new products (e.g. Centocor with Centoxin and ReoPro).

[7]In the R&D process, firms invest in many unsuccessful drugs on the way to discovering the new drug, X. The total cost of the firms discovering X can be thought of as including all the unsuccessful innovations on the path to discovering X.

(the first of) a new class of drug, $X+$, ending the life-cycle of drug X.[8]

As noted earlier, a common observation in the pharmaceutical sector is that the arrival of a runner-up drug does not always result in price competition even when the drugs are very close substitutes. For simplicity we assume that the winner and runner-up drugs are identical and that in period 3 there is no price competition under policy A with the laggard firm adopting the prevailing "catalogue" (monopoly) price for drug X.[9] Lu and Comanor (1998) and Ekelund and Persson (2003) offer empirical support for the idea of new drugs offering "little or no therapeutic gain" being introduced at prices in line with existing drugs in the U.S. (with prices being roughly double the price of existing drugs in Sweden). We also believe the following cases provide specific examples of the failure of price competition with the arrival of new "similar" drugs. Simvastatin, was the "first in class" statin to show effects on the incidence of myocardial infarction and survival (see Scandinavian Simvastatin Survival Study Group, 1994), but later stains, showing similar effects, e.g. Pravastatin (Shepherd et al., 1995; Sacks et al., 1996), were priced in the same bracket (see van Hout and Simoons, 2001). In November 1998 Enbrel (etanercept) was the first anti-TNF drug approved by the US Food and Drug Administration (FDA) for rheumatoid arthritis. Later drugs such as Remicade (infliximab, approved by the FDA in 1999) and Humira (adalimumab, approved by the FDA in 2002) were all priced similarly and often assessed as one group of almost identical agents (see Chen et al., 2006). The so-called "new oral anticoagulants" rivaroxaban, apixaban and dabigatran, which have efficacy in the prevention of stroke (Miller et al., 2012) and venous thromboembolism (Kakkos et al., 2014) provide a further example.

Policy B departs from A in that at the end of period 1, WG awards and purchases the

[8]It is straightforward to see that the assumption of "obsolescence" over "patent expiration" as marking the end of period 3 is not a strong assumption given the relevant patent period is 20 years, amongst other things.

[9]Though we take the extreme assumption of monopoly pricing, there are many factors which underpin the failure of price competition in the pharmaceutical sector including (i) the end users (patients) are not the ones either paying for the treatments or making choices about treatment selection (e.g., DiMasi and Paquette, 2004; Lee, 2004), (ii) the existence of cost-effectiveness thresholds (e.g. those associated with the National Institute for Health and Care Excellence ($NICE$), which requires at least a quality-adjusted life-year for every £30,000 of cost before approving a new drug), may operate as a price floor (see, for instance, Jena and Philipson, 2013), (iii) reimbursement limits for classes of drugs, (e.g. in the Netherlands new drugs available within a class get reimbursed against the price of the first in class), (iv) firms spend heavily on advertising to differentiate their brand, where in reality the differences between rival drugs can be minimal, which can weaken price competition.

patent for w's drug and r has no incentive to continue R&D efforts towards developing drug X, since no further patent for X will be awarded.

We now set out the costs and rewards of the game. We adopt a simple quasi-linear quadratic utility function (justifying a partial equilibrium analysis):

$$U(x, I) = \frac{\alpha}{\beta}x - \frac{1}{2\beta}x^2 + I, \tag{1}$$

where x is the quantity of the new drug X, I represents expenditure on 'other' goods and $\alpha, \beta > 0$. Welfare is the sum of profit and consumer surplus at a given set of prices. Given the utility function is quasi-linear, consumer surplus, CS, is a valid measure of welfare, where $CS(x, I) = U(x, I) - R(x) - I$ and $R(x)$ is firm revenue. Welfare, W, is therefore $W = CS + R(x) - TC$, where TC is total costs across the firms, hence:

$$W(x, I, TC) = U(x, I) - TC - I \tag{2}$$

Utility maximisation yields the familiar linear demand function:

$$x = \alpha - \beta p \tag{3}$$

where p is the drug price.

Drug X is an homogeneous good whether it is produced by firm 1 or firm 2 (it is indistinguishable in the eyes of the purchaser of drugs - who may not be the end user). Under policy A both firms' drugs are patented - there is "excess entry". Beginning with policy A, having incurred R&D costs of cT_1, the winning firm enjoys a monopoly for the duration of period 2. Assuming away production costs, profit per unit time in period 2 is given by $\pi = (\alpha - \beta p)p$. Maximising profit with respect to price yields the monopoly price, $p^m = \frac{\alpha}{2\beta}$, and profit per unit time, $\pi^m = \frac{\alpha^2}{4\beta}$. For simplicity there is no time discounting and the competitive rate of return is assumed to be zero. The costs, revenues and welfare incurred in each time period under policy A are set out in Table 1(a).

Table 1: Profit and welfare by time period T_k ($k \in \{1,2,3\}$) under policy A and policy B

		Period		
		T_1	T_2	T_3
(a)	Policy A			
	$\pi_w^A(k)$	$-cT_1$	$\frac{\alpha^2}{4\beta}T_2$	$\frac{\alpha^2}{8\beta}T_3$
	$\pi_r^A(k)$	$-cT_1$	$-cT_2$	$\frac{\alpha^2}{8\beta}T_3$
	$W^A(k)$	$-2cT_1$	$\left[\frac{3\alpha^2}{8\beta} - c\right]T_2$	$\frac{3\alpha^2}{8\beta}T_3$
(b)	Policy B			
	$\pi_w^B(k)$	$-cT_1$	$\frac{1}{\beta}\left[\frac{\alpha^2}{4} - \Omega\right]T_2$	$\frac{1}{\beta}\left[\frac{\alpha^2}{4} - \Omega\right]T_3$
	$\pi_r^B(k)$	$-cT_1$	0	0
	$W^B(k)$	$-2cT_1$	$\frac{1}{2\beta}\left[\frac{3\alpha^2}{4} + \Omega^{\frac{1}{2}}\left(\alpha - \Omega^{\frac{1}{2}}\right)\right]T_2$	$\frac{1}{2\beta}\left[\frac{3\alpha^2}{4} + \Omega^{\frac{1}{2}}\left(\alpha - \Omega^{\frac{1}{2}}\right)\right]T_3$

Key: $\Omega \equiv \left[\frac{\beta c T_2}{T_2+T_3}\right]$

Under Policy A, w sets price p^m in period 2 and this is adopted by r in period 3, hence profit over the life cycle of drug X for w and r, with profits in period 3 shared evenly, are, respectively:

$$\pi_w^A = \frac{\alpha^2}{8\beta}[2T_2 + T_3] - cT_1, \quad \pi_r^A = \frac{\alpha^2}{8\beta}T_3 - c[T_1 + T_2] \tag{4}$$

Aggregate profit, consumer surplus and welfare under Policy A are then, respectively:

$$\pi^A = \frac{\alpha^2}{4\beta}[T_2+T_3] - c[2T_1+T_2], \quad CS^A = \frac{\alpha^2}{8\beta}(T_2+T_3), \quad W^A = \frac{3\alpha^2}{8\beta}(T_2+T_3) - c[2T_1+T_2] \tag{5}$$

Valid comparisons of costs and benefits across policies A and B, on the basis introduced above, requires both conditions in Lemma 1 to hold.

