FINANCIAL HEALTH ECONOMICS

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ABSTRACT

We provide a theoretical and empirical analysis of the link between financial and real health care markets. This link is important as financial returns drive investment in medical research and development (R&D), which in turn, affects real spending growth. We document a "medical innovation premium" of 4-6% annually for equity returns of firms in the health care sector. We interpret this premium as compensating investors for government-induced profit risk, and we provide supportive evidence for this hypothesis through company filings and abnormal return patterns surrounding threats of government intervention. We quantify the implications of the premium for the growth in real health care spending by calibrating our model to match historical trends, predicting the share of GDP devoted to health care to be 32% in the long run. Policies that had removed government risk would have led to more than a doubling of medical R&D and would have increased the current share of health care spending by more than 3% of GDP.

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1. INTRODUCTION

Improvements in health have been a major component of the overall gain in economic welfare and the reduction in world inequality during the last century (Murphy and Topel (2006) and Becker, Philipson, and Soares (2005)). Indeed, an emerging literature finds that the value of improved health is on par with many other forms of economic growth during the last century, as represented by material per-capita income reflected in conventional GDP measurements. As such, the increase in the quantity and quality of life might be the most economically valuable change of that century. At the same time, the current size of the health care sector, now close to a fifth of the U.S. economy, and its continued growth have given rise to concerned public debates.

Medical innovation and its demand are central to these improvements in health and the expansion of the health care sector. Through medical progress, including improvements in knowledge, procedures, drugs, biologics, devices, and the services associated with them, there is an increased ability to prevent and treat old and new diseases. Many analysts emphasize that this surge in medical innovation is key to understanding the rapid expansion of the health care sector (Newhouse (1992), Cutler (1995), and Fuchs (1996)).

Therefore, to understand the growth of this sector, and the medical R&D that induces it, it is therefore important to understand the financial returns of those investing in medical innovation. This paper provides the first quantitative analysis of the joint determination of the financial returns of firms that invest in medical R&D and the resulting growth of the health care sector.

We first provide empirical evidence that the returns on firms engaged in medical R&D are substantially higher, around 4-6% per annum, than those predicted by standard empirical asset pricing models, such as the Capital Asset Pricing Model (Sharpe (1964)) and the Fama and French (1992) model. This large "medical innovation premium" suggests that investors in the health care industry need to be compensated for non-standard risks.

1

We provide a potential interpretation of the medical innovation premium as resulting from government risk for which investors demand higher returns on health care firms beyond standard risk-adjusted returns. In particular, we consider government-induced profit risk to be a plausible explanation for the medical innovation premium for three reasons. First, government greatly affects both the onset of profits through approval regulations and the variable profits conditional on such approval though reimbursement policies. For example, demand subsidy programs such as Medicare and Medicaid currently make up about half of medical spending in the United States and, thus, are clearly an important component affecting the profits of innovators. Second, we seek an aggregate risk component to which the health sector is particularly exposed. Government-induced profit risk has that property. Third, we discuss that several other plausible risk factors, such as for instance longevity risk, often imply a negative medical innovation premium in standard consumption-based asset pricing models, which is the opposite sign of the premium we document.

We provide supportive evidence for the hypothesis that government risk contributes to the medical innovation premium in three ways. First, we provide a text-based analysis of financial statements (10-K filings) that companies file with the Securities and Exchange Commission (SEC). The 10-K filings contain a section that asks the company about the risk factors it faces. We show that firms in the health care sector discuss government-related risk significantly more frequently than firms in other sectors. Second, we find that investors experience large negative returns when there are severe threats of government intervention.[1] Third, examining the proposed Clinton health care reforms of the 1990s, we find that health care firms experienced abnormally low returns. Moreover, firms with more negative (abnormal) returns during this period, which are therefore firms that are more sensitive to government intervention risk, are generally more exposed to the health care factor that earns the medical innovation premium. This finding is consistent with our interpretation of the medical innovation premium as compensation for government-induced

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[1]See Ellison and Mullin (2001) and Golec, Hegde, and Vernon (2010) and the Clinton health care reform as a key example.

profit risk.

Our theoretical analysis then investigates the link between financial markets, the incentives for medical innovation it induces, and real health care markets in terms of its growth resulting from this innovation. We analyze the quantitative growth of the health care sector when investors face government-induced profit risk. The model developed in this paper is a two-sector version of a rare-disaster model.[2] The economy has a large sector outside of health care that is free from disaster risk (in fact, for simplicity, free of any risk) and a smaller health-care sector facing a non-trivial probability of disaster. That disaster is government intervention that wipes out, or substantially reduces, shareholder value in the sector. This is a disaster from the perspective of the investors only, as opposed to society as a whole. With an artfully chosen stochastic discount factor for the investors, the model delivers the observed medical innovation premium. The medical innovation premium predicted by the model has two parts: an actuarially fair disaster premium and the risk premium arising from the entrepreneurial consumption reduction in the wake of the disaster. We argue that a standard CAPM regression, or a Fama-French regression, finds a substantial excess return (alpha) for the disaster-prone sector mainly because of the latter, that is, mainly because of the adverse correlation with the stochastic discount factor.

We find that the medical innovation premium has large effects on health care spending and medical R&D by calibrating our model to observed time trends from 1960 to 2010. In particular, we find that the size of the health care sector would have increased by 3% of GDP if government intervention risk had been removed and we show that the larger part of it is due to the entrepreneurial risk premium as opposed to the actuarially fair disaster premium. Furthermore, our calibration implies that R&D would more than double in the absence of the medical innovation premium, where once again the risk premium explains the bulk of the difference. This reduction in medical R&D investments in the presence of the medical

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[2]The rare-disaster approach has been used in a number of recent papers to explain equity premia; see, for instance, Barro and Ursua (2008), Barro and Jin (2011) or Gabaix (2012) We apply this idea specifically to the health care sector.

innovation premium provides a potential explanation for the "missing R&D" implied by the analysis by Murphy and Topel (2006), which suggests that the enormous value of gains in health justify much larger investments in medical R&D than are actually observed.

By 2050, our model suggests that 27% of GDP is spent on health care, conditional on no government intervention. The long-run steady state share is slightly below 32% of GDP. The CBO projects that total spending on health care would rise from 16% of GDP in 2007 to 37% in 2050 and 49% in 2082. Hence, our model produces estimates for the health care share that are somewhat lower than the CBO projections.

2. Related Literature and Institutional Background

2.1. Related Literature

Our paper relates to several strands of previous research by merging insight from three separate fields: health economics, macro-economics, and finance. Therefore, we briefly review how our work relates to some key papers in all three fields. Our paper differs from previous works by examining the joint determination of financial asset returns for those investing in medical innovation and the resulting growth in the real health care sector.

Our paper adds the analysis of R&D incentives to the macro-economic literature, which has analyzed the relationship between health and growth, see for instance Barro (1996) and Sala-i-Martin, Doppelhofer, and Miller (2004). A large empirical literature in health economics estimates the impact of economic growth on health care spending, see Gerdtham and Jonsson (2000) for a review.

A seminal paper analyzing the interrelationship between macroeconomic growth and the share of income spent on health is Hall and Jones (2007). These authors point out that a rise in the share is predicted by many reasonable preference specifications, as additional health spending increases longevity while the marginal utility for extra consumption declines with growth. Hall and Jones (2007) provide a detailed quantitative analysis of the effect and

4

social desirability of health spending.[3]

We view our paper as complementary to theirs. In particular, our focus is on the innovation in the health sector and the entrepreneurial risks associated with that investment, while these authors assume technological progress in the health sector to be deterministic and exogenous. While the long-run demand for new innovations in health might well be due to the forces Hall and Jones (2007) discuss, the key entrepreneurial risks arise from the possibility of governmental intervention rather than, say, risks in the effectiveness of health spending in increasing longevity, as we discuss in section 7. Compared to their model, our model puts the incentives for R&D at center stage, which requires us to extend the model along this dimension, while simplifying the longevity analysis performed by Hall and Jones (2007).

In finance, our paper relates to recent literature that shows that government risk affects asset prices.[4] The main contribution of our paper is to document the medical innovation premium in the health care sector and to map out the implications for investment in medical R&D and thus future health care expenditures. As a potential explanation of this risk premium, we point to the risk of government intervention.

Most closely related to our paper are Ellison and Mullin (2001) and Golec, Hegde, and Vernon (2010) who study the impact of the Clinton health care reform proposals in 1992 and 1993 on stock prices. Both papers find that health care stocks are negatively impacted by the Clinton reform plans. Furthermore, Golec, Hegde, and Vernon (2010) also show that the effect is more pronounced for R&D intensive firms and that (unexpected) R&D declines

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[3]The empirical evidence showing that health care is a luxury good is mixed, see Acemoglu, Finkelstein, and Notowidigdo (2009) and the references therein. Also, in the cross-section, health care is a necessity in the upper part of the income distribution, suggesting that technology may ultimately be the barrier to rich people from spending larger shares of their incomes on health care.

[4]For instance, Belo, Gala, and Li (2013) link the cross-section of expected stock returns to firms' exposures to the government sector. Brogaard and Detzel (2013) use the political uncertainty index of Baker, Bloom, and Davis (2013) to show that spikes in political uncertainty go together with declines in the stock market, which is largely the result of increases in risk premia. Kelly, Pastor, and Veronesi (2014) show how political uncertainty is priced in the option market using national elections and global summits, building on the theories developed in Pastor and Veronesi (2011) and Pastor and Veronesi (2012). These papers do not focus on the health care sector.

more for those firms who are more exposed to government intervention risk.[5] This evidence is consistent with the main implications of our model.

2.2. Institutional Background

Technological change that raises health care spending mainly comes from three categories: medical devices, biologics, and drugs, and the services associated with them. In the United States, the variable profits on these new technologies are determined both by private and public reimbursement policies. According to the Centers for Medicare & Medicaid Services (CMS), in 2012 about 44% of U.S. spending was publicly financed, mainly through the Medicare and Medicaid programs. However, returns in other parts of the world are more contingent on public reimbursement policies. For example, in European countries, roughly 85% of health care is publicly financed (OECD, 2013).

New health care products are often discovered by academic research; however, the high cost of development of medical products relies on outside investors, whose main focus is on (risk-adjusted) earnings. Hence, even though the research ("R") in medical R&D may not be motivated entirely by future returns, the development ("D") certainly is. Indeed, drugs and biologics are among the most R&D intensive industries in the United States.

To raise capital for the large development costs, manufacturers often use public capital markets. It is important to note that much of the production of goods and services in health care are not financed through public equity markets. Providers of hospital services, making up about a 35% of health care spending, are about 70% not-for-profit and thus rely on debt or donations instead of public equity. Physician services, making up an additional 22% of health care spending (CMS 2012), are often organized in small privately-financed clinics. Given the lack of public equity financing in these major health care sectors, it is understandable that the for-profit firms engaged in medical innovation make up a large majority of the firms listed on public equity exchanges.

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[5]Julio and Yook (2012) show more generally how corporate investment is affected negatively by political uncertainty.

Government policies in the United States disproportionally affect the returns on medical R&D investments as world sales for medical products is highly concentrated in the United States. Egan and Philipson (2013) use data from the World Bank and WHO to estimate that U.S. health care spending was about 48% of world spending in 2012 even though U.S. GDP was only about 24% of world GDP in the same year. For biopharmaceutical spending, the U.S. share of world spending is lower at about 39%, as many emerging markets spend a larger share of their overall health care on biopharmaceuticals. Given the larger markups on U.S. spending, a larger share of profits than sales is generated in U.S. markets. Because of the concentration of world profits in the United States, changes in reimbursement policies that threaten U.S. markups are of primary importance to those investing in medical R&D. This motivates our focus on the risk of U.S. government reimbursement policies on asset prices.

3. Empirical Evidence: The Medical Innovation Premium

3.1. Risk Premia in Health Care Markets

To estimate the medical innovation premium, we use data on industry returns, the Fama and French factors, and market capitalization from Kenneth French's website. The first classification we use splits the universe of stocks in five industries: "Consumer goods," "Manufacturing," "Technology," "Health care," and a residual category "Other."

The health care industry includes medical equipment,[6] pharmaceutical products,[7] and health services.[8] We also study the Kenneth French's classification into 48 industries, which splits the health care industry into the three aforementioned categories. We follow the industry classification as on Kenneth French's website for both the entire health care industry

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[6]The corresponding SIC codes are 3693: X-ray, electromedical app., 3840-3849: Surgery and medical instruments, 3850-3851: Ophthalmic goods.

[7]The corresponding SIC codes are: 2830: Drugs, 2831: Biological products, 2833: Medical chemicals, 2834: Pharmaceutical preparations, 2835: Invitro, in vivo diagnostics, and 2836: Biological products, except diagnostics.

[8]The corresponding SIC codes are 8000-8099: Services - health.

and for the three sub-industries.

We first study the returns of firms in the health care industry. In computing the returns to health care companies, we correct for standard risk factors to account for other sources of systematic risk outside of the model. Therefore, we are interested in the intercepts, or "alphas," of the following standard time-series regression:

$$(1) \qquad\qquad r_t - r_{ft} = \alpha + \beta' F_t + \varepsilon_t,$$

where F_t is a set of risk factors. We are interested in the returns of health care firms relative to firms that are not in the health care industry. To compute the relative returns, we regress the returns on a constant, the alpha, and a set of benchmark factors, F_t. The alpha measures the differential average return of health care firms that cannot be explained by standard asset pricing models.

Asset pricing models are distinguished by the pricing factors F_t they account for. As a first model, we use the excess return on the CRSP value-weighted return index, which is comprised of all stocks traded at AMEX, NYSE, and Nasdaq. This is a common implementation of the Capital Asset Pricing Model (CAPM), see Sharpe (1964). The second benchmark asset pricing model we consider is the 3-factor Fama and French (1992) model, which is labeled "Fama-French." In addition to the market factor, this model also accounts for firm size (the "SMB" factor) and the value factor (the "HML" factor). Empirically, smaller firms and firms with high book-to-market ratios, that is, value firms, tend to have higher average returns that are not explained by differences in CAPM betas. These additional two factors account for these regularities in asset markets.[9]

We present our main results for annual returns, using the Fama and French model, and for the sample from 1961 to 2012, which is the period for which we observe health

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[9]There is a large literature that provides explanations for the size and value effects, see for instance Berk, Green, and Naik (1999), Zhang (2005), Yogo (2006), Lettau and Wachter (2007), and Koijen, Lustig, and Van Nieuwerburgh (2012). In this paper, we are particularly interested in the risk premium in the health care industry above and beyond the standard risk factors and do not provide an explanation for the market, size, and value risk premia or exposures.

care spending. As the risk-free rate, $r_{f,t}$ in equation (1), we use 1-month T-bill rate from Ibbotson and Associates, Inc., rolled over for 12 months as constructed by Kenneth French and available from his website. As the return per industry, r_t in equation (1), we use the value-weighted return of all stocks in a given industry.

The results are reported in Panel A of Table 1. The first line corresponds to the alpha and the second line reports the t-statistic using OLS standard errors. We find that the health care industry earns an economically and statistically significant alpha of 5.0% (with a t-statistic of 2.4) relative to the Fama and French model.

We also report the alphas of the other industries and find that they do not have large alphas relative to the standard models. We conclude that there is a risk premium for holding health care stocks that cannot be explained by standard asset pricing factors.

If we remove health services and focus on medical equipment and pharmaceutical products, the alphas are even higher at 6.4% and 5.4% per annum, respectively. This is because the alphas on medical services are close to zero, which lowers the overall alpha of the health care sector.[10] Both alphas are statistically significant at conventional significance levels.

Although both sub-sectors, that is, medical equipment and drugs, earn significant alphas, these alphas are not necessarily driven by exposures to the same risk factor. To test this more directly, we augment the Fama and French model with the health care factor, which we define as the industry return on the entire health care sector in excess of the risk-free rate.

We report the alphas of the sub-sectors relative to the augmented Fama and French model in Panel B of Table 1. We find that the alphas are economically and statistically close to zero once the health care factor is included in the model, which is consistent with the interpretation that the same risk factor drives the alphas in both sub-sectors.

