The Global Burden of Medical Innovation

Technical Appendix[1]

A. Calculating US Contribution to Global Profits

To calculate the US contribution to global profits, let P_i and Q_i represent the price and quantity, respectively, of drugs sold in market i. For the purposes of illustration, we consider two markets, the US and everywhere else, signified by $i \in (US, exUS)$. We make the simplifying assumptions that drugs are produced for both markets with (the same) constant marginal cost c, and that manufacturers set prices outside the US such that they at least cover marginal costs, that is, $P_{exUS} \geq c$. Thus, global profits are given by

$$\pi_{Global} = (P_{US} - c)Q_{US} + (P_{exUS} - c)Q_{exUS} \qquad (1)$$

Define the percentage difference in prices between the two markets as Δ, where $P_{US} = (1 + \Delta)P_{exUS}$. Empirical evidence suggests that $\Delta > 0$.[2]

Substituting this into equation (1) gives

$$\pi_{Global} = \frac{\Delta}{1+\Delta} \cdot Q_{US}P_{US} + [(P_{exUS} - c)Q_{exUS} + (P_{exUS} - c)Q_{US}]. \quad (2)$$

The share of global profits coming from the US is equal to:

$$Share_{US} \equiv \frac{\left(\frac{\Delta}{1+\Delta} \cdot Q_{US}P_{US} + (P_{exUS} - c)Q_{exUS}\right)}{\pi_{Global}}$$

The first term in the numerator, $\frac{\Delta}{1+\Delta} \cdot Q_{US}P_{US}$, represents the portion of global profits attributable to Americans buying their drugs at higher prices than those paid by exUS customers. The second represents the profits that the US would generate if its prices fell to overseas levels. We estimate $Share_{US}$ in three steps.

First, we estimate π_{Global} by using data on total global pharmaceutical revenues,[3] $Q_G P_G$, and the net profit margins of pharmaceutical companies, n. By definition, $\pi_{Global} = nQ_G P_G$.

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[1] Adapted from (D. Lakdawalla et al., 2008).

[2] (Danzon & Furukawa, 2008).

[3] To be conservative, we use total global revenues, rather than branded revenues only.

Second, we estimate $\frac{\Delta}{1+\Delta} \cdot Q_{US}P_{US}$ using data on US branded drug revenues, $Q_{US}P_{US}$, and estimates of Δ from the literature.[4]

The last term, $(P_{exUS} - c)Q_{exUS}$, requires a more involved approach, because the cost of pharmaceutical production is not publicly available. Our approach is to infer it from publicly available information on profits and revenues. Specifically, define "baseline profits," π^*, where $\pi^* \equiv [(P_{exUS} - c)Q_{exUS} + (P_{exUS} - c)Q_{US}]$. This term represents the global profits that would obtain if US prices were equal to those in the rest of the world. Next, define the US share of baseline profits as σ_{US}. The US share of baseline profits (π^*) satisfies:

$$\sigma_{US} = \frac{(P_{exUS} - c)Q_{US}}{[(P_{exUS} - c)Q_{exUS} + (P_{exUS} - c)Q_{US}]} = \frac{Q_{US}P_{US}}{(1+\Delta)P_{exUS}Q_{exUS} + P_{US}Q_{US}}$$

All the terms in the right-hand side expression are known: US branded revenues, exUS branded revenues, and the US price differential. Thus, σ_{US} can be estimated.

In sum, we recover the total US share in profits as:

$$Share_{US} = \frac{\frac{\Delta}{1+\Delta} \cdot Q_{US}P_{US} + \sigma_{US}\pi^*}{\pi_G}$$

Each of the terms Δ, $(Q_{US}P_{US})$, σ_{US}, and π^* are recovered as explained above.

B. Future Elderly Model Analysis

We analyze the impact of reducing — all else equal — the European pharmaceutical prices by 20%, and the impact of raising them by 20%. These regimes encompass a wide variety of possible policy choices. Direct price cuts that target manufacturer prices are an obvious example, but there are a wide variety of other policies — such as economic evaluations, reference pricing in all its forms, and global budget controls — that have the effect of depressing average pharmaceutical prices.

We exclude from consideration the range of auxiliary impacts and policies that could be associated with a price-reduction policy. For example, the money saved by reducing manufacturer prices could be used in a variety of different ways — increased utilization of drugs, additional investment in education, rebates to taxpayers, and so on. However, we do not need to explicitly consider what happens to money saved, as long as we can estimate the monetary value to society generated by that dollar of savings, and compare it

[4] (Danzon & Furukawa, 2008).

to the monetary costs of the policy. This estimation is simple, provided that one dollar is worth exactly the same amount to society, no matter where it accrues.

Put differently, a policy that saves the government $100, and costs individuals $50, is net-beneficial, regardless of what the government does with the money. In practice, this approach might overstate the value of programs that save government money, because the public sector tends to be a bit less efficient at generating high returns. This will cut against a finding that price reductions are harmful, and vice-versa.

B.1 *Structure of the Microsimulation Model*

We developed a demographic and economic model to predict costs and health status for the US and European population over the age of 55.[5] A crucial component was a model of how new innovations are discovered, and how they impact the health transitions of this population. The Global Pharmaceutical Policy Model (GPPM) is a microsimulation model that tracks a US-representative sample of 55+ year-olds, and a similar European-representative sample, over time to project their health conditions, functional status, health expenditures, and mortality experience. The European sample is based on the countries represented in the SHARE (Survey of Health, Ageing, and Retirement in Europe) database: Denmark, France, Germany, Greece, Italy, the Netherlands, Spain, and Sweden. In the interests of simplicity, we consider pan-European policies implemented uniformly across these countries.[6]

The model takes as inputs the policy regimes in the US and Europe, and allows for the analysis of reducing (or increasing) manufacturer prices and revenues. The model then simulates the impact of these changes, for current and future generations, on: health care utilization, medical spending, the prevalence of major diseases, functional status, longevity, and the pace of innovation on the major diseases modeled. Details of the model's underlying estimated relationships are provided in an online technical appendix (Lakdawalla et al. (2007)), and in Lakdawalla et al. (2009). We calculate the benefit (or cost) associated with more (or less) longevity, net of changes in medical and drug cost. This excludes benefits associated with reductions in morbidity or improvements in lifestyle, and is thus a conservative approach to valuing the introduction of pharmaceuticals. The conservative approach is warranted by the difficulty of quantifying the value of morbidity reductions and lifestyle improvements. The downside is the possibility of undercounting the value of pharmaceutical innovation.