Lemma 1. *(i) Under Policy A, having sunk cT_1 in the first period of the patent race for X, the losing firm will only continue R&D towards developing X in period 2, if:*

$$\frac{\alpha^2}{8\beta}T_3 > cT_2 \tag{6}$$

(ii) Further, for policy A to be sustainable over time (in repeated plays), requires expected aggregate profit, π^A, be non-negative:

$$T_1 \leq \frac{\alpha^2}{8c\beta}[T_2 + T_3] - \frac{1}{2}T_2 \tag{7}$$

Lemma 2. *Welfare under policy A, W^A, is decreasing in T_2 if $c > \frac{3\alpha^2}{8\beta}$.*

It is straight forward to see that the conditions of Lemmas 1 and 2 are not mutually exclusive, and hence Lemma 1 can be met but R&D costs per unit time are sufficiently high that under policy A, the duplicative period 2 catch-up R&D costs can outweigh the social benefits from the supply of the new drug by the winning firm over that period.

Under policy B, we assume a budget neutral policy so that the revenue from the sale of the drug by WG exactly pays for the compensation to the winning firm: there are no transfers from elsewhere in the economy to compensate the winner under policy B. The compensation rule under policy B, which ensures that *expected* profit under policy B is the same for each firm at the start of period T_1 as under policy A, yields a degree of incentive neutrality in R&D across policies A and B, to some extent justifying the assumption of common and exogenous (i) R&D cost per unit time and (ii) T_k period lengths across the two regimes. The winning firm receives compensation, $C = \frac{\alpha^2}{4\beta}[T_2 + T_3] - cT_2$, and break-even requires that the price $\tilde{p}$ charged for the drug generates revenue that exactly covers this payment, hence:

$$\tilde{p}(\alpha - \beta\tilde{p})[T_2 + T_3] = \frac{\alpha^2}{4\beta}[T_2 + T_3] - cT_2 \tag{8}$$

Minimising $\tilde{p}$ subject to achieving the break-even constraint, Eq. (8):

$$\tilde{p} = \frac{\alpha}{2\beta} - \left(\frac{cT_2}{\beta(T_2 + T_3)}\right)^{0.5} \tag{9}$$

Profits and welfare accruing per period under policy B are reported in Table 1(b).

We now consider some properties of the outcome under policy B relative to policy A.

Proposition 1. [10] *Under policy B, the break-even price, $\tilde{p}$, is strictly lower, and consumer surplus and welfare are strictly higher, than under policy A.*

What this serves to illustrate is that even with a compensation rule under which firms' expected profits are the same as under policy A, welfare and consumer surplus can be improved

[10] Proofs to propositions are reported in the Appendix.

under policy B. Indeed, as the *Proof* illustrates the improvement in welfare comes through two channels, referring to Eq. (2): directly, through the reduction of R&D costs incurred in the development of X, and indirectly, through any increase in quantity associated with the lower break-even price required to generate the same expected profit to the firms under policy B as under policy A.

Proposition 2. *(i) Welfare under policy B is strictly increasing in T_2 and T_3. (ii) The gains in welfare and consumer surplus from policy B relative to A are strictly increasing in T_2 and T_3.*

Welfare improves under policy B relative to A because wasteful duplicative R&D costs are avoided in period 2 and price is lower across periods 2 and 3. The longer is $T_2 + T_3$, the greater is the time over which the price-reduction is enjoyed. Further, the longer is period 2 the greater is the extent of wasteful duplicative R&D under policy A and hence the greater the gain from policy B. The benefits from policy B are higher in situations where the laggard is a long way behind the winner (T_2 is long) and the market life of the drug is long ($T_2 + T_3$ is long).

3 Simulations

To get some idea about the potential welfare gains under policy B relative to A, we undertake some simulations, whereby it becomes necessary to make some further simplifying assumptions.[11] First, let $\alpha, \beta = 1$, hence, from Eq. (3), $x = 1 - p$. Second, let period 1, the winning firm's R&D period, be, $T_1 \in \{0.75, 1.50\}$, and, $T_2 + T_3 = 2$.[12] Third, let $T_2 \in \{0.10, 0.50, 0.75\}$ with the foremost (last) representing a laggard who is very close to (significantly behind) the winner. Hence, aggregate profit under policy A (based on Eq. (5)) is $\pi^A = \frac{1}{4}[T_2 + T_3] - c[2T_1 + T_2]$. Finally, we let the *expected* rate of return for a firm under

[11] Note, these simulations cannot be given comparative static interpretation - R&D cost per unit time is calibrated to achieve a certain rate of return ρ under policy A for each given parameter combination.

[12] These parameterisations allow us to model scenarios where the R&D period for X is small or relatively large compared to the market life of the drug. With the patent period of 20 years as an upper limit on the time period $T_2 + T_3$, setting T_1 at 0.75 and 1.5 implies *maximum* development times of around 8 and 15 years, respectively.

policy A take the values $\rho \in \{5\%, 10\%, 20\%\}$. Hence, $c = \frac{1}{4(1+\rho)[2T_1+T_2]}$. Table 2 reports our simulations.

Table 2: Percentage gain in welfare under policy B relative to policy A

		$T_1 = 0.75$			$T_1 = 1.50$		
		T_2			T_2		
		0.10	0.50	0.75	0.10	0.50	0.75
ρ	0.05	50.0	110.8	131.9	34.8	79.8	97.1
	0.10	45.1	99.9	118.8	31.5	72.0	87.5
	0.20	38.1	84.1	99.9	26.6	60.7	73.7

It is clear from the Table that the percentage gains from policy B are large across the parameter selection. For instance, if the laggard firm is close behind the winner so $T_2 = 0.1$, with $T_1 = 0.75$ and an expected rate of return ρ under policy A of 10%, the gain under policy B relative to A is 45%. Alternatively, if given the same $\rho = 0.1$ and $T_1 = 0.75$, but the laggard is some way further behind the winner, $T_2 = 0.5$, then the relative gain from policy B is 100%.