Our results are consistent with the findings in Fama and French (1997), who study the performance of the Fama and French (1992) model for a large cross-section of 48 industries.

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[10]The returns on services start only in the late sixties, and we therefore exclude them from the table. However, their returns are well explained by standard asset pricing models and the alphas are close to zero.

Their Appendix B shows that the model is rejected in particular due to two industries: real estate and health care. Despite the growing literature on returns in real estate markets, little is known about health care markets in this context.

For robustness, we estimate the model also at a monthly frequency and for two additional sample periods for annual returns, namely from 1927 to 2012 and from 1946 to 2012. The first sample period is the longest sample available. The second sample focuses on the post-war period. Furthermore, we compute the alphas not only relative to the Fama and French model, but also relative to the CAPM. The results for monthly returns and other sample periods are reported in the Online Appendix, but the results are broadly consistent with the findings reported in Table 1. If we use monthly data, or longer sample periods, the statistical significance of the alphas increases.

3.2.   Government Risk and the Health Care Sector

In this section, we provide new evidence on the importance of government risk for firms in the health care industry.

3.2.1.   Risk Factors Identified from 10-K filings

Our first piece of new evidence comes from a text-based analysis of 10-K reports that each firm files annually with the Securities and Exchange Committee (SEC).[11] We use the 10-K filings for 2012. As a robustness check, we also use the 10-K filings for 2006, which is before Obamacare was discussed and before the financial crisis to ensure that our results are not driven by the recent health care reforms or regulation that followed the financial crisis.

In each 10-K filing, there is a section 1.A labeled "Risk Factors." The guidelines for this section are described in Regulation S-K, Item 503(c), requesting companies to list the "most

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[11]10-K filings have been explored recently in the finance literature to define industries (Hoberg and Phillips (2011)), to measure competition (Feng Li and Minnis (2013)), to predict the volatility of stock returns (Kogan, Levin, Routledge, Sagi, and Smith (2009)), and to predict future stock returns (Loughran and McDonald (2011)).

significant factors" which affect the future profitability of the company.[12]

To illustrate the data we use in this section, we include the "Risk Factors" section of the 10-K filings of Pfizer and Apple, which are among the largest health and non-health care firms by the end of our sample, in the Online Appendix.

As is clear from the filings, various forms of government regulation are a major concern to Pfizer, while for Apple traditional risk factors such as economic conditions and competition are more relevant. Consistent with our model, Pfizer also explicitly mentions price controls and government intervention as one of the key risk factors that may affect the firm's operations.

Generalizing beyond the illustration of Apple and Pfizer, we hand-collect the sections on risk factors for the largest 50 health care companies and the largest 50 non-health care companies. For each firms, we count the number of times words related to the government or government risk appear in the filings.

The dictionary that we use is summarized in Table 2. The dictionary attempts to capture the prevalence of government-related risks in the 10-K filings. In the main dictionary, we avoid words that are government-related yet particular to the health care sector such as for instance "FDA," as this would bias our risk measurement towards the health care sector.

The results are summarized in Panel A of Table 3. For firms in the health care sector, we find that words in this dictionary appear roughly twice as much in 2012, on average 130 times, compared to, on average, 77 times for firms outside the health care sector.

However, the typical 10-K filing for health care firms is longer. As an alternative measure, we can look at the average fraction of words that appear in our dictionary. For firms within the health care sector, this fraction is 1.55% while it is only 1.24% for firms in the non-health

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[12]The precise definition is: *Where appropriate, provide under the caption "Risk Factors" a discussion of the most significant factors that make the offering speculative or risky. This discussion must be concise and organized logically. Do not present risks that could apply to any issuer or any offering. Explain how the risk affects the issuer or the securities being offered. [...] The risk factors may include, among other things, the following: (i) Your lack of an operating history; (ii) Your lack of profitable operations in recent periods; (iii) Your financial position; (iv) Your business or proposed business; or (v) The lack of a market for your common equity securities or securities convertible into or exercisable for common equity securities.*

11

care sector, implying that words from our dictionary appear 25% more frequently for firms in the health care sector.

One concern one may have is that the higher fraction of government-related words in 2012 is driven by the discussions around Obamacare. We therefore repeat the entire exercise, but now for 2006, thus before President Obama was elected. Figure 2 shows the fractions for health care and non-health care firms in both periods. We find that the fractions in both cases increase following the financial crisis, as one may expect. However, the fraction for non-health care firms increases substantially more (from 0.93% to 1.24%) than for health care firms (from 1.46% to 1.55%). These results suggest that our findings are not just driven by risks related to Obamacare or changes in regulation that followed the financial crisis.

As discussed, we omit government-related words from our main dictionary that are particular to the health care sector. We also explore how our results are affected if we include the health care-specific terms "medicare," "medicare reform," "medicaid," "medicaid reform," "ppaca," "cms," "healthcare reform," "nhs," and "fda" in our dictionary. The results for this expanded dictionary are reported in Panel B of Table 3. The differences in the average word count and the average fraction increase substantially, making the differences economically and statistically more significant.

Taken together, the text-based analysis of 10-K filings provides suggests that government risk is a relatively more important concern for firms in the health care sector.

3.2.2. Drawdowns of the Health Care Sector

Second, we study when financial investments in health care sector experienced large negative returns as a way to identify the risks to which the sector is exposed. In Figure 1, we plot the drawdowns for the health care sector alongside the drawdowns of the aggregate stock market. Drawdowns are defined as:

$$(2) \qquad D_t = \sum_{u=1}^{t} r_u - \max_{s \in \{1,...,t\}} \sum_{u=1}^{s} r_u,$$

where r_t denotes the log return on either the aggregate stock market or the health care sector. Hence, drawdowns measure the cumulative downturn relative to the highest level the indexed reached up to a certain point in time. Drawdowns are a common way to measure the risk of investment strategies (see for instance Grossman and Zhou (1993), Landoni and Sastry (2013), and Koijen, Moskowitz, Pedersen, and Vrugt (2013)).

Figure 1 points to three large downturns for the health care sector during the last two decades: in the early nineties, during the 2000-2002 technology crash, and during the 2007-2008 financial crisis. During the latter two periods, the drawdowns of the market are somewhat larger than those of the health care sector.

The drawdown in 1992 and 1993 is of most interest to us, which coincides with the discussions around Clinton's health care reform. During this period, the aggregate stock market increased, while the health care sector shows a large decline.

Interestingly, we do not find a similar drawdown during the recent Obama reforms as during the proposed Clinton reforms. Hult and Philipson (2012) provides an explanation for these two opposing effects. They stress that government expansions often lower both demand prices (premiums or copays) to raise access, but at the same time lower supply prices (reimbursements) through increased government monopsony power.

At the one extreme, when the poorest people are being added, the quantity effect will dominate the markup effect as the poorest were outside the program. For example, Medicaid expansions have this positive effect on earnings and innovation. At the other extreme, when very rich individuals are added, their utilization will not be affected much by the lower demand price in the public program but their markup will be lowered if they are subsumed under a government buyer. For example, the single-payer European payment systems may lower profits in this manner.

The non-monotonic impact of government expansions across the income distribution implies that Clinton's reforms may affect returns in opposing ways than Obama's reforms as represented by the different drawdown patterns. In particular, for the ACA under Obama,

the Medicaid expansions and the means-tested subsidies for exchange covered insurance raise the demand of the poor beyond market levels. Indeed, the CBO estimates that the ACA raises quantity, with most recent estimates suggesting that the act raised insurance coverage by over 4 percentage points.[13]

More importantly, many investor reports from the financial services sector upgraded valuations of medical R&D firms citing the increase in demand induced by ACA.[14] This may be one explanation of why the pharmaceutical industry spent an estimated $150 million in lobbying efforts in support of the ACA.[15]

In contrast, the Clinton health care plan, known officially as the Health Security Act, was a 1993 healthcare reform package that centered on regulations to provide universal and more homogeneous health care for all Americans and also had as a major component overall price controls.

The proposed Clinton reforms are therefore closer in spirit to our discussed overall markup threats and may be interpreted as more universally affecting the entire income distribution, not only the poor parts of the population as in the means-tested reforms of ACA. The extreme version of Clinton reforms would have been universal public coverage such as in many European countries, which would lead to the negative earnings effect discussed above.

Investment reports expressed concern over the potential negative effects the Clinton plan would have on health care stocks,[16] and we document that health care stocks responded negatively to this potential threat of price controls on medical R&D firms. As opposed to the industry support for the ACA, when Clinton came to office, the trade organization Biotechnology Industry Organization (BIO) was created as a response and lobbied exten-

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[13]CBO (2014), "Updated Estimates of the Effects of the Insurance Coverage Provisions of the Affordable Care Act."

[14]See for instance JPMorgan, "Global Biotech Outlook," Jan 6, 2014, BlackRock, "BGF World Health Science Fund," 2012-Q1 Commentary, BlackRock, "Equity Dividend Fund," 2014-Q1 Commentary, BlackRock, "North American Income Trust PLC," Half Year Financial report, April 30, 2014, and Morgan Stanley, "On the Markets," October 2013.

[15]See for instance: http://www.nationalcenter.org/PR-JohnsonandJohnson_042811.html.

[16]Pink Sheet, "Third Quarter FDC Index is Mixed for Drugs as Fears of Clinton Spark September Swoon," October 5, 1992.

sively against the Clinton health care plan.[17]

3.2.3. The cross-section of health care betas and event returns around Clinton's health care reforms

Ellison and Mullin (2001) and Golec, Hegde, and Vernon (2010) also show that health care stocks decline around the Clinton reform in the early nineties. These events provide a direct test of our theory as the key component of the reform was to impose price controls on new drugs. Our objective in this section is to show that firms that have higher health care betas measured over periods much longer than the Clinton reforms, experience also more negative returns during these events. This result is relevant as different exposures to the health care factor measure different exposures to the risk factor that results in the medical innovation premium. As differences in exposures to the health care factor relate to differences in abnormal returns coming from threats of government intervention, government risk may be a reasonable candidate determinant of the medical innovation premium.[18]

In our model, the exposure to the health care factor, which generates the medical innovation premium, and the exposure to government intervention risk are one-for-one related as government intervention risk is the only source of the risk premium. In reality, firms differ in their exposure to the health care factor and in their exposure to government intervention risk. We abstract from this heterogeneity for simplicity and tractability in the model, but the heterogeneity in the data allows us to test the link between the exposure to the health care factor and the exposure to government intervention risk.

Ellison and Mullin (2001) and Golec, Hegde, and Vernon (2010) identify the key event dates during the Clinton reform proposals, which we reproduce in Table 4. We first compute the health care beta, β_i^{HC}, by regressing monthly excess returns of a given firm i on the

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[17]BIO, "Milestones 2003: A History of BIO," `http://www3.bio.org/speeches/pubs/milestone03/`.

[18]Ideally, we would like to use alphas of individual firms directly, but those turn out to be to noisy. As betas are estimated more precily than alphas, we use betas with respect to the health care factor instead.

market return and the health care factor:

$$(3) \qquad r_{it} - r_{ft} = \alpha_i + \beta_i^M r_t^{MKT,e} + \beta_i^{HC} r_t^{HC,e} + \varepsilon_{it},$$

where $r_t^{MKT,e}$ denotes the excess return on the aggregate stock market and $r_t^{HC,e}$ the excess return on the health care factor. We require firms to have no missing monthly returns in 1991, 1992 or 1993, which is the period we use for the event study. Also, consistent with the empirical asset pricing literature, we remove stocks with prices below \$5 and above \$1,000.

The regression in (3) provides us the exposure to the health care factor for each firm, β_i^{HC}. The typical sample to estimate the beta is much longer than the period over which Clinton care was discussed. As follows from Table 5, the average number of years used to estimate the beta is around 20 years.

Next, we estimate the cumulative abnormal returns. We use an event window that spans from 5 days before, until 5 days after, each event listed in Table 4. We use 250 daily returns prior to the event window to estimate the betas relative to the CAPM model. If a firm has missing daily returns, it is omitted from the sample. We then compute the cumulative abnormal return by aggregating the residual from this regression (Campbell, Lo, and MacKinlay, 1997). We then sum over all event dates to get the total impact of the Clinton reform proposal on each health care stock.

We then relate the overall risk exposure of health care firms, estimated over a much longer sample on average, to the cumulative abnormal return during the events in 1992 and 1993 through a cross-sectional regression across firms:

$$(4) \qquad CAR_i = \delta_0 + \delta_1 \frac{\beta_i^{HC}}{\sigma\left(\beta_i^{HC}\right)} + u_i,$$

where $\sigma\left(\beta_i^{HC}\right)$ is the standard deviation of health care betas across firms. The coefficient δ_1 measures how the cumulative abnormal return, CAR_i, changes if the beta with respect to the health care factor, β_i^{HC}, changes by one standard deviation.

The main results are presented in Table 5. Firms with higher health care betas are more sensitive to news about future government intervention. A 1-standard deviation increase in the health case beta corresponds to a 12.2% lower cumulative abnormal return. Using heteroscedasticity-consistent standard errors, the effect is significant with a t-statistic of -3.6. As a point of reference, the average cumulative abnormal return across all firms is -23.6%. The R-squared of the regression equals 13.9%, which illustrates that abnormal returns are noisy, which is to be expected.

Taken together, firms with higher health care betas also showed larger movements during threats of government intervention. We interpret this as suggestive evidence that these firms are more sensitive to news about future government intervention.

4. A Dynamic Model of Medical Innovation and Spending

4.1. Outline of the Model

To understand the implications of our empirical findings for the health sector as well as its macroeconomic consequences, we now proceed to build a dynamic aggregate model, which centrally features the interaction between financial and real markets. We first lay out the key mechanisms and results.

The health industry risk premium α measured above arises here from the covariance between the stochastic discount factor of investors and the returns to health industry investments, both of which are driven by government risk. Assume that the government intervention may happen with some probability ω. As we show later, the health industry risk premium can then be calculated as

$$(5) \qquad \alpha = -\ln(1 - \omega) - \ln(\underline{X}),$$

see (35) and (38). The term $-\ln(1-\omega)$ reflects the actuarially fair disaster premium, whereas $-\ln(\underline{X})$ is the risk premium against this disaster and depends on preference parameters. In

section 6, we argue that it is the quantitatively larger component. R&D in the health sector needs to earn the additional premium α, no matter how it arises. That is, the dynamics of the model will depend on the preferences of the entrepreneur only via the return on health industry investments, or the sum of the aggregate market return and this premium, see equations (29), (37), and (38), and we can exploit that the premium α has been measured with some care above.

Given the government intervention risks facing medical entrepreneurs and their preferences for evaluating them, we need to specify the demand for their products. For this purpose, we consider a three-sector model in which labor is allocated across the production of consumption, medical goods and services, and medical R&D. The profitability of R&D investments depends on the supply side serving this demand. To that end, the model assumes monopolistic competition between health care suppliers, with non-entrepreneur households as the final purchasers and consumers of these goods and services.

We assume that non-entrepreneurial households are endowed with some base level of health, which they can increase by purchasing medical goods and services in the market place. To also account for the rise in R&D spending quantitatively requires some flexibility in the specification for the innovation technology (11).

Furthermore, it is quantitatively important to account for further government interventions, such as subsidies to health spending and medical R&D and we therefore included these features as well. Some additional choices such as an aggregate resource constraint on labor as the input to production and R&D are required to close the model.

After calibrating key parameters in section 6, we study the dynamics of the model as well as examine the counterfactuals, when we set α to just the actuarially fair risk premium or remove government risk altogether.

4.2. The Environment

4.2.1. Preferences and Endowments

Time is infinite, $t = 0, 1, \ldots$. The population consists of households $i \in [0, 1]$ and entrepreneurs $i \in (1, 1 + \kappa]$ for some $\kappa > 0$, where we shall think of κ being small. We focus on symmetric allocations and equilibria, with a representative household and a representative entrepreneur.