[5] We focus on the 55+ age group, because longitudinal data on health are not readily available for younger populations.

[6] While the model is capable of analyzing heterogeneity across countries, it is difficult to construct a single, heterogeneous "bundle" of policies for analysis.

B.2 *Quantitative Analysis of Policy Regimes*

We explore three kinds of policy regime changes: (1) Lowering manufacturer prices by 20% from their current levels; (2) Raising manufacturer prices by 20% from current levels; and (3) Status quo.

As discussed earlier, we model policies that lower manufacturer prices without affecting consumer prices, and thus utilization. At least in the short-run, decreases in manufacturer prices: lower current drug spending, but leave current utilization unchanged; lower revenues and the future rate of innovation; and have uncertain effects on medical spending. In the long-run, price changes can and do affect drug utilization by affecting the pace of innovation, and the drugs available.

The model simulates gains (or losses) in life expectancy due to these policy choices; as mentioned earlier, the baseline simulations value these gains using $200,000 as the value of a statistical life-year. We also calculate the impact on both drug and medical spending. The net present value of a particular policy is given by: the present value of life expectancy, less the present value of medical spending and drug spending.

B.2.1 EU Price Reductions

Our first analysis calculates the effect of further manufacturer price reductions — of 20% — in the EU. Introducing such price reductions — or, more generally, lowering manufacturer revenues by 20% while leaving consumer copayments unchanged — would affect the pace of innovation, as well as health care spending. The savings from lower prices must be weighed against the cost of foregone innovation. Figure 1 illustrates the impact on global longevity of lowering prices in the EU. The figure shows the impact on 55-59 year-old cohorts in the EU and US, at different points in time. For example, the left-most bars show the longevity impact for those aged 55-59 in 2010, while the right-most bars show the impact for those aged 55-59 in 2060. Reductions in EU prices would lower life expectancy in this cohort by about one-tenth of a year. Over time, lower revenues have cumulative effects on foregone innovations. As a result, the effects on longevity accumulate in a similar fashion. For the 2050 and 2060 cohorts, the reduction in longevity more than triples from the initial effect, to range between 0.3 and 0.4 years of life.

Figure 2 quantifies the impact of price reductions on the lifetime drug and health care spending of these same 55-59 year-old cohorts in the US and the EU sample countries. On a per capita basis, Europeans of this age group can expect to save between $5000 and $6000 over their remaining lifetimes. All these numbers are given in terms of present value for 2004 dollars. For the US population, there is no direct effect of EU price reductions on health care spending, because this policy does not affect US prices directly. However, to the extent that EU policies affect the pace of innovation, they do affect the demand for and spending on medical care throughout the world. Over a long horizon, therefore, US consumers face about $3000 less in lifetime health and drug spending, largely due to reductions in life expectancy.

The net value of a price reduction policy is equal to the cost-savings it produces, net of the cost of foregone longevity due to slower innovation. For the latest cohorts, the savings in drug and medical costs offsets the present discounted value of 0.3 to 0.4 year reductions in longevity. As a rough guide, the absolute decline of 0.3 years of life expectancy is worth approximately half that in terms of discounted life expectancy, because the reductions in survival do not all take place immediately at age 55 to 59. Therefore, we are offsetting savings of about $6000 in present value, against reductions in discounted longevity of 0.15 to 0.2 years. Therefore, a value of $40,000 or higher for a statistical life-year implies that the policy is welfare-reducing, because the cost-savings are not justified by the size of the longevity decline.

Figure 3 quantifies this reasoning by illustrating the net per capita value of the price reduction policy to 55-59 year-olds in the US and EU sample countries. Using our baseline value of a statistical life-year of $200K, we find that the price reduction policy only costs $100 per person for Europeans who were 55-59 years old in 2010, and about $400 per 55-59 year-old Americans in 2010. However, the costs of the policy mount over time, so that the 2060 cohort faces costs of $25,000 per person in the EU, and $30,000 per person in the US.

To appreciate the numbers in an aggregate context, Figure 4 quantifies the total value of price reductions to the entire 55+ population at different points in time. For example, the figures in 2010 correspond to the values for all individuals alive and aged 55+ in 2010, and so on. The aggregate costs of price reductions to the 55+ population are quite small initially, but mount over time, to reach $6.1 trillion in the US, and $4.1 trillion in the EU sample countries.

B.2.2 EU Price Increases

Figure 5, Figure 6, Figure 7, and Figure 8 illustrate the impact of raising manufacturer prices in the EU by 20%. Increases in manufacturer prices stimulate innovation, but at the expense of higher drug and medical costs. On balance, the additional innovation is worth the cost.

Figure 5 illustrates the impact of EU price increases on longevity. Americans aged 55-59 in 2010 can expect to live 0.2 years longer as a result of the EU policy change, while Americans of this age group in 2060 can expect to live 0.7 years longer. The longevity increases for Europeans of the same age are roughly similar in magnitude, ranging from 0.2 to 0.7 additional years of life.

The gross costs of this policy change are shown in Figure 6. EU price increases are projected to cost 55-59 year-old Europeans between $5300 and $7500 per capita over their remaining lifetimes. Americans face similar increases in cost, but that is entirely through the channel of increased longevity and innovation, both of which raise per capita lifetime spending on drugs and medical care.

Combining the gross benefit in longevity gain with the gross cost yields the net value of the policy, on a per capita basis, as shown in Figure 7. If the EU raised manufacturer

prices by 20%, and thus closer to US levels, both Americans and European cohorts would benefit. The benefit to the earliest American cohorts is approximately $18,000 per person, and runs as high as $57,000 per person in the latest cohort. For Europeans, the benefit ranges from $8000 to $39,000.

Figure 8 shows the total value of European price increases to the entire 55+ population at different points in time. For example, the figures in 2010 correspond to the values for all individuals alive and aged 55+ in 2010, and so on. The aggregate benefits of European price increases are positive for both geographies at all time points, and increase over time. For the populations aged 55+ in 2060, total benefits are $10 trillion in the US and $7.5 trillion in the EU sample countries.

B.2.3 Robustness Analysis

The baseline estimates of the model imply that EU price reductions would harm future generations in the EU and US, with little or no benefit to current generations. In contrast, EU price increases of roughly similar magnitude would provide benefits to cohorts on both sides of the Atlantic. However, these conclusions are subject to the assumptions of the baseline model. While we relied on the best available economic and medical evidence to parameterize the model, the issues are sufficiently controversial that this approach is not ironclad. Therefore, we assess which of our conclusions are robust to variation in these underlying assumptions.