4 Further Issues

In this Section we relax in turn a number of key assumptions underpinning the simple model outlined in Section 2 to see how the gains from policy B identified in Section 3 stand up.

4.1 Early Laggard Withdrawal under Policy B

So far we assume the firms compete right to the end of period 1 in the hope of winning the prize under policy B. However, unlike under policy A, where the laggard can expect to receive some reward so long as they complete their R&D until the end of period 2, under policy B there is no reward for the losing firm. Hence, not only does the losing firm have no incentive to continue into period 2 under policy B, but if a firm believes it is far enough behind its rival to the extent that the probability of winning is sufficiently low at some point during T_1, then it may be optimal to exit the race before the end of period 1. In our early discussion we alluded to clinical trials through which there is potentially quite a lot of information in the public domain during period 1 to inform the firms about where they stand in the race. Under policy B this

may be sufficient to yield the early withdrawal of the laggard firm, bringing additional benefits in welfare.

The benefits of early laggard withdrawal come through the laggard not incurring the full cT_1 cost of R&D which directly raises welfare under policy B but also through the lower implied compensation under policy B required to give the firms the same expected profit as under policy A. To see the latter, note that under policy A, given the conditions of Lemma 1 hold throughout, there is no incentive for early withdrawal and so expected costs are higher relative to policy B where the laggard has lower period 1 costs due to early withdrawal. Specifically, the break-even price under policy B is given by $\tilde{p} \equiv \frac{1}{2}\left[1 - \left(\frac{4c(T_2+\mu T_1)}{(T_2+T_3)}\right)^{0.5}\right]$, where μ is the proportion of period 1 remaining after the laggard withdraws from the race.

To illustrate the potential impact of early laggard withdrawal from period 1 R&D, we reproduce the simulations in Table 2 under the assumption that, under policy B, the laggard withdraws from the race three-quarters of the way through period 1 ($\mu = 0.25$).

Table 3: Percentage gain in welfare under policy B relative to policy A with early laggard period 1 withdrawal ($\mu = 0.25$)

		$T_1 = 0.75$			$T_1 = 1.50$		
		T_2			T_2		
		0.10	0.50	0.75	0.10	0.50	0.75
ρ	0.05	70.8	118.1	136.8	62.0	92.2	106.3
	0.10	64.2	106.6	123.4	56.3	83.4	96.1
	0.20	54.6	90.0	104.0	48.1	70.7	81.3

Comparison of Tables 3 and 2 show that the early laggard withdrawal can add considerably to the welfare gains under policy B. For instance, with $T_1 = 0.75$, $T_2 = 0.1$ ($T_2 = 0.5$) and an expected rate of return ρ under policy A of 10%, the gains under policy B relative to A increase from 45% (100%) with no early withdrawal to 64% (107%) with early withdrawal.

4.2 General Equilibrium Considerations

So far our analysis of the welfare benefits of policy B relative to A has been undertaken within the one-shot drug life-cycle framework. However, there are clearly potentially important general equilibrium effects associated with such a change in patenting policy. For instance, eliminating

period 2 laggard R&D under policy B may also have benefits beyond the one-shot patent game for drug X. Under policy A the laggard continues to devote their full R&D effort (wastefully) to discovering drug X through period 2. Under policy B the laggard switches their R&D effort to the next best project at the end of period 1 as there are no possible rewards for them continuing with the investment towards the development of drug X. This diverted effort may increase the speed at which some unrelated new class of drug, Y, is discovered and developed - i.e. count towards the period 1 R&D in the life-cycle of the new drug Y. In Table 4 we report the percentage gains under policy B relative to A in the case that the laggard's period 2 R&D expenditures under policy A, cT_2, are devoted, under policy B, to the development of a new unrelated drug Y. We assume that the welfare gains associated with this investment are achieved on a pro-rata basis to the gains in the one-shot life-cycle for drug X based on the investment $2cT_1$ (i.e. the minimum R&D under policy B, with no early withdrawal, before one firm is revealed as the winner in developing the new drug). Specifically, let ∇ denote the total welfare under policy B for any given parameter combination, based on the firms each investing cT_1 (this is the basis for the welfare gains reported in Table 2). Welfare per unit investment is therefore $\nabla \frac{1}{2cT_1}$. Hence in the case that laggard's period 2 investments under policy A are diverted to the discovery of the new drug Y under policy B, welfare under policy B, on a pro-rata return basis is:

$$\nabla \left(1 + \frac{cT_2}{2cT_1}\right) \tag{10}$$

The figures reported in Table 4 use Eq. 10 as a basis for calculating welfare under policy B.

Table 4: Percentage gain in welfare under policy B relative to policy A with pro-rata value added welfare on period 2 R&D

		$T_1 = 0.75$			$T_1 = 1.5$		
		T_2			T_2		
		0.10	0.50	0.75	0.10	0.50	0.75
ρ	0.05	60.0	181.1	247.8	39.3	109.7	146.4
	0.10	54.8	166.5	228.2	35.8	100.6	134.4
	0.20	47.3	145.5	199.8	30.8	87.5	117.2

From Table 4 it is clear that even taking into account this one possible general equilibrium

factor has the potential to significantly boost the welfare gains from policy B relative to policy A. Comparison of Tables 4 and 2 show that allowing the laggard's period 2 R&D (cT_2) to be diverted to alternative projects with the same expected gain in welfare on a pro-rata basis as $2cT_1$ with $T_1 = 0.75$, $T_2 = 0.5$ and an expected rate of return ρ under policy A of 10%, the gains under policy B relative to A increase from 100% (in Table 2) to 167%. In the partial equilibrium analysis under policy B, period 2 investments by the laggard are excluded from costs. Here, we include the investment costs but also include the associated welfare gains as part of a new race to develop drug Y.