Households have Cobb-Douglas preferences over health and consumption:

$$
(6) \qquad U = E \left[\sum_{t=0}^{\infty} \beta^t \frac{\left(c_t^{\xi} h_t^{1-\xi} \right)^{1-\eta}}{1 - \eta} \right],
$$

where c_t is the consumption at date t, h_t is the health, $\xi \in (0, 1)$ determines the trade-off between health and consumption[19], $0 < 1/\eta < 1$ is the intertemporal elasticity of substitution, and $\beta \in (0, 1)$ the time discount factor.

Households are endowed with one unit of time each period, which they supply inelastically as labor. The productivity of labor for producing consumption goods is growing exogenously with $\gamma > 1$. Households are further endowed with a base level of health, given by $\underline{h}\gamma^t$ for some parameter $\underline{h} > 0$, and thus assumed to be growing at the same rate as labor productivity.

The preferences of the entrepreneurs imply a stochastic discount factor M_{t+1}, see equation (31), which shall be used to price profits in the health industry. For entrepreneurs, we abstract from modelling health care consumption as well as labor supply explicitly. We think of these as rich households, for which labor income and their aggregate labor supply does not matter much, and who purchase the best medical care available, but which nonetheless constitutes only a small fraction of their income. We therefore concentrate entirely on their consumption (or what they "eat") e_t and, below, their asset holdings. We assume that

---

[19]Cobb-Douglas preferences imply that the marginal utility of consumption increases in health, which is consistent with the empirical results in Viscusi and Evans (1990), Finkelstein, Luttmer, and Notowidigdo (2008), and Koijen, Van Nieuwerburgh, and Yogo (2011).

their preferences are piecewise linear and given by

$$
(7) \qquad V_t \;=\; u(e_t) + \tilde{\beta} E_t\left[V_{t+1}\right]
$$

$$
\text{where } u(e_t) \;=\; \begin{cases} \varrho(e_t - \underline{e}_t) & \text{for} \quad e_t \leq \underline{e}_t \\[4pt] e_t - \underline{e}_t & \text{for} \quad e_t \geq \underline{e}_t \end{cases}
$$

for $e_t \geq 0$ and parameters $\tilde{\beta}, \underline{e}_t, \varrho \geq 1$. This kinked-linear specification can be viewed as a simple version of prospect theory, as in Kahneman and Tversky (1979). We allow the reference point $\underline{e}_t$ to vary with time, but shall assume that the entrepreneur treats the value of $\underline{e}_t$ as exogenously given. There are many other preference specifications that have similar implications as we discuss in an online appendix to this paper.

4.2.2. Technologies and Feasibility

The production of aggregate consumption c_t is given by

$$
(8) \qquad c_t + \kappa e_t = \gamma^t L_{ct},
$$

where L_{ct} are the total units of labor devoted to producing consumption goods. We use the consumption good at time t as numeraire.

Health is produced according to the production function

$$
(9) \qquad h_t = \underbrace{\underline{h}\gamma^t}_{\text{Exogenous health}} + \underbrace{m_t}_{\text{Health due to medical treatments}},
$$

where $\underline{h}\gamma^t$ is the base health level the household is endowed with and m_t is medical care, an input to increase the health level beyond the base health level. One may wish to impose some upper bound $\bar{h}\gamma^t$ as the maximal level of health that can be reached with state-of-the-art medical care, in order to motivate our assumption above of abstracting from medical care for entrepreneurial households.

It is well known that most health expenditures occur late in life. Furthermore, with economic and medical progress, people now live considerably longer. We view our preference specification (6) and health production equation (9) as a simple version of this phenomenon. For example, for $0 < \eta < 1$ and while $h_t \leq \bar{h}$ for some $\bar{h}$, one might wish to understand $h_t^{(1-\eta)(1-\xi)}$ as proportional to a probability of staying alive in (6), and as the preferences there arising from aggregating across a population with age heterogeneity, modelled appropriately: higher h_t then corresponds to an older population, on average. Likewise, (9) can be understood as stating that reaching a more advanced age requires medical treatments beyond a base level of health. Since we are assuming that the base level of health to rise with general technological progress, we focus entirely on the role of medical progress in changing the share of health spending and aging. As an alternative specification, one could more explicitly introduce life-extending benefits of health care or medical care, which are central in Hall and Jones (2007), which may require an extension of our preference specification.

Longevity risk is, however, an unlikely source for the observed risk premium, see section 7. To focus on our main theme, we have therefore chosen to keep to the simpler specification above. One advantage of the formulation here is that $1 - \xi$ as a key health spending share parameter can be read off directly from the preference specification (6).

Medical treatment or medical care is produced from a continuum of firms, indexed by $j \in [0, 1]$,

$$(10) \qquad m_t = \left(\int_0^1 m_{jt}^{1/\phi} dj \right)^{\phi},$$

where $\phi > 1$. As is standard in models of monopolistic competition, ϕ determines the degree of competition in the industry, and hence the market power of producers in the competitive equilibrium below.

The production of m_{jt} units of type-j medical care is given by

$$m_{jt} = q_{jt} \gamma^t L_{mjt},$$

where L_{mjt} is the total units of labor used for producing type-j medical care, γ^t is the general productivity increase, and q_{jt} is the productivity or quality level for producing type-j medical care relative to producing the consumption good. Therefore, q_{jt}^{-1} is also the marginal cost for producing m_{jt} in terms of the consumption good at time t. The evolution of the quality is given by

$$(11) \qquad q_{j,t+1} = \left(q_{jt}^\nu + d_{jt}^\nu \right)^{1/\nu},$$

where $\nu \le 1$ is a parameter, and d_{jt} is the amount of R&D invested in the type-j-knowledge q_{jt}, created with labor per

$$d_{jt} = \gamma^t L_{djt},$$

where L_{djt} is the total labor used for undertaking type-j R&D, and γ^t is the general level of productivity. This specification abstracts from the risks inherent in undertaking medical R&D or potentially sizeable fixed costs. We return to these issues in section 6.4, after analyzing the baseline version described here. We drop the j-subscript to denote aggregates. We shall focus on symmetric equilibria and thus $q_t \equiv q_{jt}$, *et cetera*. We shall return to a discussions of asymmetric equilibria in section 6.4.

Aggregate feasibility requires

$$(12) \qquad L_{ct} + L_{mt} + L_{dt} = 1.$$

4.3. Households, Entrepreneurs, Government and Equilibrium

4.3.1. Households and Entrepreneurs

Households receive labor income θ per unit of output produced with household labor, with the remainder $1 - \theta$ paid to entrepreneurs. This can be thought of as a simple stand-in for, say, a Cobb-Douglas production function, with a labor share of θ and with entrepreneurs owning the capital stock, or as a tax on labor income charged by the government to repay government bonds, which are held by entrepreneurs, or as a payment for some fixed factor of production.

Importantly, we assume, that households neither trade assets on financial markets nor hold shares in health industry firms, and that the share θ thus remains constant throughout. There is a large literature documenting that the vast majority of households do not hold stocks or only hold them in very small quantities, and that the distribution of wealth and stock holdings is far from even. Nonetheless, all households are consumers of goods and medical treatments. It is this tension that we seek to capture with this simple assumption.

In the quantitative section, we shall allow θ to be somewhat larger than the labor share, to reflect the fact that some stocks are held in small-scale retirement portfolios and alike. The central feature of our modeling assumption is that these households will not hold any part (or any substantial part) of the government intervention risk, as part of their portfolio, and thus do not provide insurance against this risk. We view this as reasonable, given what is known about the distribution of wealth and stock holdings.

Households receive medical care purchase subsidies from the government and pay taxes. They therefore maximize the utility U given by (6) by choosing c_t and m_t, subject to (9), (10) and the sequence of budget constraints

$$(13) \qquad c_t + (1 - \sigma) \int_0^1 p_{jt} m_{jt} dj + \tau_t = \theta \gamma^t,$$

taking prices p_{jt} for medical care of type j at date t, the medical care purchase subsidy σ as

well as the lump sum tax τ_t as given. The maximization problem of the households implies an aggregate demand function $D_{j,t+1}(p_{j,t+1})$ for medical care of type j. In the symmetric equilibrium, $m_{jt} \equiv m_t$.

Each period, entrepreneurs can undertake medical R&D to receive a patent that lasts one period, and thus earn profits from monopolistic competition in period $t + 1$ due to the patents created in t. More precisely, after medical care $m_{jt}, j \in [0,1]$ is produced and profits $\pi_{jt}, j \in [0,1]$ are generated, ownership of the medical care types $j \in [0,1]$ are reshuffled among the entrepreneurs, with each entrepreneur receiving $1/\kappa$ types different from the ones ever owned before. For each type j now owned, the entrepreneur receives the previous knowledge level or quality level q_{jt} for free (as the previous patent has expired). The entrepreneur undertakes R&D d_{jt} and receives a monopoly for production and sales for type j next period. The government subsidizes R&D at rate χ and may impose restrictions on pricing next period.

We can think of the entrepreneurial activity as creating a medical care firm at date t for type j, which undertakes R&D d_{jt} at date t, sells $m_{j,t+1}$ at price $p_{j,t+1}$ at date $t + 1$, pays profits $\pi_{j,t+1}$ to its owning entrepreneur and then dies, where profits $\pi_{j,t+1} = \Pi_{t+1}(q_{j,t+1})$ depend on aggregate conditions such as government pricing restrictions, as well as the firm-specific quality level $q_{j,t+1}$. Given q_{jt}, the entrepreneur will thus maximize the firm value v_{jt} given by

$$v_{jt} = \max_{d_{jt}} E_t \left[M_{t+1} \Pi_t(q_{j,t+1}) \right] - (1 - \chi)d_t,$$

subject to (11), where M_{t+1} is the stochastic discount factor of the owning entrepreneur between period t and $t + 1$.

Entrepreneurs also receive income $1 - \theta$ per unit of output produced with household labor. We do not allow further trading of these assets between households and entrepreneurs, that is, we assume that θ is constant. Given the riskless productivity growth of labor, the income of these additional assets is safe, and the entrepreneurs, as a group, bear the entire risk of changes in the profitability of medical care.

While a nonzero share of output in the non-medical sectors may flow to entrepreneurial households invested in asset markets, it is not implausible that the marginal shareholders is rather thinly diversified: while diversification could spread risks, it may diminish the influence over the firms held. Therefore, $1 - \theta$ can also be read as parameterizing the degree of diversification for entrepreneurs and shareholders of medical care companies, with $\theta = 1$ as the extreme of no diversification (and no insurance against aggregate risks to the health sector) at all.

Imposing symmetry and postponing the discussion of idiosyncratic risk and asymmetry to section 6.4, we have $d_t = d_{jt}, q_t = q_{jt}$ and $\pi_t = \pi_{jt}$. Entrepreneurs now maximize (7) subject to the sequence of budget constraints:

$$(14) \qquad e_t + \tilde{\tau}_t + (1 - \chi)\frac{1}{\kappa}d_t = \frac{1}{\kappa}\left(\pi_t + (1 - \theta)\gamma^t\right).$$

Note the division of R&D expenses and profits by κ, in order to properly distribute the continuum $j \in [0, 1]$ of firms and the share $1 - \theta$ over the small continuum $j \in [1, \kappa]$ of entrepreneurial households.

4.3.2. Government and Government Risk

The government intervenes in three ways that all affect the health care sector. First, it proportionally subsidizes R&D undertaken by the firm, so that firms only need to privately pay for a fraction $1 - \chi$ of the costs of R&D, for some $0 < \chi < 1$. We keep this level of subsidy fixed throughout. Second, it proportionally subsidizes the purchases of medical care by households, so that households only pay for a fraction $1 - \sigma$ of the market price of medical care, for some $0 < \sigma < 1$. We keep this level of subsidy fixed throughout.

Third, the government may restrict the prices firms can charge for medical care. We assume that this restriction may randomly change over time: indeed, the main risk factor we consider is this government price intervention risk.

Consider a non-intervention period, where firms are free to set prices. Profit maximization with monopolistic competition leads to the usual markup pricing over marginal costs,

$$(15) \qquad\qquad p_t = \phi/q_t \text{ and } p_{jt} = \phi/q_{jt}.$$

The resulting aggregate profits are

$$(16) \qquad\qquad \pi_t = \pi_t(q_t) = (\phi - 1)m_t \left(\phi/q_t\right) \frac{1}{q_t},$$

where $m_t = m_t(p_t)$ depends on p_t, among other date-t-variables.

When intervening, the government limits the markup, so that after-intervention aggregate profits $\hat{\pi}_t$ in the health industry are now a fraction ζ of the profits that would have obtained in unconstrained competition, given q_t,

$$(17) \qquad\qquad \hat{\pi}_t(q_t) = \zeta\pi_t(q_t),$$

where $0 \leq \zeta < 1$ is a parameter of the model. As a benchmark, suppose that all profits are eliminated, $\zeta = 0$. That corresponds to allowing no markups and forcing firms to sell at marginal costs.

Intervention is a stochastic process. For the quantitative calculations below, we need to examine the probability of transiting to intervention in $t + 1$, if the government has never intervened until date t. It is analytically convenient to fix this transition probability as a constant parameter of the model, which we denote with ω.

Only the first two types of intervention create a flow of payments from the government, so that the government budget constraint is given by

$$(18) \qquad\qquad \sigma p_t m_t + \chi d_t = \tau_t + \kappa \tilde{\tau}_t,$$

26

where τ_t are the lump sum taxes collected from households at time t and $\tilde{\tau}_t$ are the lump sum taxes collected from entrepreneurs at time t. We assume that the taxes pay for the subsidies received in each of the two segments of the population,

$$\sigma p_t m_t = \tau_t,$$

$$\chi d_t = \kappa \tilde{\tau}_t.$$

4.3.3. Equilibrium

We focus on symmetric equilibria, with representative households, entrepreneurs and firms. Given the exogenous process z_t, an equilibrium is an adapted stochastic sequence

$$\Psi = (c_t, m_t, h_t, \tau_t, e_t, \tilde{\tau}_t, L_{ct}, L_{mt}, L_{dt}, q_t, d_t, p_t, \pi_t, v_t, D_t(\cdot))_{t=0}^{\infty},$$

with q_t measurable at $t-1$, such that households maximize their utility, given prices, government interventions, and firm choices, entrepreneurs maximize utility, resulting in consumption e_t, firms maximize profits and value per setting their own price, given prices set by other firms, wages, the stochastic discount factor and government intervention, and markets clear.

5. MODEL SOLUTION AND IMPLICATIONS

We provide the model implications for the share of health care spending in section 5.1, R&D spending in section 5.2, and the medical innovation premium in section 5.3. We shall compare these to observed magnitudes in the data, after calibrating the model in section 6.

5.1. Health Care Demand

Total demand for health care is obtained from the intra-temporal optimization problem of the households,

$$
(19) \qquad \max_{m_t} \frac{\left(c_t^{\xi} h_t^{1-\xi}\right)^{1-\eta}}{1-\eta},
$$

subject to (9) as well as the household budget constraint (13). This is solved by:

$$
(20) \qquad m_t = \left(\frac{1-\xi}{1-\sigma}\right)\left(\frac{\theta\gamma^t - \tau_t}{p_t}\right) - \xi\underline{h}\gamma^t,
$$

Let $\lambda_t = p_t m_t / \gamma^t$ be the share of labor generated output spent by households on medical care. Note that $\tau_t = \sigma p_t m_t = \sigma\lambda_t\gamma^t$. With this, rewrite (20) as

$$
\lambda_t = \left(\frac{1-\xi}{1-\sigma}\right)(\theta - \sigma\lambda_t) - \xi\underline{h}p_t
$$

and solve for λ_t. We find that the share evolves as

$$
(21) \qquad \lambda_t = \frac{p_t m_t}{\gamma^t} = \frac{1-\xi}{1-\sigma\xi}\theta - \frac{1-\sigma}{1-\sigma\xi}\xi\underline{h}p_t.
$$

The model has two important implications. First, if firms do not undertake any R&D, that is, $d_t = 0$, then q_t and hence p_t do not fluctuate over time, holding markups constant. Therefore, the health spending share increases only due to medical R&D, which lowers prices. Second, and absent government intervention, the long-run share equals

$$
(22) \qquad \lambda_\infty = \frac{1-\xi}{1-\sigma\xi}\theta
$$

and therefore increases with the importance of health in the utility function $(1-\xi)$, the size of the subsidy in the output market (σ) and the size θ of the labor generated output paid

to households.