While the model contains assumptions about many variables, our analysis points to three sets of variables with quantitatively significant impacts on our predictions. The three critical parameters are: the value of a statistical life-year; the value of new drug introductions; and the responsiveness of innovation to changes in revenue. For all other parameters, either our estimates did not vary, or there is broad consensus in the literature about the best possible value.

Figure 9 displays the sensitivity of the model to variation in the value of a statistical life-year. The Figure shows how the value of a statistical life-year affects the per capita net present value of policy regimes to EU residents aged 55-59 in 2060. The figure graphs the net per capita value of both raising and lowering EU manufacturer prices, relative to the status quo.[7] As emphasized earlier, the only benefit of innovation we consider is mortality reduction. Changes in the value of a statistical life-year have a linear impact on the value of these benefits. Since the value of a life-year has no direct impact on costs, the overall impact of this parameter on net values is linear.

The figure illustrates that the qualitative predictions of the model – regarding which policies are beneficial and which are costly – are robust to a wide range of variation in the value of a statistical life-year. We consider values from $50,000 to $300,000, a range which encompasses all widely used values for this parameter. Of course, higher values of

[7] Results are extremely similar for the US net present value and European net present value.

life imply larger benefits for policies that stimulate innovation. Therefore, the size of the costs associated with price reductions rise, and vice-versa.

The second class of parameters we investigate concerns the value of new drug introductions. We analyze variation in this value along two dimensions: the probability that a new drug will be a top-seller;[8] and the "access effect" of new drugs on the number of patients getting treatment. The third dimension of drug value, which we do not explicitly consider here, is the "clinical effect," which measures the clinical benefit of using new drugs. Owing to our extremely conservative approach to quantifying clinical effects, these were calibrated to be reasonably modest — the model presumes that new treatments in lung disease and cancer confer clinical benefits, but that other innovations do not yield any.

The probability of a top-seller was estimated empirically, for each of our disease categories, using actual drug introductions from 1998 to 2002. The mean probability of a top-seller in each disease was used in our baseline estimates. To conduct sensitivity analyses, we vary the parameters uniformly over their respective confidence intervals. For example, we reduce all probabilities to place them 25% of the way between their mean and the bottom of their confidence interval, 50% of the way, 75% of the way, and at the bottom of their confidence intervals. We repeat the procedure, in reverse, to inflate the values of this parameter. Figure 10 displays the results. Not surprisingly, when the probability of a blockbuster decreases, so do the per capita benefits from price increases and costs of price controls. At the very bottom of the confidence intervals, we see that price reductions involve a relatively small cost ($1700), while price increases involve a small benefit ($1600). However, just as with the value of a statistical life-year parameter, the qualitative predictions for policy changes are largely robust to variation.

Figure 11 varies the access effect across the width of its 95% confidence interval. On average, the launch of a new top-selling drug expands access by 26%. The confidence interval around this mean ranges from 2% to 50%. Therefore, we consider values from zero to fifty percent. Perhaps the most striking aspect of this figure is its non-monotonicity, which is generated by the interaction between two offsetting forces. Higher access effects increase consumer welfare in the baseline regime, and both alternative policy regimes. On the one hand, a higher access effect makes innovation – and policies that stimulate it – more valuable. This leads to a positive relationship between the access effect and welfare, for the repeal of price controls. On the other hand, when prices are lower, higher access effects might be more important as a means of generating scarce innovations. The result is that the net value of EU policy changes does not change very much in response to shifts in the access effect. The benefits of price increases range from $33,000 per capita at the low end, to $61,000 at the high end. On the other hand, the cost of price cuts range from $13,000 per capita to $29,000 per capita.

[8] We make the very conservative assumption that only top-selling drugs have any positive effects on patient health. In other words, we assume that the introduction of all other drugs adds no value for patients.

The last parameter we analyze, and the one with the most important qualitative impact, is the responsiveness of innovation to revenues. Estimates in the economics literature suggest that a one percent increase in pharmaceutical revenues leads to a four percent increase in the number of new molecules (Acemoglu and Linn, 2004). However, the paucity of estimates in the literature warrant caution in interpreting this parameter. As a result, we consider values ranging from zero to 5.0. As argued earlier, several papers in the literature suggest that innovators respond, at least a little, to changes in revenues. Therefore, zero seems a strict lower bound on this parameter. Figure 12 plots the impact of changes in this parameter on the net present value of policy to cohorts of 55-59 year-olds. Depending on the value of this parameter, EU price reductions can generate $5000 of benefit per person to the 2060 cohort of 55-59 year-olds, or impose up to $64,000 of cost. At a value of 1.0, price reductions are almost exactly welfare-neutral, and below this value, they are somewhat welfare-improving. The key drawback of price reductions is not their obvious costs or benefits, but instead their substantial downside risk. On the other hand, the worst-case scenario for price increases is a welfare loss of $4000 per person, and that for the case where innovation does not respond to revenues at all – a case that has been rejected in the empirical literature.[9] The baseline case is a $39,000 welfare gain, while the best-case is a welfare gain of over $100,000.

[9] Several papers, in different contexts, have reported a nonzero link between pharmaceutical innovator revenues and innovation (Acemoglu & Linn, 2004; Danzon, Wang, & Wang, 2005; Finkelstein, 2004).

Figure 1: Effect of EU Price Reductions on Longevity among 55-59 year-olds in the US and Europe.