However, given what we have seen earlier about incentives for the laggard to withdraw early from the period 1 race, the figures in Table 4 may well understate the extent of the gains to policy B arising from this one general equilibrium consideration. The earlier the laggard withdraws, the higher the investment diverted to the development of the new drug Y with associated pro-rata welfare gains. The relevant factor for pro-rata calculations with early laggard withdrawal would be $\frac{c(\mu T_1+T_2)}{c(2-\mu)T_1} > \frac{cT_2}{2cT_1}$. Further, the partial equilibrium welfare gains to be factored up are now $\Delta > \nabla$, where, for any parameter combination, Δ is the total welfare gain from policy B, as reported in Table 3. On the other hand, the picture may be a little more complicated since the laggard's diverted cT_2 R&D expenditure may go towards speeding up the obsolescence of drug X if the investment goes towards drug $X+$ thus shortening period 3.[13]

4.3 Multi-Firm R&D Competition and Product Differentiation

So far we assume two identical rival firms competing in an R&D race to develop drug X. We now consider the gains to policy B where the number of rival firms might exceed 2 and the firms' drugs have some horizontal differentiation so rival drugs have genuine value added. As before, we initially assume an absence of price competition in period 3 under policy A with the winner

[13]Whilst this effect may have beneficial consequences in terms of welfare, allowing T_3 to be endogenous would have implications for the modelling of the reward system which lies beyond the scope of the current paper. However, it remains the case though that if, through the trials evidence, WG observes there is a good chance of the laggard's efforts resulting in $X+$, a significant improvement on X that would make X redundant, it may not wish to pursue the patent purchase policy on X.

succeeding at the end of period 1 and the $n-1$ runner up firms catching up simultaneously at the end of period 2. Letting utility take the form (e.g. Singh and Vives, 1984; Hackner, 2000):

$$U(\mathbf{x}, I) = \sum_{i=1}^{n} x_i - \frac{1}{2}\left[\sum_{i=1}^{n} x_i^2 + 2\gamma \sum_{i \neq j} x_i x_j\right] + I,$$

the horizontally differentiated demands for firm i, are:

$$x_i = \Psi^{-1}[1 - \gamma - (1 + \gamma(n-2))p_i + \gamma \sum_{j \neq i} p_j] \tag{11}$$

where $\Psi \equiv (1-\gamma)(1+\gamma(n-1))$ and $\gamma \in [0,1]$ represents the degree of substitutability of drug i with respect to drug j. The drugs are perfect substitutes (unrelated) under $\gamma = 1$ ($\gamma = 0$). $\mathbf{x}$ is an n-vector of demands for each of the firms' horizontally differentiated drugs, X_i.[14] Under policy A in period 2 the winning firm, w, sets price equal to p^m and earns profit π^m per unit time as there are no rival drugs on the market (in period 2 with only one firm demand is given by $x = 1 - p$). In period 3 the $n-1$ rival firms have caught up and placed their patented variants of the winning drug on the market. As before we assume that the new arrivals adopt the joint profit maximising price, which, it is easy to verify, is exactly the monopoly price, $p^m = \frac{1}{2}$. Consequently, from Eq. (11), firm output in period 3 is $x_i(p^m) = \frac{1}{2[1+\gamma(n-1)]}$. Welfare under policy A is then:[15,16]

$$W^A(n) = \frac{3}{8}T_2 + \frac{3n}{8[1+\gamma(n-1)]}T_3 - ncT_1 - (n-1)cT_2$$

In our simulations the R&D cost per unit time is calibrated so that the expected return under policy A is ρ. The relevant expression for the R&D cost per unit time is now:

$$c = \frac{T_2 + \frac{nT_3}{[1+\gamma(n-1)]}}{4(1+\rho)[nT_1 + (n-1)T_2]}$$

[14] This differentiation can be thought of in the context that drug X_i might not work 100% of the time for 100% of patients, so the different variants X_j of the same drug might work for different patients, or have different side effects.

[15] As before, welfare is the sum of (per unit time) "utility minus I" weighted by the length of each period net of R&D costs.

[16] In equilibrium, $\sum_{i \neq j} x_i x_j = \frac{n(n-1)}{2}(x_i^m)^2$, given the sum of integers from 1 to $n-1$ is given by $\frac{n(n-1)}{2}$.

Under policy B, the $n-1$ rival firms are denied access to the market in period 3 and hence have no incentive to continue period 2 R&D investments towards developing drug X_r ($r \neq w = 1, ..., n$). To maintain the same expected profit for firms under policy B as under policy A, the winning firm must be paid compensation $C(n)$ such that total profit $C(n) - ncT_1$ under policy B is equal to total profit under policy A (again expected profits are the same under both policies), which is given by $\frac{1}{4}\left[T_2 + \frac{nT_3}{[1+\gamma(n-1)]}\right] - ncT_1 - (n-1)cT_2$. Hence:

$$C(n) = \frac{1}{4}\left[T_2 + \frac{nT_3}{[1+\gamma(n-1)]}\right] - (n-1)cT_2$$

With only one drug on the market, using Eq. 3, the break-even price and welfare are then, respectively:

$$\tilde{p}(n) = \frac{1}{2}\left[1 - \left(1 - \frac{4C(n)}{T_2+T_3}\right)^{0.5}\right], \quad W^B(n) = \left[\tilde{x}(n) - \frac{1}{2}\tilde{x}(n)^2\right][T_2+T_3] - ncT_1 \tag{12}$$

where $\tilde{x}(n) = 1 - \tilde{p}(n)$. Table 5 reports simulations for the gain in welfare under policy B in the case where the product differentiation parameter is set at $\gamma = 0.75$ and with selections $n = 2$ and $n = 5$.[17] Again, comparative static interpretation cannot be given to the figures in the Table under different parameter assumptions since they are calculated on the basis that they produce a rate of return ρ under policy A. Indeed, direct comparisons with figures in Table 2 are also problematic since the benchmark case of policy A now reflects product differentiation

Table 5: Percentage gain in welfare under policy B relative to policy A with multiple differentiated drugs: $n \in \{2, 5\}$ and $\gamma = 0.75$

			$T_1 = 0.75$			$T_1 = 1.50$		
			T_2			T_2		
			0.10	0.50	0.75	0.10	0.50	0.75
$n = 2$	ρ	0.05	-	48.7	72.1	-	15.7	42.0
		0.1	-	61.0	88.0	-	23.9	52.8
		0.2	-	48.7	72.1	-	15.7	42.0
$n = 5$	ρ	0.05	x	48.1	75.2	-	7.7	42.3
		0.1	-	61.8	92.9	-	17.9	54.7
		0.2	-	48.1	75.2	-	7.7	42.3

[17] Elements with a "$-$" indicate parameter combinations where the "single market" revenue under policy B cannot match the "multi market" revenue under policy A and so expected profit cannot be equalised across the regimes.

in period 3. However, the figures do show that substantial gains are still possible by pursuing policy B even in cases where under policy A multiple firms enter the market in period 3 offering non-trivial value added in their variant X_r - variety which is not experienced under policy B. Of course, for a high enough degree of product differentiation (low ρ) it is possible that the welfare change from adopting policy B is negative. Nevertheless, even with $\gamma = 0.75$ and for a given rate of return under policy A, Table 5 shows that large welfare gains are possible across a range of parameter assumptions even with $n = 5$.