While γ^t is the labor produced output, total output is given by

$$y_t = (1 + \kappa)\gamma^t + \pi_t,$$

and includes the profits of health-care companies, see (16) and (17). If there is no intervention in period t, these profits are

$$(23) \qquad \pi_t = (1 - \phi^{-1})m_t p_t = (1 - \phi^{-1})\lambda_t \gamma^t,$$

To compare model output to the data, it is reasonable to think of y_t as income from a growing stock of capital and labor that can be spent on consumption and health care, that is, as gross domestic product net of gross investment (but inclusive of health R&D, which we shall think of as negligibly small, for this calculation). Since gross investment is about 16 percent of total output in the data, measured output will be about 1.19 times output y_t in the model. Health spending as a share $\psi_t = p_t m_t/(1.19 y_t)$ of measured output is therefore

$$(24) \qquad \psi_t = 0.84 \frac{\lambda_t}{1 + (1 - \phi^{-1})\lambda_t},$$

absent government intervention, assuming that labor-produced output by entrepreneurs is negligible, $\kappa \approx 0$. The long-run value absent government intervention is then

$$(25) \qquad \psi_\infty = 0.84 \left(\frac{1 - \sigma\xi}{(1 - \xi)\theta} + 1 - \phi^{-1} \right)^{-1}.$$

Note that θ enters this equation, because we have assumed that the health care demand by the "rich" entrepreneurs is negligible compared to the entire economy, even though their consumption share is not.

In the benchmark scenario of a permanent intervention by the government, where markups

are eliminated entirely, private incentives to undertake R&D collapse. Assuming that the government does not directly finance R&D or organizes this industry in some other way, the quality of medical care remains constant from the intervention point onward. The price p_t for medical care drops from ϕ/q_t to $1/q_t$ due to the elimination of the markup. Equation (21) then implies an increase of the gross income share λ_t spent on medical care in the period of the intervention, due to this price drop and its effect on valuing the health endowment $\underline{h}$. From there onwards, the gross labor-produced output share λ_t remains constant, and will be bounded above by $(1 - \xi)\theta/(1 - \sigma\xi)$. Moreover, it will equal 1.19 times the overall share of measured output, since profits in the health industry are now zero. If the government finds a way to continue R&D indefinitely, the quality q_t may continue to grow to infinity, and the long-run share λ_t once again converges to $(1 - \xi)\theta/(1 - \sigma\xi)$. Similar remarks hold, if not all of the markup is eliminated, or if the interventions are only temporary.

Note that patents last one period by assumption and thus, the R&D incentives at date t are governed entirely by the probability and degree of government intervention in $t + 1$, and do not depend on any future periods. Other government intervention scenarios, other than the benchmark permanent intervention, can easily be understood. For example, in case of a temporary, but assured intervention with a complete elimination of markups, the private incentives for R&D collapse during the assured-intervention episode, but resume as soon as there is some positive probability that the government may not intervene next period. Likewise, if the intervention does not eliminate markups entirely, R&D incentives are reduced rather than eliminated altogether, with corresponding lower growth of quality. The exact magnitudes depend on the probabilities as well as the degree of markup control, and follow from the calculations for optimal medical R&D, which we shall present now.

5.2. Optimal Medical R&D

Consider a single firm j, choosing some R&D level d_{jt}, resulting in $q_{j,t+1} = \left(q_{jt}^\nu + d_{jt}^\nu\right)^{1/\nu}$. Given our symmetry assumption, we can drop the index j on q_{jt}, and write $q_{j,t+1} =$

$\left(q_{jt}^{\nu} + d_{jt}^{\nu}\right)^{1/\nu}$: however, we need to keep j in d_{jt} and $q_{j,t+1}$ to study the individual incentives for R&D. Suppose the R&D choices of all other firms result in the aggregate state of medical knowledge q_{t+1}. The markup equation (15) and the usual monopolistic competition calculations for firm-individual demand imply

$$\pi_{j,t+1} = \left(\frac{q_{j,t+1}}{q_{t+1}}\right)^{1/(\phi-1)} \pi_{t+1},$$

regardless of whether the government has intervened or not: the power $1/(\phi-1)$ shows up due to the elasticity of demand, and not due to the markup per se. The value maximization problem of the firm can therefore be written as

$$\max_{d_t \geq 0} E_t \left[\left(\frac{q_{j,t+1}}{q_{t+1}}\right)^{1/(\phi-1)} M_{t+1}\pi_{t+1} \right] - (1-\chi)d_{jt},$$

$$\text{s.t. } q_{j,t+1} = \left(q_t^{\nu} + d_{jt}^{\nu}\right)^{1/\nu},$$

taking as given the aggregate variables q_t, q_{t+1}, M_{t+1} and π_{t+1}, and q_{t+1} known at date t. In case of an interior solution, the first-order condition is

$$(26) \qquad 1 - \chi \;=\; \frac{\left(q_t^{\nu} + d_{jt}^{\nu}\right)^{1/\nu-1} d_{jt}^{\nu-1}}{q_{t+1}(\phi-1)} \left(\frac{q_{j,t+1}}{q_{t+1}}\right)^{\frac{1}{\phi-1}-1} E_t \left[M_{t+1}\pi_{t+1}\right].$$

Imposing symmetry yields

$$(27) \qquad 1 - \chi = \frac{d_t^{\nu-1}}{q_t^{\nu} + d_t^{\nu}} \frac{1}{\phi-1} E_t \left[M_{t+1}\pi_{t+1}\right],$$

which can be solved for d_t, if q_t and $E_t \left[M_{t+1}\pi_{t+1}\right]$ are known. Note though, that both M_{t+1} and π_{t+1} generally depend on q_{t+1} and therefore on d_t, as well as on the government intervention decision in $t+1$.

Suppose there has been no government intervention until date t. The specification (7) and suitable parameter restrictions on $\underline{e}_t$ and $\underline{e}_{t+1}$ eliminate the dependence of M_{t+1} on q_{t+1}

and ensures that it takes the two values $\tilde{\beta}$, if there is no intervention in $t+1$, and $\varrho\tilde{\beta}$, if there is government intervention in $t+1$. We examine this in greater detail in section 5.3 below.

With (17) and the conditional intervention probability ω, equation (27) can then be rewritten as

$$(28) \qquad 1 - \chi = \frac{d_t^{\nu-1}}{q_t^\nu + d_t^\nu} \frac{1}{\phi - 1} \pi_{t+1} \left((1-\omega)\tilde{\beta} + \omega\varrho\tilde{\beta}\zeta \right),$$

where π_{t+1} is now the no-intervention level of profits, given $q_{t+1} = (q_t^\nu + d_t^\nu)^{1/\nu}$. Thus, substitute π_{t+1} out with (23) and in turn replace λ_{t+1} per equation (21) to obtain

$$(29) \qquad 1 - \chi = \frac{d_t^{\nu-1}}{q_t^\nu + d_t^\nu} \left(\frac{1-\xi}{1-\sigma\xi} \frac{\theta}{\phi} - \frac{1}{(q_t^\nu + d_t^\nu)^{1/\nu}} \frac{1-\sigma}{1-\sigma\xi} \xi \underline{h} \right) \left((1-\omega)\tilde{\beta} + \omega\varrho\tilde{\beta}\zeta \right).$$

While this may seem like a somewhat daunting equation, the key is now that it is a non-linear equation in d_t, given parameters and given q_t. It can be analyzed and solved using conventional methods. With that, one can now solve for the entire model dynamics forward, given initial conditions.

5.3. Risk Preferences and the Stochastic Discount Factor

The budget constraint of the entrepreneurs as well as the government budget constraint implies

$$(30) \qquad \kappa e_t = (1-\theta)\gamma^t + \pi_t - d_t$$

so that consumption of the entrepreneurial households is the entrepreneurial share of labor-produced output plus current period profits of medical care firms minus the expenses for creating the next generation of such firms. With the preferences given in (7), the stochastic

discount factor M_{t+1} is

$$(31) \qquad M_{t+1} = \begin{cases} \tilde{\beta} & \text{if} \quad e_t > \underline{e}_t,\ e_{t+1} > \underline{e}_{t+1}, \\ \varrho\tilde{\beta} & \text{if} \quad e_t > \underline{e}_t,\ e_{t+1} < \underline{e}_{t+1}, \\ \tilde{\beta}/\varrho & \text{if} \quad e_t < \underline{e}_t,\ e_{t+1} > \underline{e}_{t+1}, \\ \tilde{\beta} & \text{if} \quad e_t < \underline{e}_t,\ e_{t+1} < \underline{e}_{t+1}. \end{cases}$$

We shall assume (or calibrate) $\underline{e}_t$ so that the entrepreneurial consumption e_t is always above this threshold in a non-intervention period, and below it in a period of government intervention. We call this the calibration assumption.

To explain the observed premium in the data, we only need this calibration assumption to hold during the observed time span. For the long-run quantitative explorations below, we shall impose it forever, however. In our calculations below, e_t grows in the non-intervention scenario, so that we simply need $\underline{e}_t < e_0$ to assure the first half of this statement. This would follow from assuming a constant reference value $\underline{e}_t \equiv \underline{e}$.

To assure the second half of the calibration statement for a constant reference value $\underline{e}$ and for the observed data, one needs that a government intervention within the next decade depresses entrepreneurial consumption below the entrepreneurial consumption level e_0 of our observed data. In the extreme case of a complete elimination of markups and a zero entrepreneurial share of labor-produced output, entrepreneurial consumption falls to zero: we then just need $e_0 > \underline{e} > 0$. By continuity, this is then still true for a low, but nonzero markup level as well as a low, but nonzero entrepreneurial share of labor income.

However, if the entrepreneurial share of labor produced output is large compared to the profit income from medical care firms or if the reduction in markup is rather modest or if one seeks to impose the calibration assumption for all periods t, and thus also for the future without allowing for complete elimination of markups or with a nonzero entrepreneurial share of labor produced output, one needs to allow the reference value $\underline{e}_t$ to vary with time

and to tune it such that it lies just in between the value of entrepreneurial consumption that obtains with and without government intervention. Put differently, more modest government interventions or more diversification, expressed as a smaller value for θ, do not per se invalidate our calibration assumption: they just make it harder to achieve and thus lessen its plausibility. It should also be noted that nothing in the calibration assumption depends on the government intervention being permanent or temporary. Once the calibration assumption is granted, the rest of the analysis follows. If the calibration assumption is not satisfied, then one requires another mechanism to generate the medical innovation premium and to study its macro-economic implications. If the medical innovation premium arises to some part as a risk premium, then assumptions are needed to generate sufficient volatility in the stochastic discount factor, as here.

With the calibration assumption, the stochastic discount factor M_{t+1} in a non-government intervention period can be rewritten as

$$(32) \qquad\qquad M_{t+1} = R^{-1} X_{t+1},$$

where

$$(33) \qquad\qquad R = 1/E_t[M_{t+1}] = \frac{1}{\tilde{\beta}\,(1 - \omega + \omega \varrho)}$$

is the rate of discounting that is not particular to the health care risk. In a model with standard productivity shocks *et cetera*, R ought to reflect the risk pricing of such shocks. It is rather straightforward to extend our preference specification and model to account for other risk factors such as aggregate stock market risk or even the Fama-French factors. However, to focus on the economic mechanism at work, we restrict attention to the government risk factor only.

The second component of the stochastic discount factor, X_{t+1}, satisfies

$$(34) \qquad\qquad 1 = E_t[X_{t+1}]$$

and is the component arising out of the health care sector aggregate return risk, which we have modelled as the risk of government intervention. It satisfies

$$(35) \qquad X_{t+1} = \begin{cases} \overline{X} = \varrho/(1 - \omega + \omega\varrho) \;, & \text{if no interv. in } t, \text{ interv. in } t+1, \\ \underline{X} = 1/(1 - \omega + \omega\varrho) \;, & \text{if no interv. in } t \text{ and } t+1, \end{cases}$$

for the main cases of interest. Per (34), note that

$$(36) \qquad\qquad 1 = (1 - \omega)\underline{X} + \omega\overline{X}$$

and that $\overline{X} > \underline{X}$. Therefore, when the government intervenes, the marginal utility of wealth of the agent pricing the assets is high. This covariance of marginal utility and profits generates a positive risk premium for health care firms that is not accounted for with the traditional risk factors used in standard asset pricing models.

Consider a health industry asset that pays a return Q at date $t+1$ on a unit of investment at date t, if there has been no government intervention, and pays ζQ, if the government intervened, see (17). Since $1 = E_t[M_{t+1}Q]$, the return needs to satisfy

$$(37) \qquad\qquad Q = \frac{R}{(1 - \omega)\underline{X} + \omega\zeta\overline{X}} = \frac{1}{(1 - \omega)\tilde{\beta} + \omega\varrho\tilde{\beta}\zeta}.$$

This logic applies in particular to equation (29), where we can replace the factor $(1 - \omega)\tilde{\beta} + \omega\varrho\tilde{\beta}\zeta$ at the end with Q^{-1}. Thus, given a value for Q, ω as well as ζ disappears from this equation. As a result, knowledge of Q is sufficient for calculating the dynamics of the model, and will be independent of the probability of the government intervention during the no-intervention epoch and independent of the degree of profit reduction ζ, given Q. In

our quantitative section, we can therefore exploit our measurement of Q from our empirical section above to obtain the entire dynamics.

An entirely safe asset would have the return R. To disentangle risk aversion from disaster risk for the return Q, suppose, that the government intervention for this particular asset was uncorrelated with the intervention giving rise to the stochastic discount factor of the entrepreneur. To keep the algebra simple, let us further assume total elimination of profits in case of government intervention, $\zeta = 0$. In that case, this disaster-risk-only return $\tilde{Q}$ must solve

$$\tilde{Q} = \frac{R}{(1 - \omega)}.$$

Further, we can decompose the medical innovation premium α, written as the log excess return on investing in a health industry asset, into two pieces,

$$(38) \qquad \alpha = \ln(Q) - \ln(R) = -\ln(1 - \omega) - \ln(\underline{X})$$

where the first piece is the log excess return that is entirely due to the disaster risk inherent in health industry assets, while the second piece is due to the entrepreneurial risk aversion against such a disaster. If $\zeta > 0$, a similar decomposition easily obtains, but the resulting formulas are more convoluted.

While we have derived this stochastic discount factor from the preference specification (7), the latter is not essential: only the properties of the stochastic discount factor above matter for the solution of the model. We could have thus alternatively started with assuming these properties of M_{t+1} and then reverse-engineer entrepreneurial preferences, which give rise to this stochastic discount factor. For the kinked-linear preference specification in (7), it is easy to solve for $\tilde{\beta}$ and ϱ, given ω, $\overline{X}$, $\underline{X}$ and R, satisfying (36), from equations (33) and (35), but the reverse-engineering approach can be applied to a wider variety of utility specifications, which would thus serve just as well. We explore this route in a online appendix to this paper.

The simple form of the stochastic discount factor and the binary nature of the government intervention risk allow for a particularly simple way of solving the model, while respecting key nonlinearities elsewhere in the model during the convergence phase to the steady state.

6. Calibration and Quantitative Implications

In section 6.1, we discuss how we calibrate the model's parameters, and provide intuition for how parameters are identified. We then use the model in section 6.2 for two counterfactuals. First, we consider the case in which the government risk is removed all together ($\omega = 0$). Second, we consider the case in which the government risk is still present ($\omega > 0$), but the stochastic discount factor is uncorrelated with government risk. We conclude this section by studying the long-run implications of the model in section 6.3.