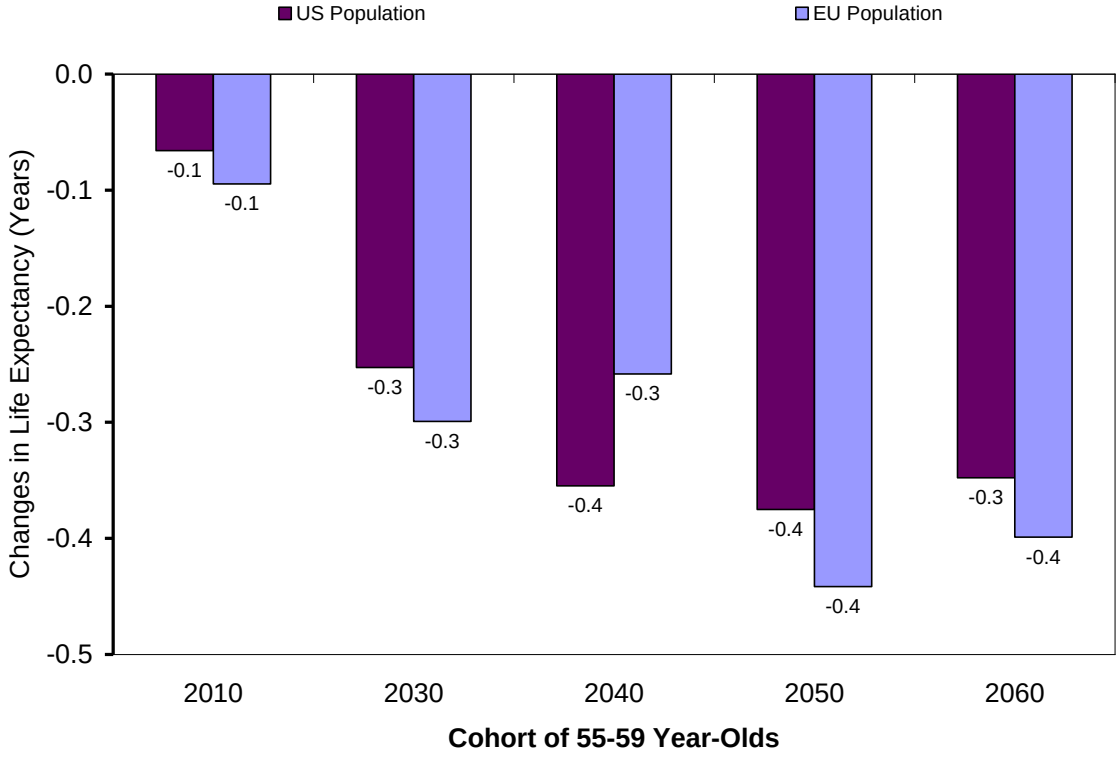


Figure 2: Effect of EU price reductions on lifetime drug and health care spending for cohorts of 55-59 year-olds in the US and Europe.

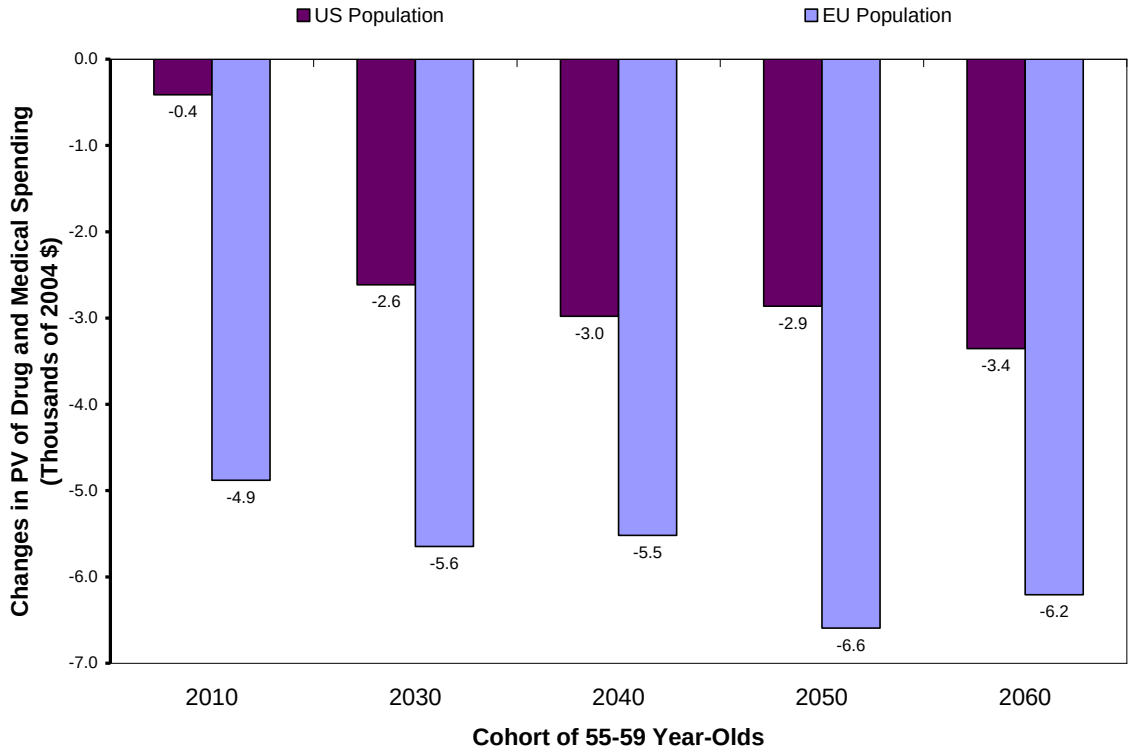


Figure 3: Net per capita value of EU price reductions to 55-59 year-olds in the US and Europe.