4.4 Period 3 Price Competition

As we have seen, there is much evidence to suggest that price competition may not result in period 3 of the drug life-cycle. Accordingly, we have assumed the arrival of the laggard in period 3 under policy A leads to the adoption of the prevailing price and sharing of monopoly profits. The evidence might suggest an absence of price competition but here we briefly consider the implications of relaxing our monopoly price assumption in period 3 under policy A in favour of price competition using the model of product differentiation from Section 4.3.

Introducing period 3 price competition in the multi-firm differentiated product model under policy A involves replacing the prevailing (period 2) price and quantity assumption which yields p^m and x^m in period 3 with individual firm price $p' = (1-\gamma)/(n\gamma - 3\gamma + 2)$, where $p_i = p_j = p'$, and firm output x in accordance with Eq. (11), which we denote x'. Welfare under policy A is then:

$$W^A(n) = \frac{3}{8}T_2 + \left[nx' - \frac{(nx')^2}{2}\right]T_3 - ncT_1 - (n-1)cT_2$$

In our simulations the R&D cost per unit time is calibrated so that the expected return under policy A is ρ. The relevant expression for the R&D cost per unit time is now:

$$c = \frac{\frac{1}{4}T_2 + p'nx'T_3}{(1+\rho)[nT_1 + (n-1)T_2]}$$

Under policy B, the $n-1$ rival firms are denied access to the market in period 3 and hence have no incentive to continue period 2 R&D investments towards developing drug X_r ($r \neq w =$

$1, ..., n$). To equate expected profits for the firms across the two regimes, the winning firm must be paid compensation:

$$C(n) = \left[\frac{T_2}{4} + p'nx'T_3\right] - (n-1)cT_2 \tag{13}$$

With only one drug on the market, using Eq. 3, the break-even price and welfare are then found by using $C(n)$ from Eq. (13) in Eq. (12).

Table 6 reports simulations for the gain in welfare under policy B relative to A allowing price competition under policy A in period 3 with product differentiation parameter $\gamma = 0.75$ and $n \in \{2, 5\}$. Note, that the effect of price competition is dramatic in terms of period 3 price under policy A - with $n = 2$ (5) the price falls from the monopoly level of 0.5 in period 2 to 0.2 (0.07) in period 3 which is clearly at odds with the evidence that we cite regarding price stickiness.

Table 6: Percentage gain in welfare under policy B relative to policy A with period 3 price competition, $\gamma = 0.75$ and $n \in \{2, 5\}$

			$T_1 = 0.75$			$T_1 = 1.50$		
			T_2			T_2		
			0.10	0.50	0.75	0.10	0.50	0.75
$n = 2$	ρ	0.05	-15.0	7.9	23.8	-17.1	-0.8	11.6
		0.10	-14.9	6.8	21.8	-16.9	-1.3	10.4
		0.20	-14.7	5.0	18.5	-16.4	-2.2	8.5
$n = 5$	ρ	0.05	-20.1	-25.4	7.2	-21.0	-9.4	0.8
		0.10	-20.1	-5.6	6.3	-20.9	-9.6	0.3
		0.20	-20.0	-6.3	4.8	-20.7	-9.9	-0.7

From Table 6 it is clear that non-trivial gains still exist from pursuing policy B even when one of our key assumptions, an absence of period 3 competition, is relaxed in favour of product differentiation and price competition. However, it is also clear that non-trivial loses from policy B might arise in cases where, contrary to the cases we cite, intense price competition (reducing price by 60%-90%) prevails under policy A.

4.5 Production, Marketing and Opportunity Costs

For simplicity we have so far assumed zero costs. We now relax this assumption in favour of constant marginal production costs, ϕ, marketing costs and a competitive rate of return.

Ballance et al. (1992) estimate production costs for pharmaceuticals at 35% of sales. In our simulations, in addition to the modelling assumptions made in Section 3, we impose $\phi x^m(\phi) = zTR^m(\phi)$, where $TR^m(\phi)$ and $x^m(\phi)$ are the monopoly revenue and output per unit time with constant marginal cost ϕ and $z \in \{0.2, 0.4\}$. Hence our modelling assumptions will allow production costs under the status quo (policy A) to be 20% and 40% of sales.

Under policy A monopoly price, quantity and profit per unit time are, respectively, $p^m(\phi) = \frac{1+\phi}{2}$, $x^m(\phi) = \frac{(1-\phi)}{2}$ and $\pi^m(\phi) = \frac{(1-\phi)^2}{4}$. The maximising revenue is $TR^m(\phi) = \frac{1}{4}(1-\phi^2)$. Since $\phi x^m(\phi) = zTR^m(\phi)$, solving for ϕ, we have $\phi = \frac{z}{2-z}$.

We also wish to take account of marketing costs. It has been argued in the literature that a large part of the costs incurred by pharmaceutical firms are made up of marketing for information/ dissemination and product differentiation. Estimates place marketing expenditures between 15% (Pharmaceutical Manufacturers Association, 1988) and 22% of sales (Ballance et al., 1992). Much of pharmaceutical marketing expenditure is focussed on 'detailing' involving sales visits to doctors and providing product samples. Berndt (2002) finds that, since the relaxation of regulations in the U.S. in 1997, direct-to consumer marketing has increased rapidly but still accounts for only around 15% of total pharmaceutical advertising. Lakdawalla and Philipson (2012), on the other hand, suggest that so long as it causes output to increase towards the competitive level, marketing can improve efficiency and welfare.

Under policy A we let marketing costs equal a proportion θ_k of sales in period k ($k \in \{2, 3\}$). Given the above estimates for marketing costs and related discussion, we assume period 2 marketing, where there is a single firm operating in the industry, is due to "detailing" and is not wasteful and $\theta_2 = 0.1$, whilst in period 3, where there are two firms competing to differentiate their "identical" drugs, the marketing costs escalate wastefully, so that $\theta_3 = 0.2$. Hence, there is a sense the average proportion of sales devoted to marketing expenditure is between 10% and 20% with 10% assumed to be the amount needed to deliver 'detailing' which we assume is informationally productive.[18] With rival firms co-existing in period 3, expenditure

[18]Implicitly, in line with Lakdawalla and Philipson (2012), we are saying that this "efficient" level of marketing under policy A is that which ensures demand is represented by $x = 1-p$ in each period, rather than say $x = \alpha - p$ where $\alpha < 1$. For consistency we set the level of marketing expenditure under policy B equal to this "efficient" level thereby preserving $x = 1 - p$ in each period.

is doubled with the new expenditure being entirely wasteful since it either duplicates existing 'detailing' of an identical drug or represents pure rent seeking behaviour. Under policy B there is no rival firm in period 3 and hence marketing costs are assumed to remain at proportion θ_2, as under monopoly in period 2 with policy A.