6.1. Moments, Parameters, and Sensitivity

We need to calibrate the parameters

$$(39) \qquad \{\gamma, \underline{h}, \nu, q_0, \underline{X}, \overline{X}, \phi, \xi, \zeta, \chi, \sigma, \theta\}.$$

The parameters β and η have no implications for medical innovation or spending decisions and therefore do not need to be calibrated. We calibrate the model to five periods of 10 years starting in 1960. Thus, $t = 0$ corresponds to 1960 and $t = 5$ corresponds to 2010. For the calibration we shall additionally impose that $z_t = 0$, $t = 0, \ldots, 5$, which corresponds to no government intervention.

Real output growth during this period is about three percent per annum, with or without the profits in the health industry. Therefore, we set $\gamma = 1.35$ per decade so that labor-produced output grows at three percent per annum.

Concerning the markup, Caves, Whinston, and Hurwitz (1991) estimate that prices of drugs fall by 80% if a patent of a drug expires and generic drugs become available. This

suggests $\phi = 5$. However, other expenses, such as marketing costs, decline as well after patent expiration, which suggests a lower number. As a starting point, we therefore set $\phi = 3$.

We then turn to the subsidy on medical care and medical R&D. According the the CMS, about 50% of aggregate health care spending occurs via Medicare and Medicaid. We therefore set $\sigma = 50\%$. Further, we set the R&D subsidy to $\chi = 0.5$, consistent with estimates of Jones (2011).

In calibrating government intervention risk, we initially consider the case in which government intervention reduces health care prices to marginal costs. This implies $\zeta = 0$. We set the probability of government intervention to $\omega = 10\%$, which implies that the probability that the government did not intervene in a 50-year period equals 59%. We also explore the implications for our main results of changing ω from $\omega = 10\%$ to $\omega = 20\%$, implying a a probability of no intervention over 50 years of less than 33%. We therefore view $\omega = 20\%$ as an upper bound for a reasonable intervention probability. One could, of course, increase ω far enough so that the observed α is entirely due to the actuarially fair disaster premium, with $\underline{X} = 1$ in equation (38). To achieve a 5% alpha per year beyond the "usual" 4% annual rate of return then requires $\omega = 1 - (1.04/1.09)^{10} = 37.5\%$. The probability of no intervention for a 50-year period then equals 9.6%. Put differently, it is very improbable that no intervention has taken place so far: an explanation, which we do not find plausible.

Next, we calibrate the stochastic discount factor. R is the relevant discount rate in the absence of government intervention risk. For the arguments given in McGrattan and Prescott (2003), we set this discount rate to 4% per annum, capturing the rate of return on a balanced stock-bond portfolio. This implies a value of $R = 1.48$. This discount factor should not be interpreted as the safe return, but rather reflects other macroeconomic risks, not explicitly modelled here, which affect investment choices, including the investments in medical R&D. We assume that investments in the health care industry carry an additional premium of 5% per annum, or $Q = 1.09^{10} = 2.37$ per decade. With ω, equation (37) now delivers values for

$\tilde{\beta}$ as well as $\underline{X}$, while (33) delivers the value for ϱ.

In our model, only health industry assets are risky, whereas all others are safe. If one were to run a CAPM regression in our model, then these assets would have a premium compared to the market return, which happens to be the safe return. While our model is highly stylized, it does allow us to interpret the CAPM premia of the empirical section as a version of the preference-driven model-based premia here.

Second, equity generally is a claim on the leveraged assets of a company, while we investigate the premia on the unlevered investment in health care companies in the model. However, pharmaceutical firms in particular tend to have very low debt levels, since most of their investment is in intangibles. We therefore directly match the return on assets to the return on equity.

The parameter θ plays a dual role in the model. It measures the degree of diversification for the entrepreneurs. First, a low value for θ means that entrepreneurs own a large share of the economy aside from health industry equity, thus buffeting the impact of a potential government intervention. While this is important when inspecting functional form assumptions for the entrepreneurs, this aspect is now mute, given the quantitative assumptions about the risk premium against government intervention. Second, since entrepreneurs consume no (or only a negligible) part of their income on medical services, a low value for θ lowers the overall demand for medical services, given aggregate output. It is this force that is of quantitative importance here, as can also be seen from (25) and the discussion there. We therefore set $\theta = 0.8$ and thus somewhat higher than the labor share in order to take into account the demand for medical services by rich stock holders.

We select the remaining four parameters, $\underline{h}$, ν, q_0, and ξ to match the R&D share in 1990 and 2010, as well as the health share in 1960 and 2010. We use data on health care spending from the CMS and data on R&D spending is from Jones (2011). For the R&D share in 2010, we extrapolated from 2006, using the average R&D growth rate from 1987 to 2006 and the average GDP growth rate from 1987 to 2006.

In Table 6 we summarize the model parameters. We illustrate the fit of the model relative to the data in Figure 3: they are the same for $\omega = 10\%$ or $\omega = 20\%$, given the remark following equation (37).

6.2. Risk Premia, Medical Innovation, and Medical Spending

To understand the impact of government intervention risk and risk premia on health care spending and investment in medical R&D, we proceed in two steps. First, we remove all government risk. Removing government risk altogether has two effects. On the one hand, there is no risk premium effect anymore. On the other hand, the expected profits of firms engaged in medical R&D increase. To separate both effects, we also consider the cases where the government risk is still present, but there is no risk premium effect: it is here that we need to distinguish between $\omega = 10\%$ and $\omega = 20\%$. By comparing these three counterfactuals, we can assess the cash flow and discount rate effects separately.

6.2.1. First Counterfactual: No Government Risk

The first counterfactual we consider is when all government risk is removed, that is, $\omega = 0$. Since there is no risk, the stochastic discount factor takes the same value in both states, that is, $M_{t+1} = R^{-1}$. The results are presented in figure 4. The solid line presents the benchmark case. The dashed line, which is furthest from the benchmark case, corresponds to the case in which we remove government risk altogether. The figure applies to the no-government intervention epoch.

In the absence of government risk, the discount rate which firms apply to medical R&D investments is lower and the expected profits are higher. As such, medical R&D rises more rapidly. By 2010, the R&D share more than doubles the R&D share in the presence of risk premia and government risk.

As a result of medical R&D, the price of medical care falls and the health care share rises more rapidly as well. The impact is quantitatively large as the share of GDP spent on

medical care rises from nearly 18% to 21% in 2010 in this counterfactual scenario.

It is important to keep in mind that these reflect the accumulated impact over a span of fifty years of removing the government intervention risk. Contrast this to removing the government intervention risk for single year only. As a back-of-the-envelope calculation, the effect should only be 1/50 as large: the share of GDP spent on medical care would rise by about 0.06% of GDP in 2010 or about 9 billion US dollars. The same calculation for R&D shows that R&D would rise by about 2.6 billion US dollars in 2010, when removing the intervention risk for one year or when calculating the one-year effect of removing government intervention risk. Interestingly, Golec, Hegde, and Vernon (2010) argue that the Clinton Administration's Health Security Act of 1993 might have reduced R&D spending by about 1 billion US dollars, as a "conservative" estimate, "even though it never became law". Our R&D measure for the sector is more inclusive and about twice as large as theirs. Furthermore, they essentially examined the impact of an increased probability of some government intervention, whereas our number pertains to the full effect of overall government intervention. We therefore view our quantitative implications as broadly in line with their findings.

6.2.2. Second Counterfactual: No Government Risk Premium

As a second counterfactual, we consider the case in which the government risk is present ($\omega = 10\%$ or $\omega = 20\%$), but we set the price of government intervention risk to zero, $\underline{X} = \overline{X} = 1$. This case corresponds to the two middle (dash-dotted and dotted) lines in Figure 4. This case allows us to understand two effects that are in play in the first counterfactual separately. More precisely, if all government risk is removed, then $E_t[\pi_{t+1}]$ increases and the price of this cash flow, $E_t[M_{t+1}\pi_{t+1}]$, increases as well. We are particularly interested in the effect of risk premia on medical innovation and spending, and therefore want to hold constant the impact on expected profits, $E_t[\pi_{t+1}]$.

Based on Figure 4, we see that removing the risk premium alone accounts for three quar-

ters of the increase in the health care share and R&D share for $\omega = 10\%$ and is responsible for about half of it at $\omega = 20\%$. This compares well to the following back-of-the-envelope calculation. A per-decade intervention risk of 20% yields an annual intervention risk of about 2%. With an annual risk premium of 5%, about 3% of that must then be due to the risk premium against this intervention. We have argued above that $\omega = 20\%$ is an upper bound for a reasonable intervention probability. We conclude that the risk premium as compared to the actuarially fair disaster premium is the more important component for explaining the "missing R&D" compared to the no-intervention scenario, as well as the financial health premium for investors in that sector. Table 7 provides a numerical summary of our results.

6.3. Long-Run Implications

Absent government intervention, the long-run health care share implied by the model is ψ_∞, see equation (25), which equals 32% in the presence of subsidies. If subsidies in the output market are removed, that is, $\sigma = 0$, the share decreases to 25%. Note that the shares differ from $1 - \xi$, since the profits of the health sector are counted as part of GDP and thus, in this ratio. Figure 5 illustrates the evolution of the health care spending share and the R&D share as implied by the model, provided no government intervention takes place and comparing the benchmark with the three counterfactuals. Obviously, the convergence is rather slow and the health care share is expected to increase to 30% by 2050. This prediction is similar to the model of Hall and Jones (2007). While the limit for the health spending share without government intervention is independent of ω, given Q, this is not true for the $R\&D$ share: indeed, without government intervention risk, it converges to about 2.5% of GDP rather than 1.6% of GDP.

Once the government intervenes, R&D activity will come to a halt, if left to private markets. The R&D share drops to zero, the gross income share λ_t spent on medical care jumps, but then remains constant, as explained below equation (21).

6.4. R&D with Fixed Costs, Idiosyncratic Risk, and Heterogeneity

In our model, the only source of aggregate risk is the government intervention risk.[20] Furthermore, R&D success is a smooth, non-probabilistic function of R&D effort, and there is no heterogeneity across firms in equilibrium. While these are useful assumptions in the service of the simplicity of the model, it is useful to understand whether our results carry over to a more general specification, and under what conditions, as one may regard a richer set of possibilities here as important for understanding medical R&D and the competition in the health industry. The purpose of this section is to clarify how the results reported thus far can be generalized.

Consider qualities q_{jt} and prices p_{jt} for all firms $j \in [0,1]$. As usual in monopolistic competition models, define

$$(40) \qquad q_t = \left(\int_0^1 q_{jt}^{1/(\phi-1)} \, dj \right)^{\phi-1} , \quad p_t = \left(\int_0^1 p_{jt}^{1/(1-\phi)} \, dj \right)^{1-\phi} , \quad d_t = \int_0^1 d_{jt} \, dj$$

where we allow for stochastic variations across $j \in [0,1]$, including idiosyncratic risk: in that case, the integrals should be understood as Pettis integrals, see Uhlig (1996). The aggregate equilibrium dynamics in the model remains the same, if the dynamics of the aggregators q_t, p_t and d_t remain the same. This then is the property that needs verification, if additional features are added. Given the markup pricing, the dynamics for p_t is implied by the dynamics for q_t; hence, it remains to verify the dynamics for q_t and d_t.

Consider now some more general model specification, including idiosyncratic risk and firm heterogeneity. Assume first that entrepreneurs cross-insure each other. I.e., while each pursues the objective of profit maximization for the firm managed by that individual entrepreneur, share holdings in the health industry are diversified across entrepreneurs, idiosyncratic risk is washed out in their portfolio and the stochastic discount factor depends

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[20]As noted in section 6.1, we calibrate the non-intervention return to be 4 percent rather than the safe rate of 1 percent to account for the fact that there are other aggregate risks, which demand a risk premium in equilibrium and therefore lower medical R&D.

on aggregate risk only. Examine a generalized version of the firm maximization problem stated just before (26), allowing for a firm-specific starting quality $\tilde{q}_{jt}$ as well as a potentially random outcome for $q_{j,t+1}$,

$$(41) \qquad v(d_{jt}, \tilde{q}_{jt}) \;=\; \max_{d_{jt}} \left(E_t \left[\frac{M_{t+1}\pi_{t+1}}{q_{t+1}^{1/(\phi-1)}} \right] \right) E_t \left[q_{j,t+1}^{1/(\phi-1)} \right] - (1-\chi)d_{jt}$$
$$\text{s.t.} \quad q_{j,t+1} = f(d_{jt}, \tilde{q}_{jt}, \mu_{j,t+1})$$

for some random variable $\mu_{j,t+1}$, idiosyncratic and identically distributed across j and t, and some suitable function $f(\cdot, \cdot, \cdot)$. With this notation, we allow the starting point $\tilde{q}_{j,t+1}$ in $t+1$ to be different from $q_{j,t+1}$: for the aggregate dynamics, we then need to clarify the relationship between the two. We assume date-t-conditional independence of the random idiosyncratic outcome $\mu_{j,t+1}$ from the aggregate variables $M_{t+1}, \pi_{t+1}, q_{t+1}$. This independence between idiosyncratic and aggregate risk allows us to separate the expectations of the firm-individual piece and the aggregate piece above.

Suppose now, that

$$(42) \qquad\qquad E_t \left[q_{j,t+1}^{1/(\phi-1)} \right] = \left(\tilde{q}_{jt}^\nu + d_{jt}^\nu \right)^{1/((\phi-1)\nu)}$$

locally around the equilibrium choice $d_{jt} = D_t(\tilde{q}_{jt})$ of the model above, for any initial $\tilde{q}_{jt}$. Note that this property is satisfied in the absence of idiosyncratic risk, see equation (11), and therefore consistent with the baseline version of the model. With (42), the first-order condition for d_{jt} in (42) around that equilibrium choice remains unchanged. If it also characterizes the global maximum, then the choice for d_{jt} remains unchanged, given $\tilde{q}_{jt}$. This includes several interesting special cases.

One case, without idiosyncratic risk, is a non-binding fixed cost for R&D as an alternative to (11) for the specification of $f(\cdot, \cdot, \cdot)$. Say,

$$\tilde{q}_{j,t+1} = q_{j,t+1} = 1_{d_{jt} > 0.9 D_t(\tilde{q}_{jt})} \left(\tilde{q}_{jt}^\nu + d_{jt}^\nu \right)^{1/\nu}$$

where $1_{d_{jt}>0.9D_t(\tilde{q}_{jt})}$ indicates that the next-period quality $q_{j,t+1}$ will be zero, unless R&D efforts d_{jt} exceed the threshold of 90% of the equilibrium choice $D_t(\tilde{q}_{jt})$. Furthermore, given the same starting point $\tilde{q}_{j0} \equiv q_0$ at date 0 for all firms, a symmetric equilibrium $q_{jt} \equiv q_t, d_{jt} = d_t$ will persist. Obviously, the equilibrium dynamics changes with a threshold that binds in equilibrium or other initial conditions: our aim here is simply to show that there are versions of our model which include fixed costs and which nonetheless give rise to the same dynamics.

For the easiest cases involving idiosyncratic risk, assume an R&D externality to hold across all firms: while $q_{j,t+1} = f(d_{jt}, \tilde{q}_{jt}, \mu_{j,t+1})$ is the profit-relevant next-period quality for the date-t investing firm and thus relevant for the firm problem (41) stated above, assume that new firms j in date $t+1$ all start from the same quality level $\tilde{q}_{j,t+1}$, which is possibly different from $q_{j,t+1}$. More precisely, assume that all firms start from

$$(43) \qquad\qquad\qquad \tilde{q}_{jt} = q_t,$$

for every period t, where q_t is given by the quality average in (40). Assume that (42) holds and that the starting point q_0 here is the same as in the baseline model. By induction, we shall show that we obtain the same aggregate equilibrium as in the baseline model. Assume, that q_t here and given by (40) at some given date t coincides with q_t of the baseline model. With (43), the R&D efforts $d_{jt} = d_t$ are then the same across all firms and coincide with d_t of the baseline model. Comparing (11) to (42), it follows that $E_t\left[q_{j,t+1}^{1/(\phi-1)}\right]$ coincides with $q_{t+1}^{1/(\phi-1)}$ of the baseline model. Equation (40) then shows that

$$q_{t+1} = \left(E_t\left[q_{j,t+1}^{1/(\phi-1)}\right]\right)^{\phi-1}$$

here must coincide with q_{t+1} of the baseline model as well, completing the induction argument.