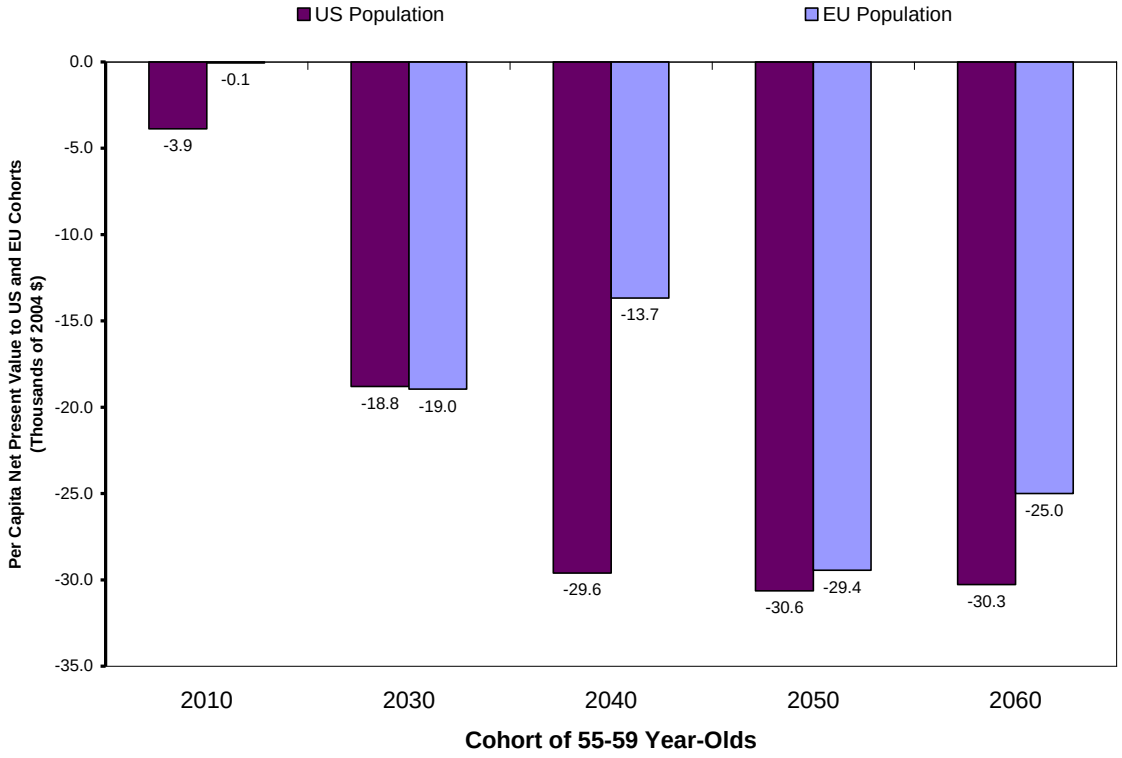


Figure 4: Aggregate net present value of EU price reductions to 55+ population in the US and Europe, by cohort.

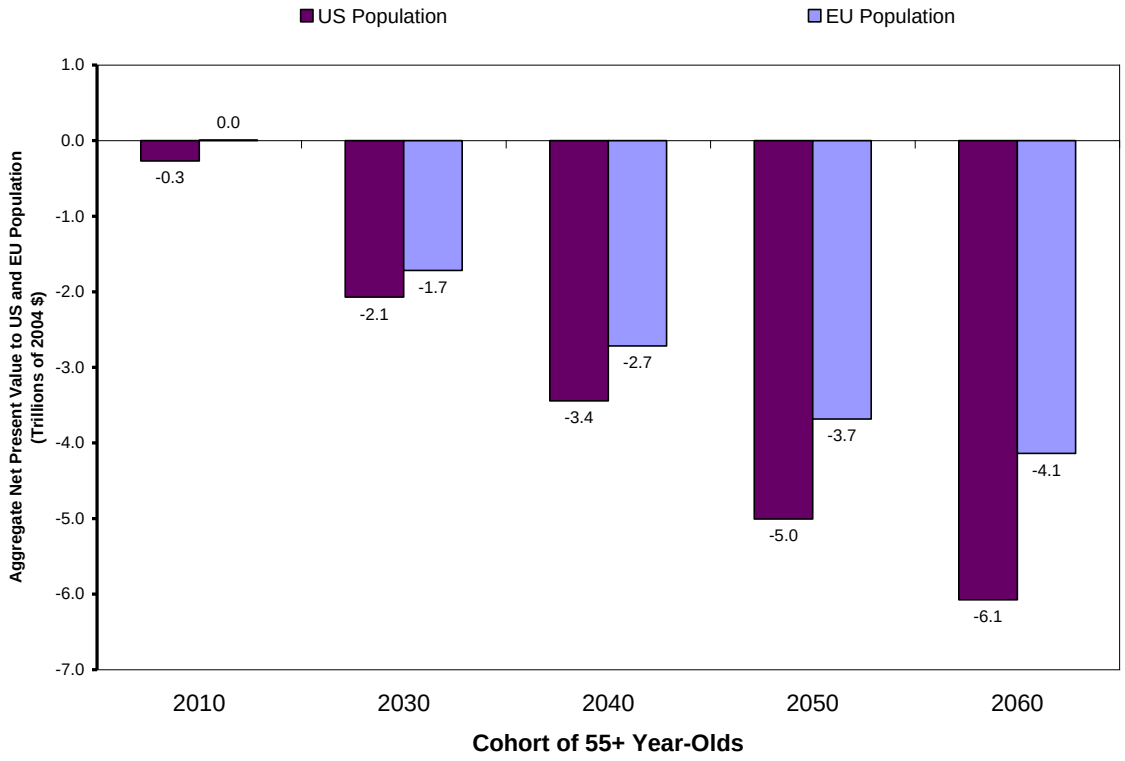


Figure 5: Effect of EU price increases on longevity among 55-59 year-olds in the US and Europe.

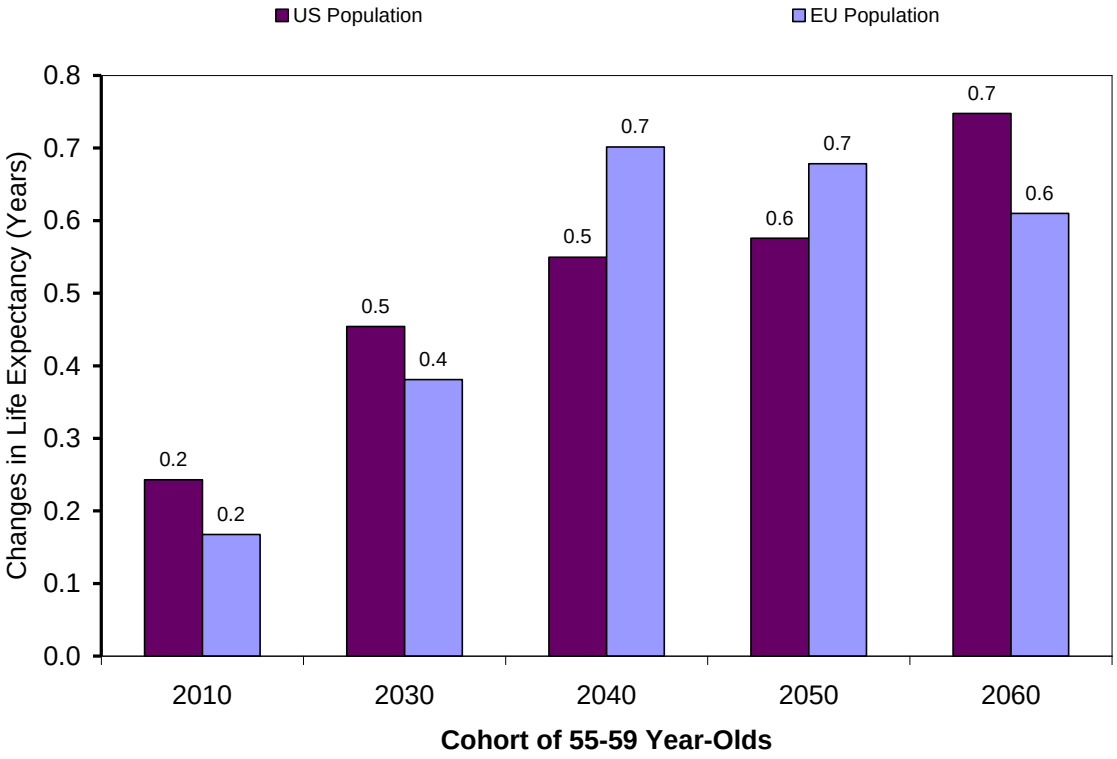


Figure 6: Effect of EU price increases on per capita medical spending for 55-59 year-old cohorts in the US and Europe.