Taking into account marketing and production costs, the expected rate of return (net of the competitive rate of return) on R&D expenditure (investment) under policy A is given by:

$$\rho = \frac{\frac{1}{4}(1-\phi)^2(T_2+T_3) - \frac{1}{4}(1-\phi^2)(\theta_2 T_2 + \theta_3 T_3) - c(\phi)(1+\rho_c)(2T_1+T_2)}{c(\phi)(2T_1+T_2)} \tag{14}$$

where ρ_c is the competitive rate of return. As before, we want to study the model for given levels of the expected rate of return for a firm under policy A. However, now we are going to allow the expected rate of return to be net of the competitive rate. Solving Eq. (14) for c, we have:

$$c(\phi) = \frac{\frac{1}{4}(1-\phi)^2(T_2+T_3) - \frac{1}{4}(1-\phi^2)(\theta_2 T_2 + \theta_3 T_3)}{(1+\rho+\rho_c)(2T_1+T_2)}$$

Under policy A, winner and laggard (economic) profits and welfare, are respectively:

$$\pi_w^A(\phi) = \frac{(1-\phi)^2}{8}[2T_2+T_3] - \frac{(1-\phi^2)}{4}[\theta_2 T_2 + \frac{\theta_3}{2}T_3] - c(\phi)(1+\rho_c)T_1,$$

$$\pi_r^A(\phi) = \frac{(1-\phi)^2}{8}T_3 - \frac{(1-\phi^2)}{4}\frac{\theta_3}{2}T_3 - c(\phi)(1+\rho_c)[T_1+T_2],$$

$$W^A(\phi) = \left(x^m(\phi) - \frac{1}{2}x^m(\phi)^2\right)[T_2+T_3] - \phi x^m(\phi)[T_2+T_3] - \frac{(1-\phi^2)}{4}[\theta_2 T_2+\theta_3 T_3] - c(\phi)(1+\rho_c)[2T_1+T_2]$$

Under policy B with the break-even price $\tilde{p}(\phi)$, the winning and losing firms earn profits:

$$\pi_w^B(\phi) = (\tilde{p}(\phi)-\phi)(1-\tilde{p}(\phi))[T_2+T_3] - \frac{(1-\phi^2)}{4}[\theta_2 T_2 + \frac{\theta_3}{2}T_3] - c(\phi)(1+\rho_c)T_1, \quad \pi_r^B(\phi) = -c(\phi)(1+\rho_c)T_1, \tag{16}$$

where it is assumed that the marketing cost per unit time for a single firm, which under policy A is expressed as a share of revenue under policy A, is the same per under policy B. Setting

the sum of profit equal under policy A and B and solving for $\tilde{p}(\phi)$:

$$\tilde{p}(\phi) = \frac{(1+\phi)}{2} - \frac{1}{2}\left[\frac{4c(\phi)(1+\rho_c)T_2 + \frac{1}{2}\theta_3(1-\phi^2)T_3}{[T_2+T_3]} - 4\phi\right]^{0.5}$$

With the introduction of constant marginal production costs, marketing and the competitive rate of return, welfare under policy B is given by:

$$W^B(\phi) = \left(\tilde{x}(\phi) - \frac{1}{2}(\tilde{x}(\phi))^2\right)[T_2+T_3] - \phi\tilde{x}(\phi)[T_2+T_3] - \frac{(1-\phi^2)}{4}\left[\theta_2 T_2 + \frac{\theta_3}{2}T_3\right] - 2c(\phi)(1+\rho_c)T_1$$

where $\tilde{x}(\phi) = 1 - \tilde{p}(\phi)$.

Table 7 reports the percentage welfare gains under policy B relative to A. Note, the figures reported here are not directly comparable to those in Table 2 as the benchmark level of ρ here now includes production, opportunity and marketing costs. However, the key point is that introducing production costs of 20% or even 40% of sales value, wasteful marketing costs (in period 3 under policy A) and opportunity costs does not meaningfully change the nature of the rewards to policy B relative to A.

Table 7: Percentage gain in welfare under policy B relative to policy A with production, marketing and opportunity costs

			$T_1 = 0.75$			$T_1 = 1.50$		
			T_2			T_2		
			0.10	0.50	0.75	0.10	0.50	0.75
$z = 0.2$	ρ	0.05	70.4	112.6	129.2	62.2	87.9	100.0
		0.10	65.3	103.2	118.2	57.9	80.9	91.8
		0.20	57.7	89.3	101.9	51.5	70.5	79.5
$z = 0.4$	ρ	0.05	74.7	112.7	127.9	67.4	89.8	100.5
		0.1	69.6	103.8	117.5	63.0	83.0	92.6
		0.2	61.9	90.4	101.9	56.4	72.9	80.8

5 Conclusions & Discussion

The system of rewarding innovations in the pharmaceutical sector is frequently singled out for criticism on the basis that it tends to offer inadequate incentives for innovating firms to focus on non-trivial developments, since rewards can be earned from innovations with little incremental

value. A small, but significant, literature has begun to address these failings, including work exploring alternative ways of rewarding innovation. Our paper contributes to this literature by examining the innovation issue in a drug life-cycle framework focussing on removing the incentive to pursue small incremental innovations which neither offer value-added nor yield welfare benefits from driving price competition. We study potential welfare gains from a policy (B) in which a patent is awarded only to the winning firm's drug and then purchased by the government and priced to cover the compensation paid to the winning firm. Compensation is set so as to maintain the expected profit for firms under "existing" patent policy, A. Policy B yields welfare gains because the laggard firm has no incentive to undertake wasteful duplicative R&D, avoiding associated costs and, because in the absence of duplicatory costs, the break-even price required to cover compensation for the winning firm is lower than the price that would have prevailed under policy A. Simulations in our basic model reveal that welfare gains arising through these channels of heavily upwards of 20% exist over a wide range of parameter assumptions.

We argue our policy proposal might have been relevant for some of the statins and ACE-inhibitors, or more recently the new oral anticoagulants and the current PKCS-9 inhibitors. While much energy is spent to distinguish these, the real differences seem small and society might have benefitted had development of some of these stopped earlier and resources been diverted elsewhere.