The easiest way to guarantee (42) is to perturb the R&D outcome (11) with an exogenous

and idiosyncratic factor $\mu_{j,t+1} \geq 0$,

$$(44) \qquad q_{j,t+1} = f(d_{jt}, \tilde{q}_{jt}, \mu_{j,t+1}) = \mu_{j,t+1} \left(\tilde{q}_{jt}^{\nu} + d_{jt}^{\nu} \right)^{1/\nu},$$

where

$$(45) \qquad 1 = E_t \left[\mu_{j,t+1}^{1/(\phi-1)} \right].$$

As a particular example, one might wish to assume that $\mu_{j,t+1} = \alpha^{\phi-1}$ with some probability $0 < \alpha < 1$ and $\mu_{j,t+1} = 0$ with probability $1 - \alpha$, idiosyncratic across j and t, capturing the idea that medical R&D succeeds only occasionally. With the assumption (43) of the R&D externality across all firms and thus $\tilde{q}_{jt} \equiv q_t$, $d_{jt} \equiv d_t$, one obtains the previously calculated equilibrium. It is straightforward to generalize this result to a richer set of specification, where the probability distribution of R&D or the probability of R&D success actually depends on R&D effort, without changing the resulting equilibrium. The key is to "split" the extensive or probabilistic dimension from the intensive or quality-level dimension in such a way that (45) continues to hold.

Matters become more involved, once one allows heterogeneity across firms and persistence in the R&D outcome, dispensing with the R&D-externality-across-all-firms assumption and replacing it with the assumption that

$$\tilde{q}_{j,t+1} = q_{j,t+1} = f(d_{jt}, q_{jt}, \mu_{j,t+1}).$$

The calculations and required functional choices for obtaining the same dynamics still remain reasonably tractable, if one assumes that $\phi = 2$. One can then rewrite (42) as

$$(46) \qquad E_t \left[\frac{q_{j,t+1}}{q_{jt}} \right] = \left(1 + \left(\frac{d_{jt}}{q_{jt}} \right)^{\nu} \right)^{1/\nu}.$$

As an example, assume the specification of a random multiplicative disturbance (44), imposing

$$1 = E[\mu_{jt}],$$

which coincides with (45) due to $\phi = 2$. One can now see that proportionality

$$\frac{d_{jt}}{q_{jt}} = \frac{d_t}{q_t}$$

satisfies (46) as well as (40) and thus provides the equilibrium with the same aggregate dynamics as before. Note that there is considerable and persistent heterogeneity across firms in this case.

Building on these insights, and at the cost of further algebra and unwieldy functional form specifications, it appears to be possible to combine the features of the cases above, allow for $\phi \neq 2$ and introduce correlated risks as well. This may be an interesting research project to pursue in order to study the dynamics of the industrial organization of the health industry or other industries, but is beyond the scope of this paper.

With the kinked-linear utility specification for the entrepreneur, it furthermore is not hard to calculate the dynamics of the model, if there is no portfolio diversification and insurance across entrepreneurs. In that case, the risk premium arises due to both idiosyncratic risks as well as aggregate risks, and one needs additional analysis to disentangle the two. We find this to be a less attractive specification for the model, though, since it seems a priori more plausible that investors hold a somewhat diversified portfolio and will be particularly enticed to do so if risk premia are due entirely or to a large extent to idiosyncratic risk. We do not find it plausible that such a risk premium could persist over the long span of time, as we have observed in the health industry.

7. Mechanisms for Health Care Risk Premia

7.1. Broad Intuition for Alternative Mechanisms

In this section, we discuss qualitatively and in an exploratory fashion various economic mechanisms that may give rise to the medical innovation premium. This boils down to understanding how certain shocks, in general equilibrium, co-move with the investors' marginal utility. This section uses a broad theory brush, focusing on the key economic arguments and without providing a comprehensive list of assumptions and caveats. We first provide a broader overview, and then examine some approaches in somewhat more careful detail.

The key finding from the empirical results is the medical innovation premium, which implies that $\partial U/\partial c_{t+1}$ is low when health industry profits π_{t+1} are high. *Ceteris paribus*, marginal utility is low if consumption is high.

To analyze other factors that may yield the medical innovation premium, consider a representative household that demands medical care m, resulting in health $h = m$. Medical care can be provided with productivity (or "quality", "inverse of marginal costs") q, and sold at price p, while subsidized at rate σ. The subsidies are financed per lump-sum taxes τ on the household. Assume a linear production function and denote the markup with ϕ. Profits of the medical sector are π. Aggregate income is y, while aggregate consumption is c. Preferences by the household are given by a utility function $u(c, h)$.

For a linear production function, the relationship between prices, marginal costs, markups and profits are:

$$(47) \qquad p = \frac{\phi}{q} \ \text{ and } \ \pi = (\phi - 1)\frac{h}{q}.$$

The household budget constraint is:

$$(48) \qquad y + \pi = c + (1 - \sigma)ph + \tau.$$

The government budget constraint is:

$$\sigma p h = \tau. \tag{49}$$

Together, we obtain the following two key equations:

$$c \;=\; y - h/q = y - \pi/(\phi - 1), \tag{50}$$

$$\pi \;=\; (\phi - 1)h/q. \tag{51}$$

These equations imply that approaches that treat y, ϕ, q as parameters or constants are challenging to pursue. Consider the following sources of uncertainty:

1. Medical progress, including longevity: If q increases, so will h. See section 7.2 for further details.

2. Preference shocks for h, with c and h separable or complements in the utility function $u(\cdot, \cdot)$.

3. A shock to the subsidies σ.

The challenge is the following. Suppose that these shocks result in surprise increases in profits π. They will then lead to lower consumption. Conversely, lower profits go together with higher consumption. In the cases above, this should yield a negative, not a positive alpha.

Approaches which treat all of π, h, c, y, ϕ, q as endogenous have more potential to be successful. Consider the following sources of uncertainty:

1. Medical progress and productivity. Suppose a surprise increase in q leads to a more productive workforce, thereby increasing y. It is then possible, in principle, to have both π and c increase.

2. A preference shock for h, where c and h are (strong) substitutes in the utility function $u(\cdot, \cdot)$. Suppose that h is increased and thus profits π increase, while consumption c decreases. In principle, it is nonetheless possible that the marginal utility of consumption decreases as well.

3. Government regulatory risk regarding ϕ: if ϕ declines unexpectedly, then so will π and c, while h increases.

These approaches face challenges on their own. The first one may not be sufficient quantitatively: while medical progress has perhaps led to somewhat longer working life and to fewer absentee hours due to sickness in the US after the Second World War, these effects may be too small to sensibly generate the medical innovation premium that we estimate in our empirical work. The second approach may not be plausible. Per own introspection, it does seem to us that consumption, and marginal increases thereof, are more fun and not less fun, if one is healthy.[21] We therefore chose the third approach as the key approach in this paper. The arguments above are painted with a broad brush: it is entirely conceivable, even plausible, that reasonable exceptions can be found that allow the pursuit of other alternatives. For some of them, more detail is useful to reveal where the challenges lie exactly. We shall do so in particular for longevity risk.

7.2. Risk Premia Due to Longevity Effects

Longevity is the key to understanding the growth of health expenditures in the model of Hall and Jones (2007). Our paper is not in contrast to theirs; rather, it is complementary. While longevity may indeed be key (and indeed, our long-run improvements in health may well be interpreted as increases in longevity), we argue here that they are unlikely to be the risk factor giving rise to the medical innovation premium.

Consider a three-period extension of the model above, $t = 0, 1, 2$, where the household

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[21]This is also with the empirical results in Viscusi and Evans (1990), Finkelstein, Luttmer, and Notowidigdo (2008), and Koijen, Van Nieuwerburgh, and Yogo (2011).

surely survives until $t = 1$. The probability of survival from $t = 1$ to $t = 2$ depends on health, $f(h_1)$, where $f'(h_1) > 0$. The household's problem can then be summarized by:

$$(52) \qquad \max_{(h_1)} u(c_0) + \beta E_0 [u(c_1)] + \beta^2 E_0 [f(h_1) u(c_2)],$$

where the maximization is subject to the resource constraints, $y_t + \pi_t = p_t h_t + c_t$, the prices of medical care, $p_t = \phi_t/q_t$, and firm profits, $\pi_t = h_t (\phi_t - 1)/q_t$.[22] Unless noted otherwise, we focus on shocks to q_t that lower the marginal cost of producing medical care.

Optimal period-1 health follows from $\max_{(h_1)} u(c_1) + f(h_1) b$, where $b = \beta E_1 [u(c_2)] > 0$ a constant. In this case, we have $c_1 = y_1 - h_1 q_1^{-1} = y_1 - (\phi_1 - 1)^{-1} \pi_1$, which implies that consumption and profits are negatively correlated. Since $M_1 = \beta u'(c_1)/u'(c_0) = \beta u'(y_1 - (\phi_1 - 1)^{-1} \pi_1)/u'(c_0)$, profits and the stochastic discount factor are positively correlated. This implies a negative risk premium for health care firms. This holds true regardless of the survival function $f(h_1)$ and as long as $u'(c) < 0$.

8. Conclusion

Despite the fact that improvements in health care and health have been major components of the overall gain in economic welfare during the last century, the continued financial incentives for medical innovation and the resulting growth of the health care sector are not well-understood. Although it is generally believed that medical innovation and its demand are central components of the expansion of this sector, little is known about what risks affect the returns of R&D investments and how those risks, in turn, affect future spending growth.

We provided an empirical and theoretical analysis of the link between financial and real health care markets. We first documented a "medical innovation premium" for the returns of medical R&D firms in the United States during the period from 1960 to 2010 and provided suggestive evidence of government intervention risk as a determinant of this premium. The

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[22]Relative to our full model, we consider a simpler production for health with $\underline{h} = 0$ and $\nu = 1$, which implies that medical spending maps one-to-one to health, $m_t = h_t$.

excess returns relative to standard risk adjustments were estimated to be 4-6% per annum, which is large and about the same size as other asset pricing puzzles, such as the equity risk premium and the value premium during this period. Motivated by this finding, we provided a theoretical analysis of the joint determination of financial and real health care markets. We interpreted the medical innovation premium to result from government markup risks that might require investors to demand higher returns on medical R&D investments beyond standard risk-adjusted returns.

We simulated the quantitative implications of the medical innovation premium on health care spending and on expenditures on medical R&D. We found that there would have been a sizeable expansion of the health care sector by 3% of GDP as well as more than a doubling of R&D efforts, in the absence of government risk, holding back innovation. The difference is due to an actuarially fair disaster premium as well as a risk premium against that disaster. We found that the risk premium is the larger component.

Our analysis raises many future questions that need to be addressed to more fully understand the growth of health care sectors around the world. First, if government uncertainty discourages health care R&D, then how are standard analyses of government interventions taking into account of this effect? For example, most governments across the world attempt to stimulate medical R&D through various push-and-pull mechanisms. But if the government uncertainty attached to such mechanisms discourages R&D, how much does this uncertainty reduce the intended effects of such R&D stimuli? Second, discounting future public health care liabilities by U.S. Treasury rates, as is done for future Medicare liabilities by the CBO, rather than how markets discount health care spending, seems inappropriate in light of the medical innovation premium documented in this paper.[23] Third, many policy proposals to slow spending growth in health care need to incorporate the government risk and its effect on medical R&D. For example, the 2010 report of the National Commission on Fiscal Responsibility and Reform suggests imposing restrictions on publicly-financed health care

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[23]See Geanakoplos and Zeldes (2011) and Lucas (2010) for recent work on the valuation of government liabilities.

spending tied to GDP growth. Our framework and analysis can be used to consider imposing government restrictions on health care spending and to quantify their effects, including the growth effects introduced by policy uncertainty of implementing the restrictions themselves.

More generally, we believe future analyses need to better incorporate the interaction between financial markets that affect R&D investments, government risk, and the resulting growth of the health care sector. The growth of the health care sector depends on medical R&D, which is affected by government risk, which in turn means that greater uncertainty introduced by government intervention discourages medical R&D. This important feedback mechanism implies that any future growth of government programs, such as for instance Medicare, is tied to the risk of policies surrounding those programs. Overall, we believe that further explicit analyses of the dynamic incentives for continued medical progress are warranted given the dramatic effects such progress has on overall health care spending and health.

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	Consumer goods	Manufacturing	HiTec	Health	Other	Medical equipment	Drugs
CAPM	1.81	1.66	-0.83	3.31	0.22	3.71	3.70
T-statistic	1.40	1.54	-0.54	1.61	0.17	1.40	1.78
Fama and French	-0.13	1.04	1.67	5.01	-2.66	6.44	5.37
T-statistic	-0.09	0.84	0.86	2.44	-2.75	2.05	2.63
No. of observations	52	52	52	52	52	52	52

Panel B: Industry alphas relative to models extended with the health care factor

	Medical equipment	Drugs
CAPM + HC factor	0.22	0.31
T-statistic	0.14	0.71
FF+ HC factor	0.81	0.37
T-statistic	0.47	0.70
No. of observations	52	52

Table 1: Industry alphas

The table reports in Panel A the alphas relative to the CAPM and the 3-factor Fama and French model for different industries. The sample is from 1961 - 2012 and returns are annual. The first five industries add up to the market. The last two columns report the alphas of two sub-sectors of the health care sector: medical equipment and drugs. In Panel B, we add the health care sector (Column 4) to either the CAPM or the Fama and French model and report the alphas of both sub-sectors of the health care sector.

Dictionary to identify government risk

Congress	Government regulation(s)	Political risk(s)
Congressional	Government approval	Politics
Debt ceiling	Government debt(s)	Price constraint(s)
Federal	Government deficit(s)	Price control(s)
Federal funds	Government intervention(s)	Price restriction(s)
Fiscal imbalance(s)	Law(s)	Regulation(s)
Government(s)	Legal	Regulatory
Government-approved	Legislation	Regulatory compliance
Government-sponsored	Legislative	Regulatory delay(s)
Governmental	Legislatory	Reimbursement(s)
Governmental program(s)	Patent law(s)	Subsidy
Government program(s)	Political	Subsidies
Governmental regulation(s)	Political reform(s)	

Table 2: Dictionary for 10-K filings

The table reports the dictionary that we use to identify how frequently firms highlight risk factors that are associated with government risk.

Panel A: Main dictionary without health care-specific terms

2006		Average word count	Average fraction of words
	Health care sector	76.36	1.46%
	Non-health care sector	35.46	0.93%
2012			
	Health care sector	130.06	1.55%
	Non-health care sector	77.12	1.24%

Panel B: Dictionary including health care-specific terms

2006		Average word count	Average fraction of words
	Health care sector	100.08	1.92%
	Non-health care sector	36.18	0.94%
2012			
	Health care sector	165.56	1.97%
	Non-health care sector	79.72	1.29%

Table 3: Average word count to measure government risk from 10-K filings

Panel A of the table reports the average number of words in a firm's 10-K filing appears in the dictionary in Table 2. The average is taken across the 50 largest firms in the health care sector and the 50 largest firms in the non-health care sector. The first column reports the average word count, while the second column measures the average fractions of words (that is, word count scaled by the length of the document). Panel B reports the results if we expand the dictionary to include government-related words that are specific to the health-care sector. We report the results for 2006 and 2012.

Event date	Description of event
January 19, 1992	Clinton issues health care reform proposals before New Hampshire primary
February 18, 1992	Clinton unexpectedly finishes second in the New Hampshire primary
March 10, 1992	Clinton does well in the Super Tuesday primaries
April 7, 1992	Clinton wins New York primary and becomes the favorite to win the Democratic nomination
June 4, 1992	Republicans in the House of Representatives offer their health care reform proposal
September 24, 1992	Clinton speaks at Merck on health care reform
November 3, 1992	Clinton wins presidential election
January 25, 1993	Clinton names Hillary Clinton to head his Health Care Task Force
February 12, 1993	Clinton says drug prices are too high
September 11, 1993	New York Times describes probable regulations based upon a leaked copy of the plan
September 22, 1993	Clinton officially announces his health care reform plan

Table 4: Key event dates around Clinton's health care reforms

The table summarizes the key event dates and a description of the event during Clinton's health care reforms. The table is reproduced from Golec, Hegde, and Vernon (2010).