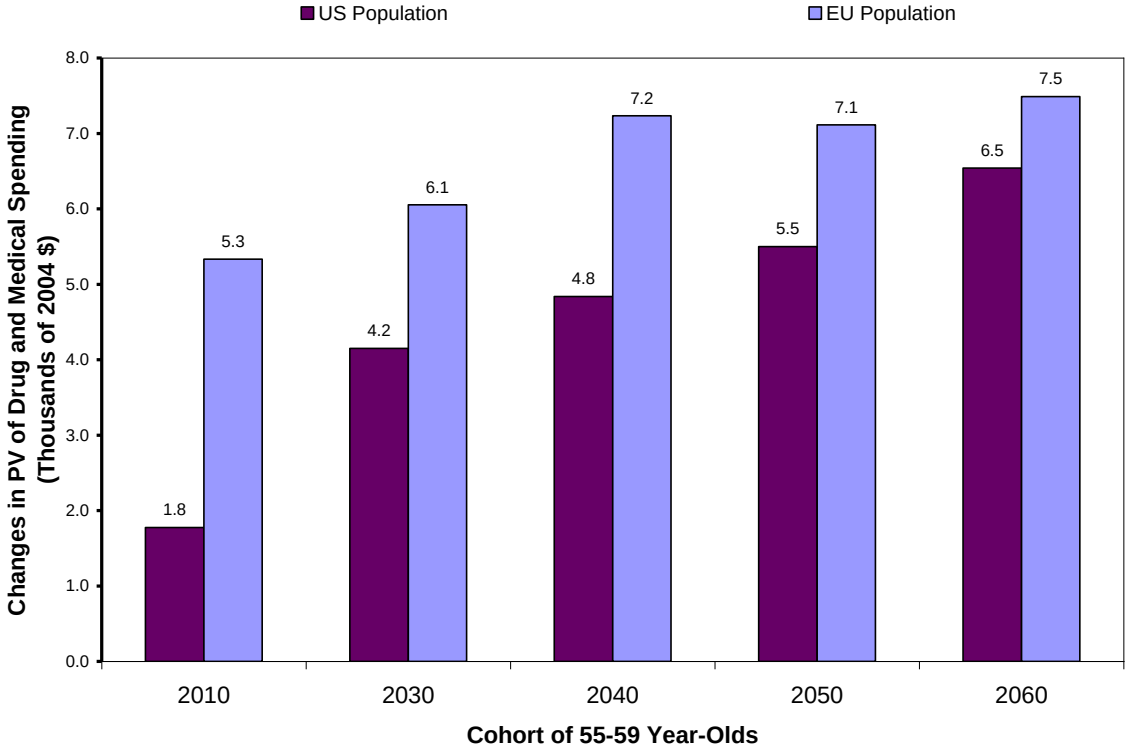


Figure 7: Net per capita value of EU price increases to 55-59 year-olds in the US and Europe.

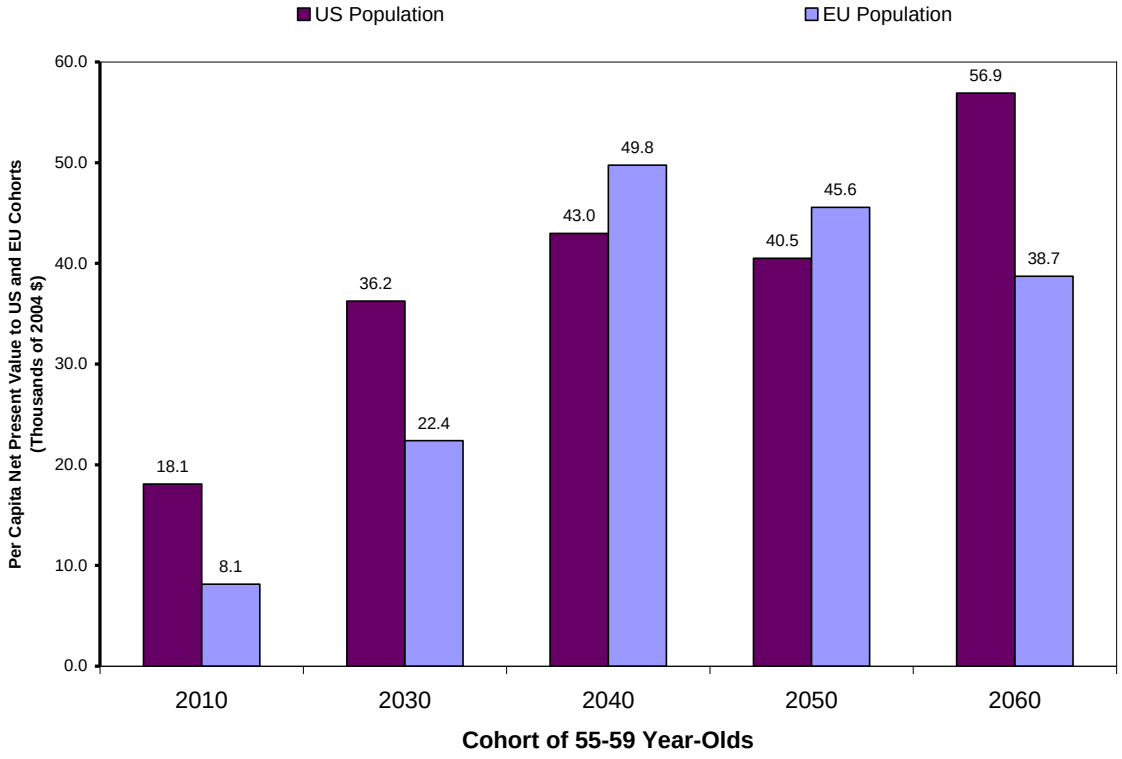


Figure 8: Net present value of EU price increases to 55+ population in the US and Europe, by cohort.