Some of our simplifying assumptions are for modelling expedience and transparency, whilst others have some basis in the pharmaceutical sector. However, Section 4 relaxes some of these assumptions and shows that non-trivial gains still exist from employing the patent purchase model. Indeed, whilst welfare gains under policy B are quite robust to the introduction of production costs and product differentiation, we show that the extent of the gains can increase quite dramatically when early laggard withdrawal from the patent race and general equilibrium considerations are included. We saw that with product differentiation and intensive price competition in period 3 under policy A (reducing prices by 60%-90% in period 3), non-trivial gains to policy B may still exist although for some parameter combinations similar size losses

were also feasible. As we stated at the outset, in practice we often fail to observe any significant price competition as the result of new drugs entering the market even when these new drugs exhibit little value-added i.e. are close substitutes. However, if there were strong reason to believe that heavy price competition would prevail in any particular case then the regulatory authority might not wish to pursue policy B for that drug life-cycle.

We focussed on compensation which was incentive neutral over policies A and B to allow a focus on the gains from diverting duplicative research efforts rather than stimulating new R&D.[19] In reality, offering more generous compensation might speed up the development of X as well as $X+$ (the drug that makes X obsolete) and/or Y (a new unrelated drug), but apart from the latter which we briefly consider in Section 4, this lies beyond the scope of the current paper. It is worth noting, however, that if R&D is incremental then policy B, by deterring runner-up firms from discovering X, may slow the firm's progress towards discovering $X+$. However, the effects of such damage to incremental R&D progress is likely to be limited. First, patenting requires the winning firm to disclose its technology allowing runner-up firms to learn relevant secrets useful in the "incremental" development of $X+$. Second, if the runner-up truly believes that continuing R&D towards discovering their own X is essential in discovering $X+$ then they will undertake this R&D but the costs in our model will be counted under the development of the new drug, $X+$, and not X, and so to some extent we capture this in our general equilibrium modelling. However, it is important to note that if, based on trials evidence, it was thought that the laggard's efforts were likely to result in a drug $X+$ which would make X obsolete at some time in the near future, policy B might not be pursued for drug X.

Indeed, implementing the patent purchase policy would require policy-makers to decide which "new" drugs to target with policy B along with an overhaul of pharmaceutical patenting, as much more will ride on the decision to award a patent in cases where policy B is pursued. However, unlike many other sectors, the quality of public information about "new" drugs makes pharmaceuticals a special case lending itself particularly well to patent purchase with trials information allowing policy-makers to identify early on cases where the gains for pursuing a

[19]This incentive neutrality also lent support to the endogeneity in the model of the "constant" R&D cost per unit time and durations of the periods of the drug life-cycle over the two policy regimes.

patent purchase approach would likely yield large gains or, alternatively, be unjustifiably risky.

Finally, as discussed in the introduction, much attention has been given to the reward system in buyouts and their impact on the effectiveness of the policy. Gallini and Scotchmer (2001) stress the importance of the prize being linked to the social value of the innovation. Hollis (2004) who offers a detailed discussion of many of the issues surrounding patent buyouts, suggests an efficient pricing system for pharmaceuticals based on incremental value. Shavell and van Ypersele (2001) propose a system in which the reward exceeds profit but lies below the social value of the innovation - thereby having the potential to further raise welfare and stimulate additional R&D. In our life-cycle model we have assumed a constant investment rate for R&D based on an industry stylised fact and backed this up by choosing a compensation rule which supports incentive neutrality on R&D across policies A and B. Hence, we have explicitly abstracted away from these prize-incentive R&D stimulation considerations in order to focus on a policy which diverts existing R&D effort away from low value added prospects. However, the question of rewarding innovators with compensation close to full surplus achieves its gains through R&D breakthroughs happening more quickly, for which the subsidies required to fund this need to be balanced against those gains. Indeed, alongside endogenising R&D effort and maximising welfare using subsidies, others areas for future work include extending the scope of the analysis to allow multiple indications; free-rider effects amongst regional jurisdictions; and allowing for complementary *as well as* substitute R&D.

Appendix A Proofs to Propositions

Proof to Proposition 1. First, note that total revenue is strictly increasing in p for $p \in [0, p^m)$. Second, under policy A total revenue ($\frac{\alpha^2}{4\beta}[T_2 + T_3]$) is strictly greater than the highest compensation, C ($\frac{\alpha^2}{4\beta}[T_2 + T_3] - cT_2$), under policy B. Hence, the break-even price, $\tilde{p}$, under policy B required to generate revenue equal to C is strictly lower than the price under policy A: $\tilde{p} < p^m$. Accordingly, the break-even quantity under policy B is $\tilde{x} \in (x^m, \alpha)$. Since from Eq. (1) consumer surplus is strictly increasing in x for $x < \alpha$ and given $\tilde{x} \in (x^m, \alpha)$, then consumer surplus under C must be strictly greater than that under policy A. Regarding welfare, policy B with C is strictly superior over policy A for two reasons. From Eq. (2) welfare is strictly increasing in x and decreasing in costs. However, under policy B with C, x is strictly greater and total costs are strictly smaller (by the amount cT_2) relative to policy A. □

Proof to Proposition 2. (i) First we can express: $W^B = \frac{T_2+T_3}{2\beta}\left\{\frac{3\alpha^2}{4} + \Omega^{\frac{1}{2}}\left(\alpha - \Omega^{\frac{1}{2}}\right)\right\} - 2cT_1$ where $\{.\} > 0$. Hence, $\frac{\partial W^B}{\partial T_2} = \frac{1}{2\beta}\{.\} + \frac{1}{2\beta}\Omega\left[\frac{\alpha}{2}\Omega^{-\frac{1}{2}} - 1\right]$ Given $\{.\} > 0$ and from Lemma 1(i) $[.] > 0$, it follows that $\partial W^B/\partial T_2 > 0$. Similarly, $\frac{\partial W^B}{\partial T_3} = \frac{1}{2\beta}\{.\} + \frac{cT_2}{2(T_2+T_3)}\left(-\frac{\alpha}{2}\Omega^{-\frac{1}{2}} + 1\right)$ which simplifies to: $\partial W^B/\partial T_3 = \frac{3\alpha^2}{8\beta} + \frac{\alpha}{4\beta}\Omega^{\frac{1}{2}} > 0$. (ii) Let G be the gain in welfare under policy B relative to policy A, hence: $G = W^B - W^A = \frac{T_2+T_3}{2\beta}\Omega^{\frac{1}{2}}\left(\alpha - \Omega^{\frac{1}{2}}\right) + cT_2$. Hence, $\frac{\partial G}{\partial T_2} = \frac{1}{2\beta}\{.\} + \frac{cT_3}{2(T_2+T_3)}\left[\frac{\alpha}{2}\Omega^{-\frac{1}{2}} - 1\right]$. Given $\{.\} > 0$ and from Lemma 1(i) $[.] > 0$, it follows that $\partial G/\partial T_2 > 0$. Similarly, $\frac{\partial G}{\partial T_3} = \frac{\alpha}{4\beta}\Omega^{\frac{1}{2}} > 0$. Finally, since welfare is strictly greater under policy B than policy A but aggregate profit is the same, the gain in welfare under B must derive from increasing consumer surplus hence the gains in consumer surplus under policy B relative to policy A must be strictly increasing with T_2 and T_3, completing the proof. □

References

Ballance, R., Pogany, J., Forstner, H., 1992. The World's Pharmaceutical Industries: An International Perspective on Innovation, Competition and Policy. Edward Elgar, Aldershot, U.K., prepared for the United Nations Industrial Development Organization.