Intercept	-6.5%
t-statistics	-1.15
Slope coefficient	-12.2%
t-statistic	-3.63
R-squared	13.9%
Number of firms	119
Average number of years used to estimate health care betas	21.1

Table 5: Cross-sectional regression of cumulative abnormal returns on health care betas

The table reports the results of a cross-sectional regression of the cumulative abnormal return of a firm during the Clinton health care reform on the beta of a given firm on the health care factor in (4). The beta is standardized by the cross-sectional standard deviation of the beta. The sample end in December 2012.

Parameter	Description	
γ		1.35
ϕ	Markup	3
ζ	Constrained markup	1
χ	R&D subsidy	50%
σ	Medical care subsidy	50%
R	10-yr benchmark return	1.48
Q	10-yr return on health R&D, if no interv.	2.37
θ	labor share	0.8
q_0	Initial level of medical knowledge	7.8
ν	Curvature R&D production function	0.42
$\underline{h}$	Health endowment	3.2
ξ	Weight non-health consumption in U	0.54
$\underline{X}$	Price of government risk, if $\omega = 10\%$:	0.69
$\underline{X}$	Price of government risk, if $\omega = 20\%$:	0.78

Table 6: Model parameters

The table summarizes the calibrated model parameters for two levels of government intervention risk (ω) and full elimination of profits upon intervention, $\zeta = 1$. The parameters below the line are solved for by matching four observations regarding the health-spending-to-GDP share and the health-R&D-share-to-GDP share. Note that the parameters are identical across ω, except for $\underline{X}$: given the no-intervention returns R and Q as well as zero profits upon intervention, the dynamics during the non-intervention episode must be the same, see equation (37).

	Benchmark Benchmark	No government risk premium, $\omega = 20\%$	No government risk premium, $\omega = 10\%$	No government risk
Health share				
1960	5.1%	5.1%	5.1%	5.1%
1970	6.8%	7.1%	7.3%	7.5%
1980	8.9%	9.7%	10.2%	10.6%
1990	11.6%	12.9%	13.6%	14.2%
2000	14.7%	16.3%	17.1%	17.9%
2010	17.9%	19.6%	20.5%	21.2%
R&D share				
1960	0.1%	0.1%	0.1%	0.1%
1970	0.1%	0.2%	0.2%	0.3%
1980	0.2%	0.3%	0.4%	0.6%
1990	0.3%	0.6%	0.7%	0.9%
2000	0.5%	0.8%	1.0%	1.3%
2010	0.7%	1.1%	1.4%	1.6%

Table 7: Health and R&D share dynamics for both counterfactuals and different levels of government risk.

The table illustrates the impact of government risk and the medical innovation premium on health care and R&D spending. The first column provides the benchmark results, the second column removes government risk altogether, while the third column considers the counterfactual in which there is government risk, but this risk is not priced in equilibrium.
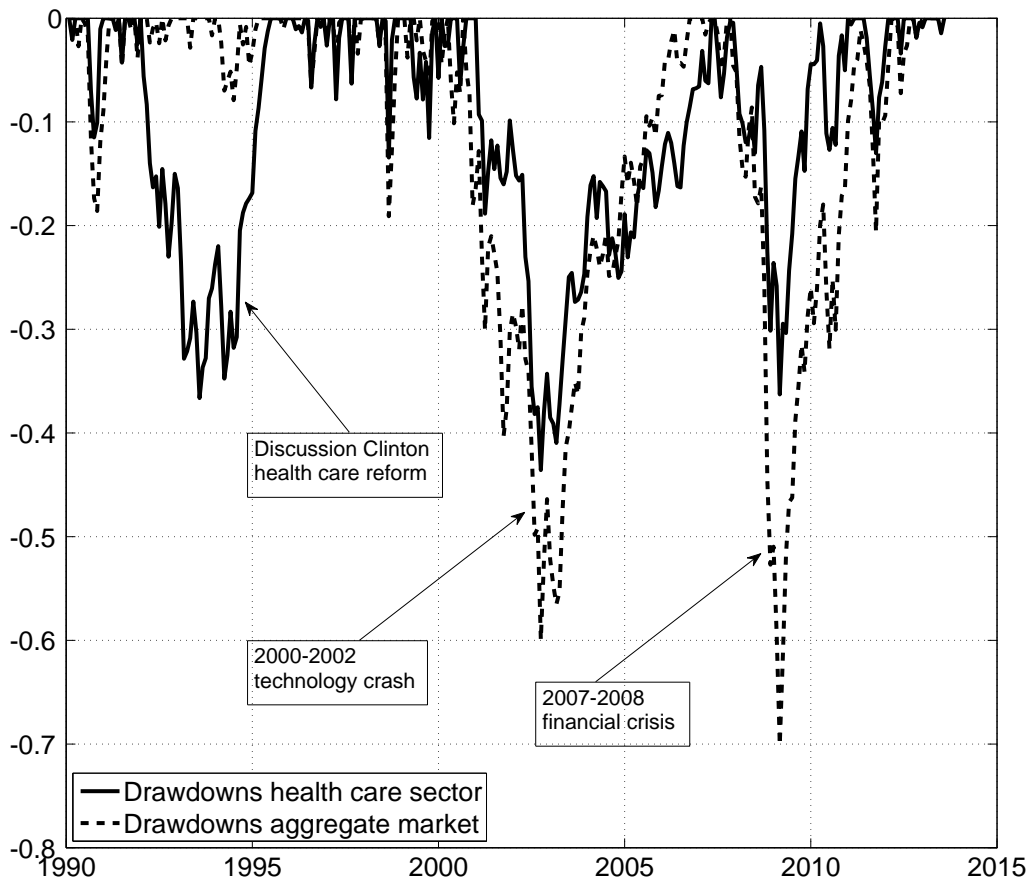
Figure 1: Drawdown dynamics for the health care sector and the aggregate stock market.

The figure reports the drawdown dynamics of the health care sector and the overall stock market from 1990 until 2013. Drawdowns are defined in (2).
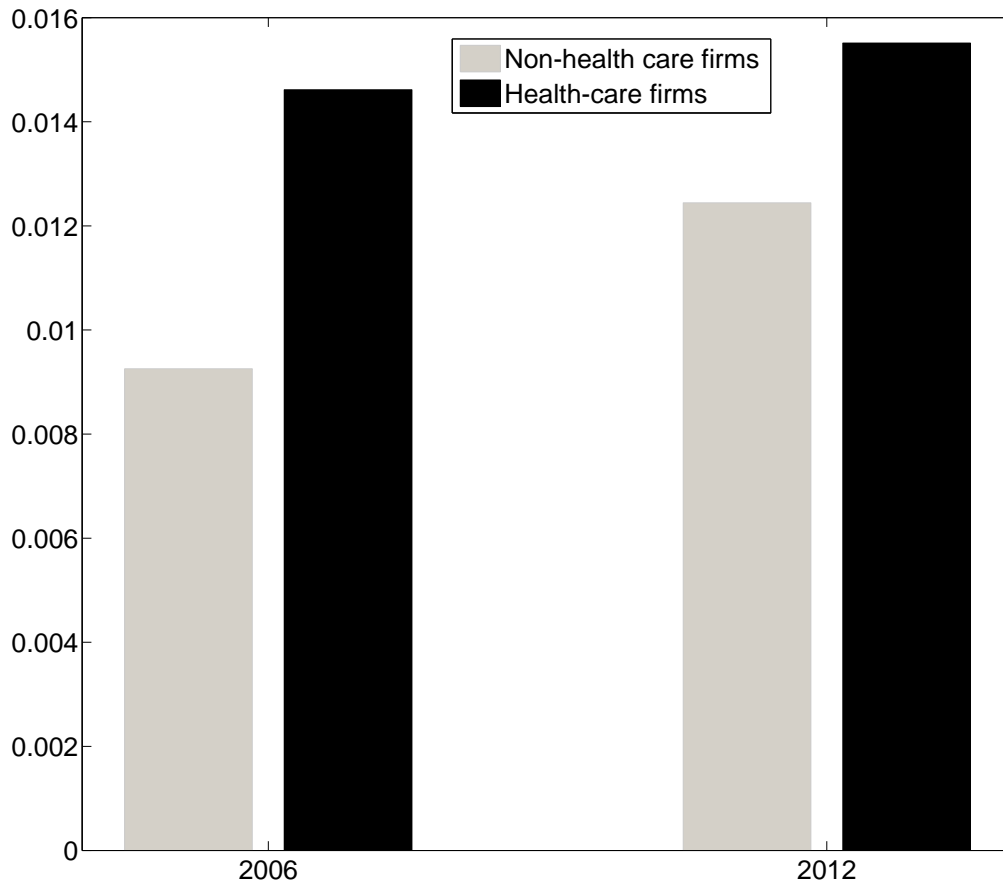
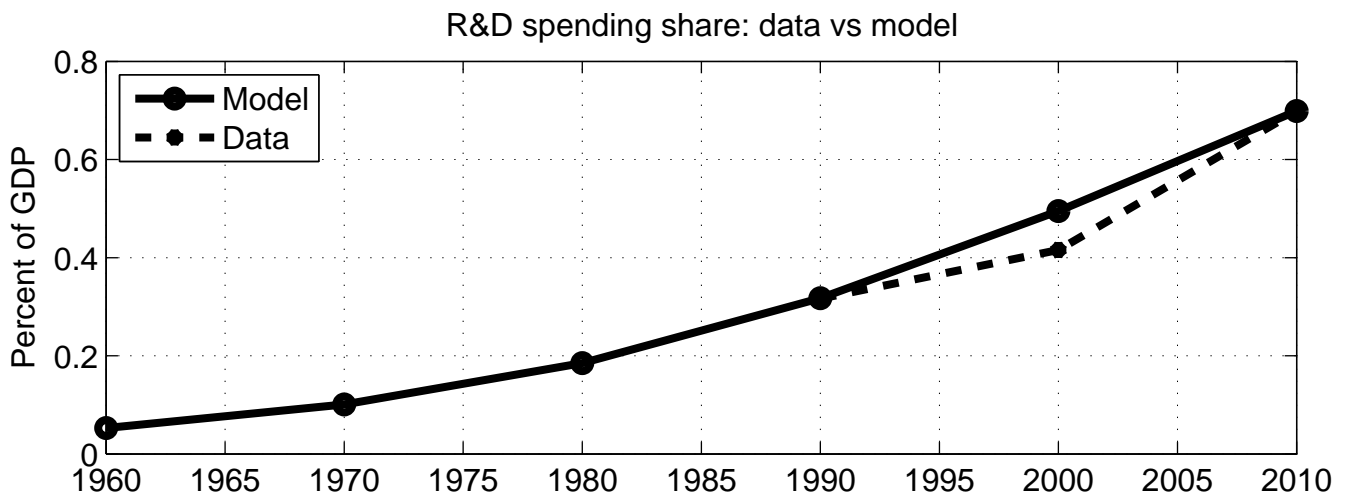Figure 2: Fraction of government-related words in 10-K filings in 2006 and 2012.
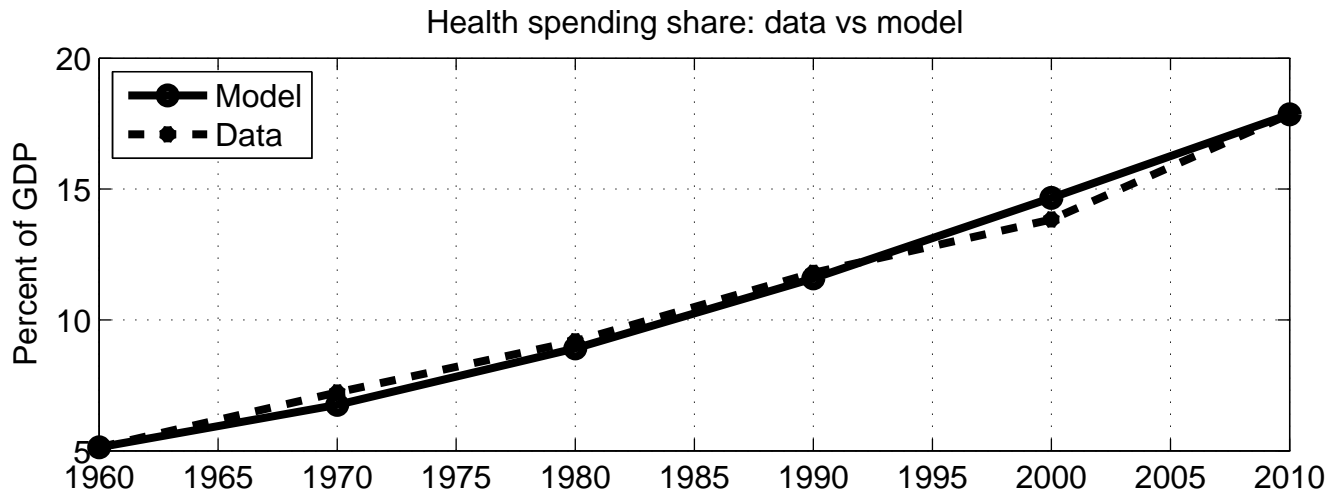
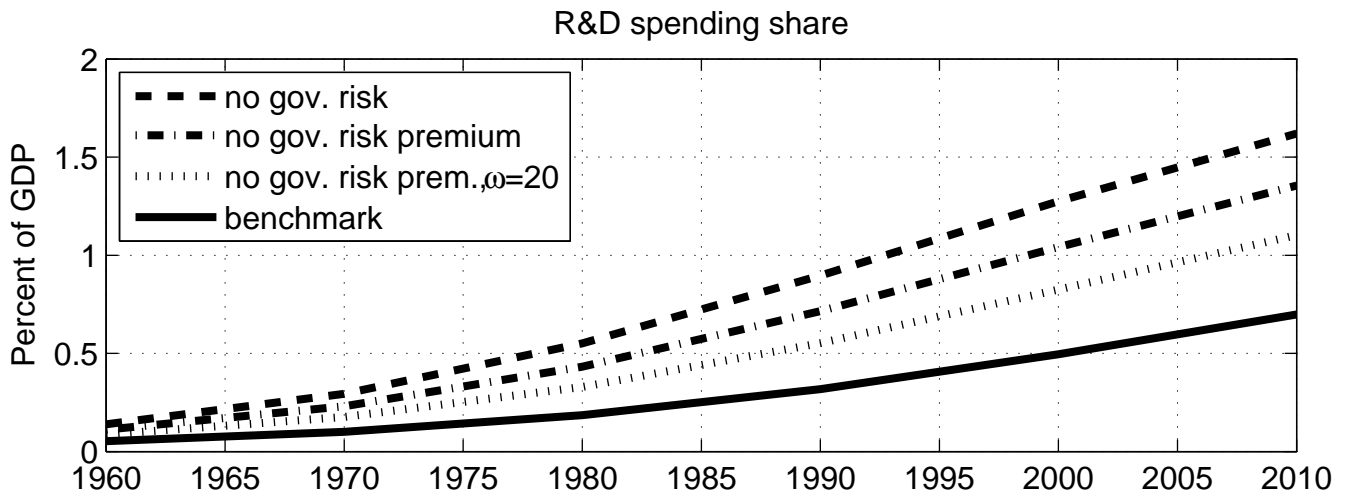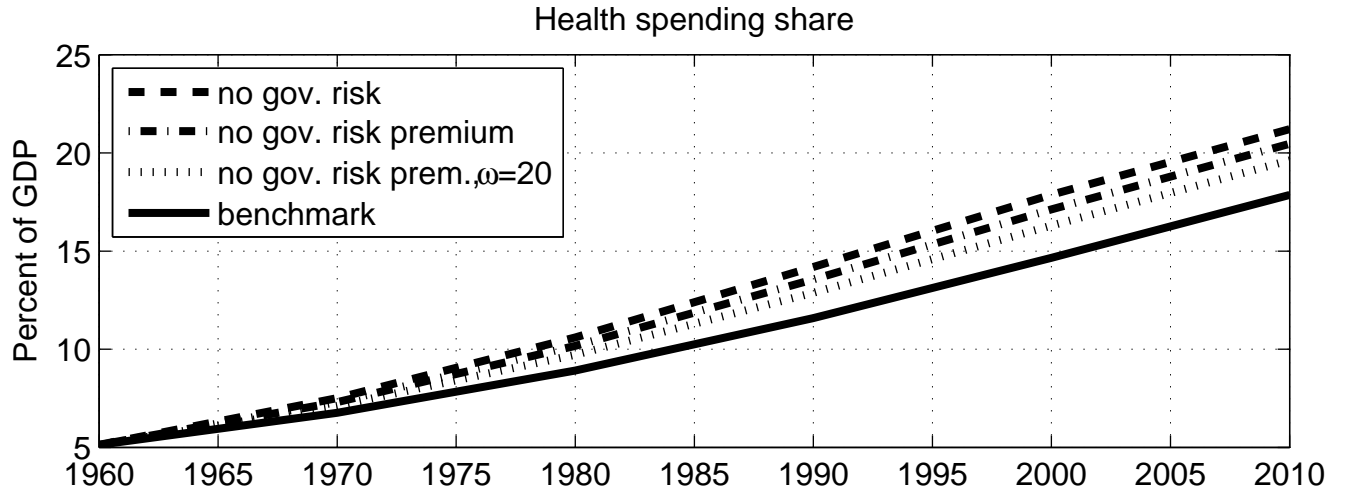Figure 3: Health and R&D share in the model and in the data