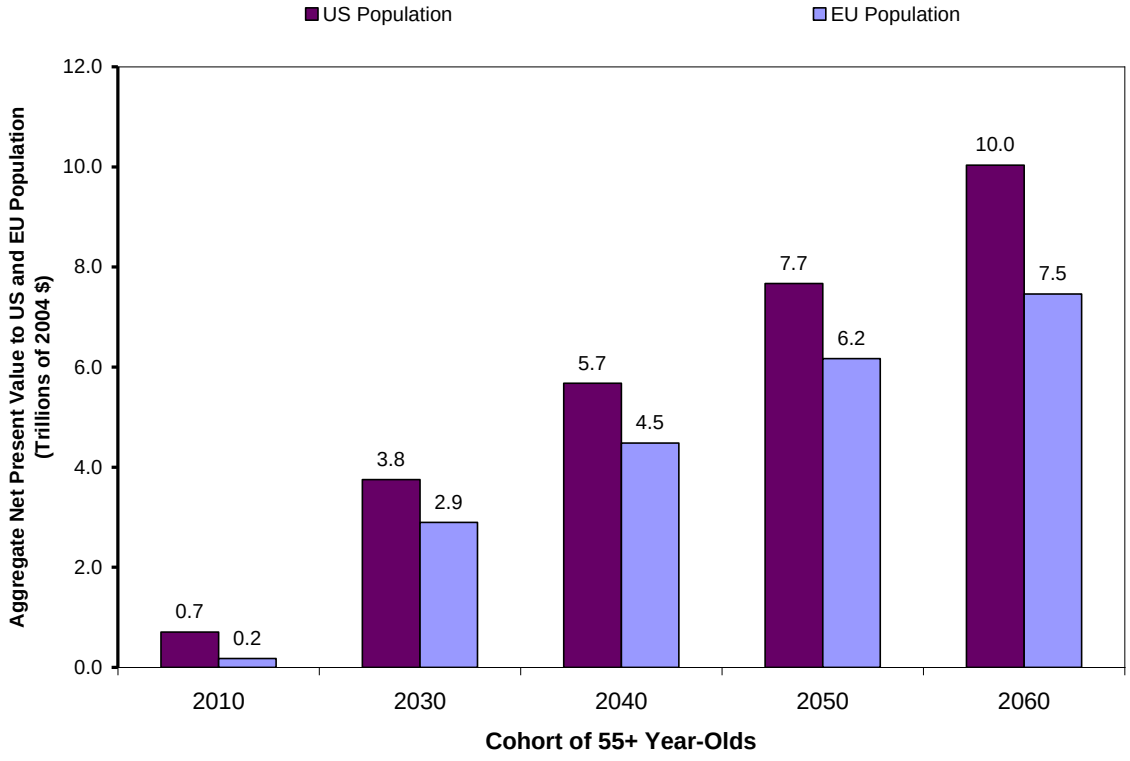


Figure 9: The value of a statistical life-year and model implications.

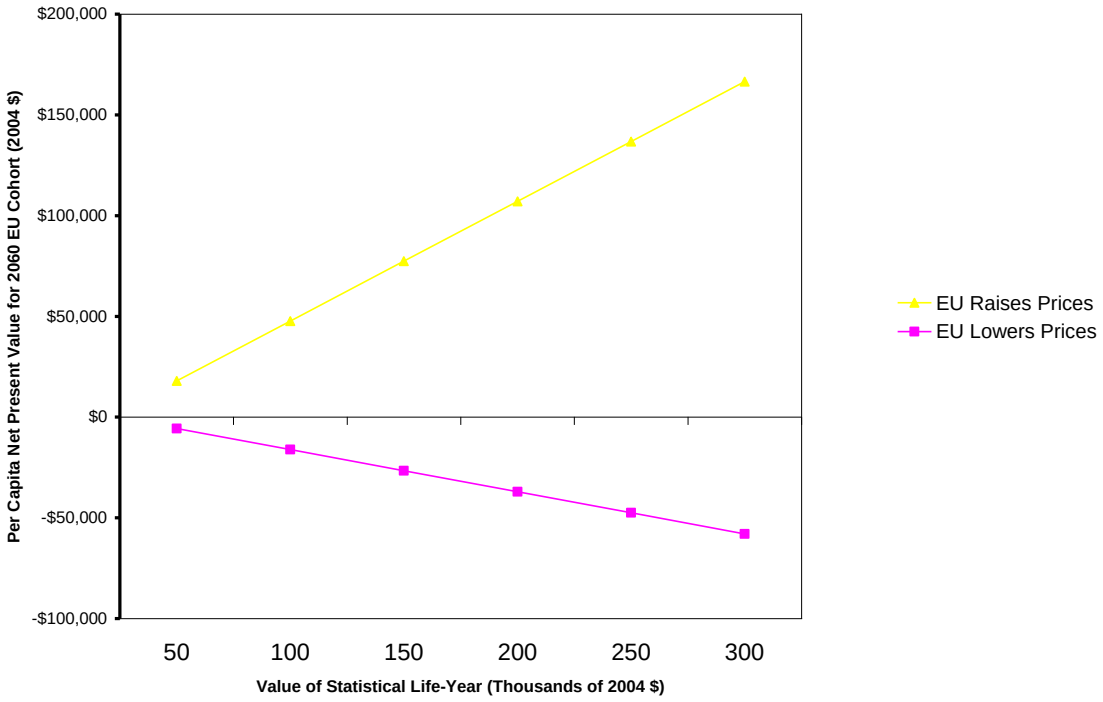


Figure 10: Likelihood of blockbuster and model implications.