Berndt, E. R., 2002. Pharmaceuticals in u.s. health care: Determinants of quantity and price. Journal of Economic Perspectives 16 (4), 45–66.

Chen, Y., Jobanputra, P., Barton, P., Jowett, S., Bryan, S., Clark, W., Fry-Smith, A., Burls, A., November 2006. A systematic review of the effectiveness of adalimumab, etanercept and infliximab for the treatment of rheumatoid arthritis in adults and an economic evaluation of their cost-effectiveness. Health Technology Assessment 10 (42), 1–229.

DiMasi, J., Paquette, C., 2004. The economics of follow-on drug research and development: Trends in entry rates and the timing of development. Pharmacoeconomics 22 (Suppl. 2), 1–14.

Ekelund, M., Persson, B., 2003. Pharmaceutical pricing in a regulated market. Review of Economics and Statistics 85 (2), 298–306.

Gallini, N., Scotchmer, 2001. Intellectual property: When is it the best incentive mechanism. Innovation Policy and the Economy 2, 51–78.

Gravelle, H., 1998. Ex post value reimbursement for pharmaceuticals. Medical Decision Making 18, S27–S38.

Guell, R. C., Fischbaum, M., 1995. Toward allocative efficiency in the prescription drug industry. The Milbank Quarterly 73, 213–229.

Hackner, J., August 2000. A note on price and quantity competition in differentiated oligopolies. Journal of Economic Theory 93 (2), 233–239.

Harberger, A. C., 1954. Monopoly and resource allocation. Americal Economic Review 44 (2), 77–87, papers and Proceedings of the Sixty-sixth Annual Meeting of the American Economic Association.

Hollis, A., 2004. An efficient reward system for pharmaceutical innocation. Tech. rep., Insitute of Health Economics, University of Calgary.

Jena, A. B., Philipson, T. J., 2013. Endogenous cost-effectiveness analysis and health care technology adoption. Journal of Health Economics 32 (1), 172–180.

Kakkos, S. K., Kirkilesis, G. I., Tsolakis, I. A., November 2014. Efficacy and safety of the new oral anticoagulants Dabigatran, Rivaroxaban, Apixaban, and Edoxaban in the treatment and secondary prevention of venous thromboembolism: A systematic review and meta-analysis of phase iii trials. European Journal of Vascular and Endovascular Surgery 48 (5), 565–575.

Kremer, M., 2000a. Creating markets for new vaccines. part i: Rationale. Innovation Policy and the Economy 1, pp. 35–72.

Kremer, M., 2000b. Creating markets for new vaccines. part ii: Design issues. Innovation Policy and the Economy 1, pp. 73–118.

Kremer, M. R., 1998. Patent buyouts: A mechanism for encouraging innovation. Quarterly Journal of Economics 113 (4), 1137–1167.

Lakdawalla, D., Philipson, T., 2012. Does intellectual property restrict output? an analysis of pharmaceutical markets. The Journal of Law & Economics 55 (1), 151.

Lee, T., 2004. 'Me-too' products: Friend or foe? New England Journal of Medicine 350 (3), 211–212.

Lu, Z., Comanor, W., 1998. Strategic pricing of new pharmaceuticals. Review of Economics and Statistics 80 (1), 108–118.

Marshall, A., 1890. Principles of Political Economy. Maxmillan, New York.

Miller, C. S., Grandi, S., Shimony, A., Filion, K., Eisenberg, M., August 2012. Meta-analysis of efficacy and safety of new oral anticoagulants (Dabigatran, Rivaroxaban, Apixaban) versus Warfarin in patients with atrial fibrillation. The American Journal of Cardiology 110 (3), 453–460.

Nordhaus, W. D., May 1969. An Economic Theory of Technological Change. American Economic Review 59 (2), 18–28.

Pharmaceutical Manufacturers Association, 1988. Statistical Factbook. Washington.

Sacks, F. M., Pfeffer, M. A., Moye, L. A., Rouleau, J. L., Rutherford, J. D., Cole, T. G., Brown, L., Warnica, J. W., Arnold, J. M. O., Wun, C.-C., Davis, B. R., Braunwald, E., 1996. The effect of pravastatin on coronary events after myocardial infarction in patients with average cholesterol levels. New England Journal of Medicine 335 (14), 1001–1009, pMID: 8801446.

Scandinavian Simvastatin Survival Study Group, November 1994. Randomised trial of cholesterol lowering in 4444 patients with coronary heart disease: the Scandinavian Simvastatin Survival Study (4S). The Lancet 344 (8934), 1383–1389.

Shavell, S., van Ypersele, T., 2001. Rewards vs. intellectual property rights. Journal of Law and Economics XLIV, 525–547.

Shepherd, J., Cobbe, S. M., Ford, I., Isles, C. G., Lorimer, A. R., Macfarlane, P. W., McKillop, J. H., Packard, C. J., 1995. Prevention of coronary heart disease with pravastatin in men with hypercholesterolemia. New England Journal of Medicine 333 (20), 1301–1308, pMID: 7566020.

Singh, N., Vives, X., Winter 1984. Price and quantity competition in a differentiated duopoly. RAND Journal of Economics 15 (4), 546–554.

Smith, A., 1762. Lectures on jurisprudence. University of Glasgow.

van Hout, B. A., Simoons, M. L., 2001. Cost-effectiveness of HMG coenzyme reductase inhibitors: Whom to treat? Europeamn Heart Journal 22 (9), 751–761.

Weyl, E. G., Tirole, J., 2012. Market power screens willingness-to-pay*. The Quarterly Journal of Economics.

Wright, B. D., 1983. The economics of invention incentives: Patents, prizes and research contracts. American Economic Review 73, 691–707.