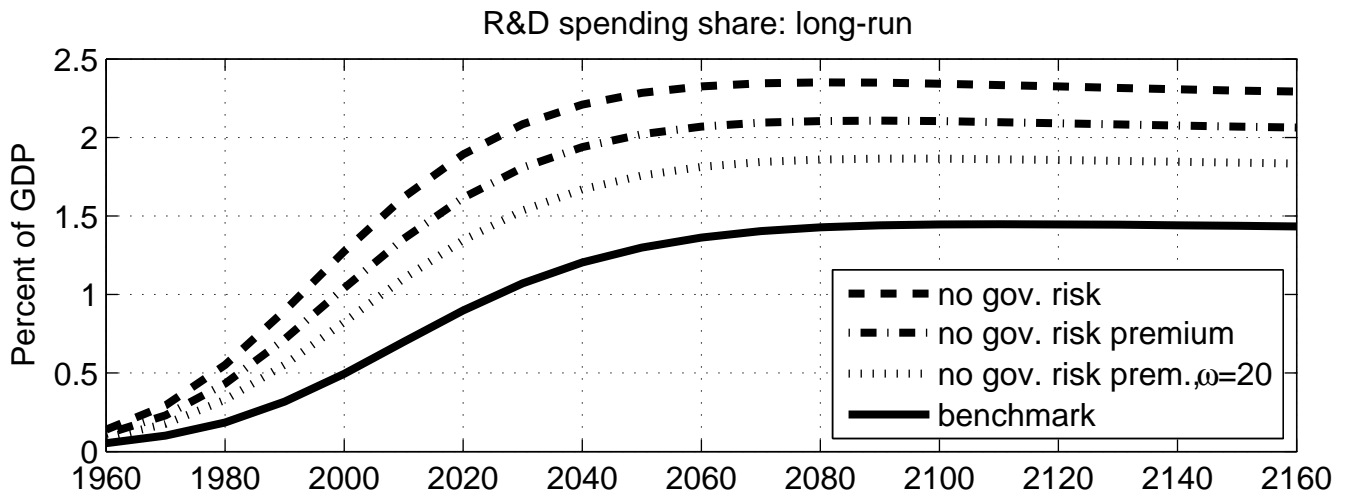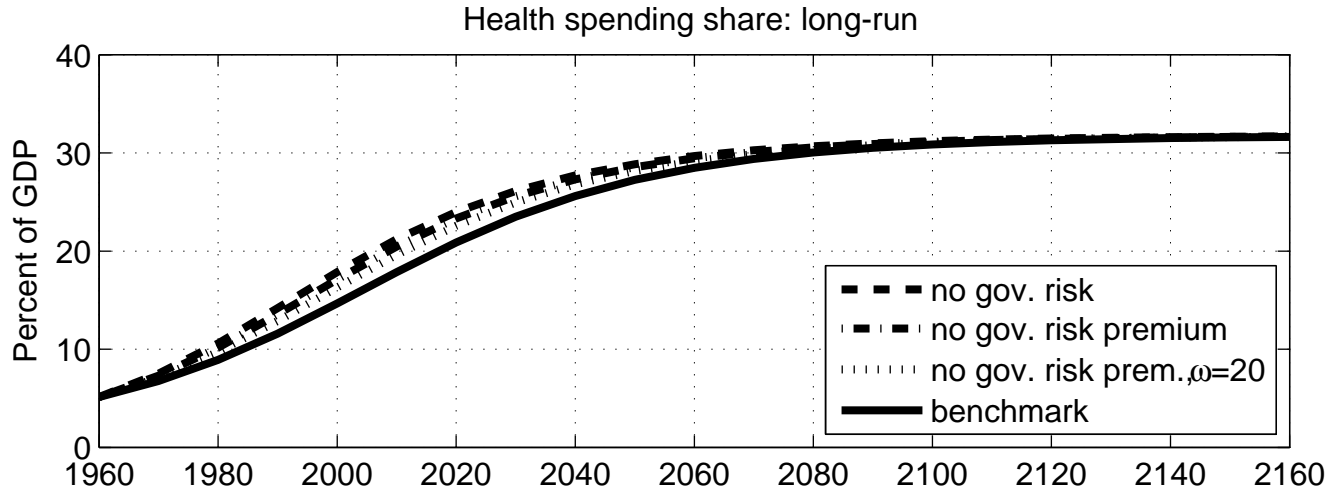Figure 4: Counterfactual dynamics of health care and R&D spending.

Figure 5: Model-implied long-run dynamics of the health and R&D share

Online Appendix: Not For Publication

Given the numerical solution to the model, it may be instructive to "reverse-engineer" the preferences, i.e., to find a value function $V(\{c_{e,t}\}_t)$ in terms of the stochastic stream of entrepreneurial consumptions so that the assumed stochastic discount factors result from the appropriate first-order conditions. It should be clear that there is considerable freedom in doing so.

Consider again the decomposition of the stochastic discount factor (32) as $M_{t+1} = R^{-1}X_{t+1}$, where X_{t+1} is the stochastic component reflecting government intervention risk, with $E[X_{t+1}] = 1$, see (35). Suppose now, that the preferences of the entrepreneur are time separable,

$$V(\{c_{e,t}\}_t) = E\left[\sum_{t=0}^{\infty} \tilde{\beta}^t u(c_{e,t})\right]$$

The consumption of the entrepreneur $c_{e,t}$ in the absence of government intervention are proportional to profits minus outlays for R&D, as stated in equation (11) of the paper. The consumption of the entrepreneur with government intervention could either be read as zero, or, in a slight extension of the model, assumed to be some fraction $0 \leq \xi_t < 1$ of the non-intervention consumption $c_{e,t}$ at the time of the intervention.

The standard relationships between preferences and stochastic discount factors deliver

$$(53) \qquad R^{-1}\underline{X} = \tilde{\beta}\frac{u'(c_{e,t+1})}{u'(c_{e,t})}$$

$$(54) \qquad R^{-1}\overline{X} = \tilde{\beta}\frac{u'(\xi_t c_{e,t+1})}{u'(c_{e,t})}$$

From the numerical calculation done for $t = 1, \ldots, 6$, one finds that entrepreneurial consumption is growing over time, though not exactly at a constant rate.

The easiest solution to the equations (53) above is to assume that the utility function is piecewise linear, with a concave kink at some positive level of consumption below $c_{e,1}$ and with imposing that ξ_t takes post-intervention consumption to a level below $c_{e,1}$: $\xi_t = 0$ will be one possibility that does the trick. This is the assumption we have used in the main text, see (7). With the piecewise linear utility function, one needs to solve for β per

$$(55) \qquad R^{-1}\underline{X} = \tilde{\beta}$$

and find the slope below the kink (at $c = 0$, say) relative to the slope above the kink (at $c_{e,t}$,

say) per

$$\frac{\overline{X}}{\underline{X}} = \frac{u'(0)}{u'(c_{e,t})}$$

Such preferences are a simple version of loss-aversion preferences that have been proposed for a variety of phenomena, including asset pricing, see Kahneman and Tversky (1979).

If $\tilde{\beta}$ does not satisfy (55), but instead is some other value between that value and, say, $\beta = 1$, one can solve the integration problem as follows. For a given value of $\tilde{\beta}$ strictly in this range and with some normalization for $u'(c_{e,1}) > 0$, calculate recursively

$$u'(c_{e,t+1}) = \frac{\overline{X}}{\tilde{\beta}R}u'(c_{e,t})$$

Note that $0 < u'(c_{e,t+1}) < u'(c_{e,t})$. Find a continuous decreasing non-negative function $u'(c_e)$ connecting these points: this is feasible, since $c_{e,t}$ is an increasing sequence. Integrate to find the utility function $u(c_e)$.

While there are many solutions, it may be instructive to see whether one can bound this exercise, using the CRRA specification. While the CRRA specification will not work exactly, one can calculate $\bar{\eta}$ as the minimal η so that

(56) $$R^{-1}\underline{X} \;\geq\; \tilde{\beta}\left(\frac{c_{e,t+1}}{c_{e,t}}\right)^{-\eta}, \text{ for all } t = 1,\ldots,6$$

and $\underline{\eta}$ as the maximal η, so that

(57) $$R^{-1}\underline{X} \;\leq\; \tilde{\beta}\left(\frac{c_{e,t+1}}{c_{e,t}}\right)^{-\eta}, \text{ for all } t = 1,\ldots,6$$

Imposing CRRA preferences with these η, one can furthermore ask, what consumption reduction fraction ξ_t will be necessary in order to reach the marginal utilities required for the intervention case. The results are in table 8. It turns out that the $\eta-$bounds are fairly close to each other, indicating that CRRA is a pretty good fit even for $\tilde{\beta}$-values different from that in equation (55), for any of the values of β. Furthermore, the values for η are within the entirely reasonable range of $[0, 2]$.

The consumption reduction fraction are arbitrary for $\eta = 0$, and otherwise range from 0.04 to 0.33. A slightly different utility specification uses a (close-to-) CRRA utility function above these consumption levels, and linear below, splicing it together smoothly at that point: then, one may use any post-intervention consumption level below that consumption reduction level. In that case, one needs a different felicity function for every period.

71

$\tilde{\beta}$ (p.a.):	0.92	0.94	0.97	0.98	1.00
$\bar{\eta}$:	0.0	0.6	1.1	1.5	1.8
cons.reduct.fract.:	arb.	0.04	0.16	0.26	0.33
$\underline{\eta}$:	0.0	0.5	1.0	1.3	1.6
cons.reduct.fract.:	arb.	0.03	0.13	0.22	0.29

Table 8: Calculating η-bounds and the corresponding consumption reduction fraction, as a function of β.

It should finally be noted that one needs

$$R^{-1} = \tilde{\beta}\frac{u'(\tilde{c}_{e,t+1})}{u'(\tilde{c}_{e,t})}$$

for the post-intervention consumption levels $\tilde{c}_{e,t}$. This will automatically be satisfied for $\tilde{c}_{e,t} \equiv 0$ and the kinked utility specification detailed above. For the CRRA specification, one will need a constant growth rate of $\tilde{c}_{e,t}$. Since the required preferences are not exactly CRRA, one needs slightly uneven growth for $\tilde{c}_{e,t}$ in order to compensate.

B. Robustness of the Medical Innovation Premium

In the main text, we document the medical innovation premium for annual returns for our main sample from 1961 - 2012 using both the CAPM and the 3-factor Fama and French model.

For robustness, we estimate the model both at a monthly frequency and an annual frequency. If we estimate the model at a monthly frequency, we multiply the alphas by 12 to annualize them. We also consider three different sample periods: 1927.1-2013.7, 1946.1-2013.7, and 1961.1-2013.7. The first sample period is the longest sample available. The second sample focuses on the post-war period. The third sample coincides with the period for which we have data on aggregate health care spending. The returns on services start only in the late sixties, and we therefore exclude them from the table. However, their returns are well explained by standard models and the alphas are close to zero.

The annual results are in Panel A and the monthly results in Panel B of Table 9. The first number corresponds to the alpha; the second number is the t-statistic using OLS standard errors. We find that the health care industry tends to produce economically and statistically significant alphas betwen 3-5% per annum, depending on the benchmark model and the sample period. If we remove health services and focus on pharmaceutical products and medical equipment, the alphas are even higher at 4-7% per annum. This is because the alphas on medical services are close to zero.

We also report the alphas on the other industries, which do not have large alphas relative to the standard models. We typically find that the results are somewhat stronger using the Fama-French model. We conclude that there is a risk premium for holding health care stocks that cannot be explained by standard asset pricing factors.

Panel A: Annual returns

1927-2012	Consumer goods	Manufacturing	HiTec	Health	Other	Medical equipment	Drugs
CAPM	1.25	1.12	0.68	3.98	-0.96	4.33	4.35
	1.22	1.49	0.57	2.35	-1.01	2.11	2.48
Fama and French	0.78	0.53	2.11	5.56	-2.60	5.80	5.96
	0.74	0.74	1.73	3.37	-3.54	2.83	3.42

1946-2012	Consumer goods	Manufacturing	HiTec	Health	Other	Medical equipment	Drugs
CAPM	1.19	1.66	-0.29	4.29	-0.86	4.07	4.68
	1.07	1.81	-0.21	2.10	-0.77	1.70	2.25
Fama and French	-0.06	0.92	1.91	5.72	-3.10	6.27	6.06
	-0.05	0.96	1.25	2.77	-3.82	2.36	2.87

1961-2012	Consumer goods	Manufacturing	HiTec	Health	Other	Medical equipment	Drugs
CAPM	1.81	1.66	-0.83	3.31	0.22	3.71	3.70
	1.40	1.54	-0.54	1.61	0.17	1.40	1.78
Fama and French	-0.13	1.04	1.67	5.01	-2.66	6.44	5.37
	-0.09	0.84	0.86	2.44	-2.75	2.05	2.63

Panel B: Monthly returns

1927.1-2013.7	Consumer goods	Manufacturing	HiTec	Health	Other	Medical equipment	Drugs
CAPM	1.46	0.74	0.46	3.07	-1.24	3.27	3.47
	2.12	1.24	0.52	2.43	-1.50	2.03	2.54
Fama and French	1.45	0.26	1.60	3.89	-2.72	3.53	4.34
	2.12	0.48	2.06	3.16	-3.91	2.22	3.27

1946.1-2013.7	Consumer goods	Manufacturing	HiTec	Health	Other	Medical equipment	Drugs
CAPM	1.25	1.34	-0.59	3.18	-0.92	2.85	3.67
	1.61	1.91	-0.58	2.40	-1.12	1.71	2.54
Fama and French	0.58	0.25	1.57	4.85	-3.02	3.81	5.50
	0.75	0.39	1.75	3.78	-4.13	2.25	3.98

1961.1-2013.7	Consumer goods	Manufacturing	HiTec	Health	Other	Medical equipment	Drugs
CAPM	1.76	1.33	-1.01	2.64	-0.10	2.82	3.11
	1.92	1.55	-0.84	1.76	-0.10	1.65	1.89
Fama and French	0.79	0.17	1.24	4.78	-2.46	4.10	5.54
	0.85	0.21	1.14	3.29	-2.82	2.33	3.52

Table 9: Industry alphas