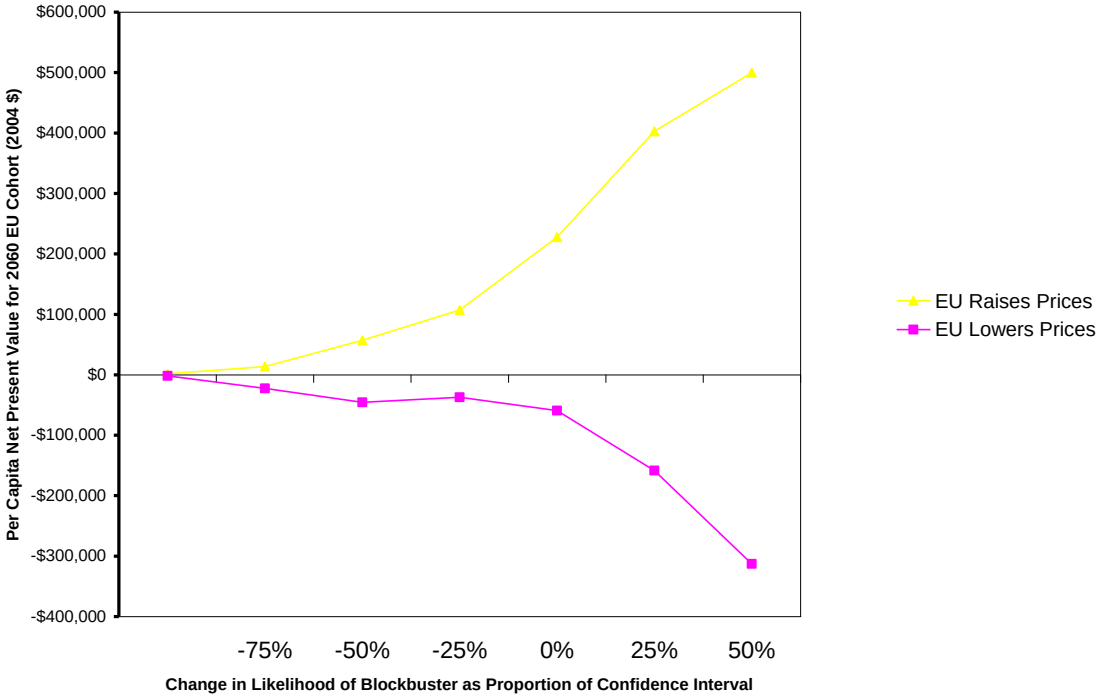


Figure 11: Access effect and model implications.

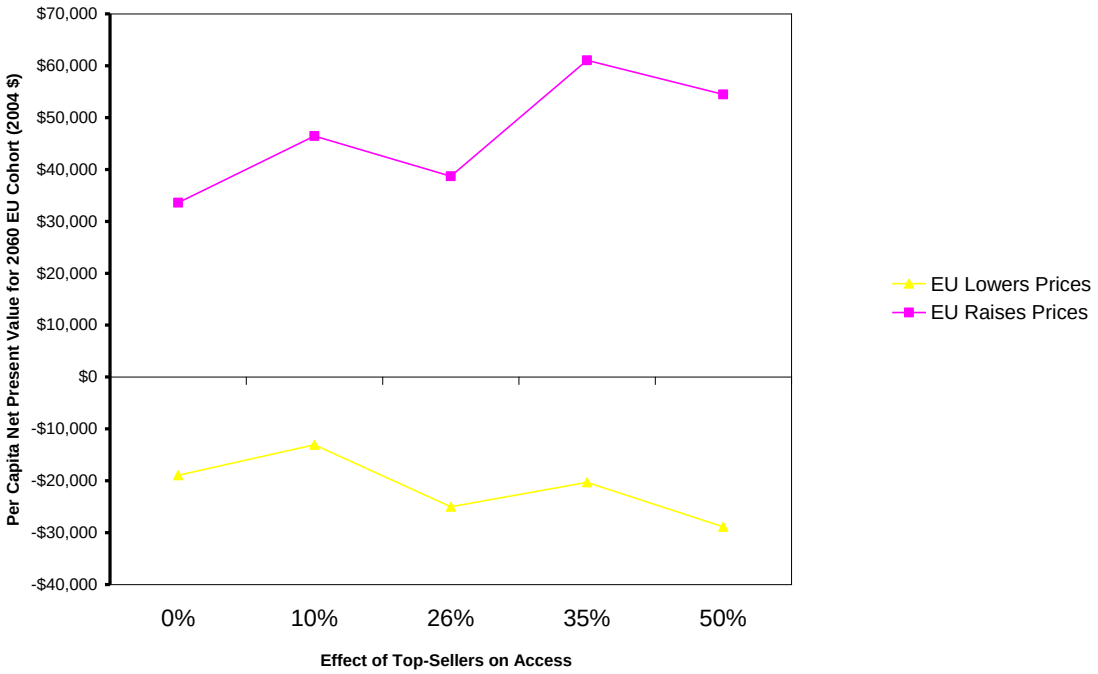
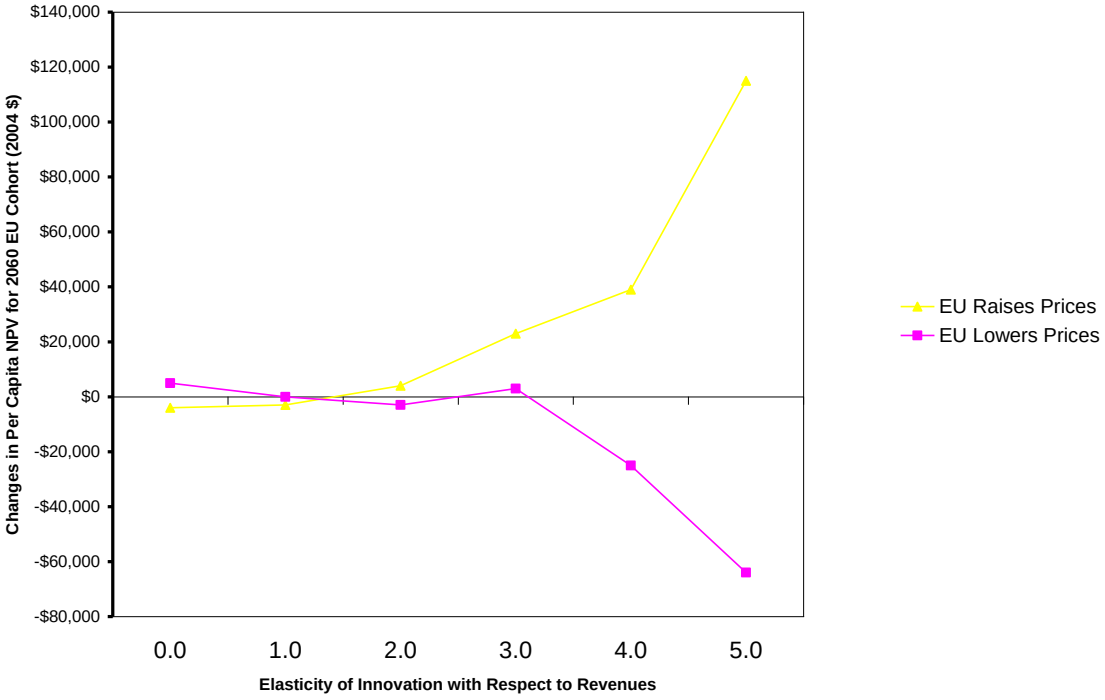


Figure 12: Innovation-responsiveness and model implications.



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