Honors Elements of Economic Analysis II

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Potential US Market Shares of mRNA Vaccine Producers

Introduction

In the following report, we analyze what the potential market share as a percentage of total production of three current producers of mRNA vaccines, Pfizer, Moderna, and CureVac, would be if these firms sold directly to consumers rather than to the US Government. We assume that the firms are price-takers rather than price-setters as the firms do not currently sell vaccines at prices equal to what research shows their marginal costs to be. Thus, the model we create is in the style of the Cournot Model, with a price function that takes supply as an input: $P(Q) = \alpha - \beta Q$. The constants in this model are derived from real-world data, including the price that the US Government paid per mRNA vaccine prior to March 1st, 2021, the number of vaccinated adults in the US as of October 2021, and the total number of adults in the US as of October 2021. We then create cost functions of the form $C_i(q_i) = c_i q_i + C$, where c_i is the marginal cost of each firm, derived from real-world data taken from Public Citizen, and C is the sunk cost of R&D for an mRNA vaccine, a value also derived from real-world data taken from the Congressional Research Service. Using our price and cost functions, we solve the Cournot-Nash Equilibrium for the case of two firms, Pfizer and Moderna, to model what the current market might look like if vaccines were sold directly to consumers. We then solve the Cournot-Nash Equilibrium for the case of three firms, Pfizer, Moderna, and CureVac, to model what a future market might look like if CureVac's vaccine candidate clears clinical trials and if these vaccines were sold directly to consumers. Lastly, we examine the price per vaccine in both cases, the profits of the firms in both cases, whether there is enough space in the market for CureVac and other competitors, and the percentage of the population that gets vaccinated in both cases. Lastly, we note that we do make several assumptions with this model. We assume that the firms are price-takers, not price-setters, and that firms are not colluding. We assume that the price the US Government paid per vaccine, combined with the percentage of vaccinated adults by October 2021, provide enough data to roughly model consumer behavior through our price function. We assume that consumers are not interested in other vaccines, such as Johnson and Johnson's viral vector vaccine. We assume that consumer preference for getting vaccinated is reflected in the price the government paid, despite the fact that the vaccine was functionally free for US residents — We say functionally because it was likely paid for by taxes. Perhaps most importantly, we assume that a COVID vaccine, at the time our data is drawn from, is not a necessary good, although it almost certainly was a necessary good given the severity of the pandemic. These last two assumptions allow us to use the price that the US Government paid per vaccine as a benchmark for our price function.

Model

We begin by creating a model for the price of mRNA vaccines given total demand in the United States adult population with the form $P(Q) = \alpha - \beta Q$, where α is the maximum price one consumer may be willing to pay and β is a coefficient meant to model the percent of consumers willing to pay a certain price for a vaccine. We note that, according to Statista, 72% of US adults were vaccinated by October 2021[1]. The reason for picking this specific month as our basis point is because our model makes use of the fact that the US struck a new deal with Pfizer to purchase 200 million doses of vaccine in July 2021 with delivery starting in October 2021. Thus, the amount of vaccinated individuals as of October 2021 was the result of earlier US Government purchases for which we have accurate data. We note that in our price model, 100% of consumers would not buy vaccines at a price $p = \alpha$. Thus, we would like to set $p/0.28 = \alpha$. The US Government purchased 300 million doses of Pfizer and 300 million doses of Moderna's mRNA vaccine at costs of \$5.97 billion and \$5.894 billion, respectively, according to the Congressional Research Service[2]. Thus, the average cost that the US Government paid per vaccine is $\frac{5.97+5.894}{0.3+0.3} = \$19.77$. We take this to be the price at which 72% of consumers were willing to get vaccinated. At this point, we have made two assumptions. First, the number of vaccinated people is entirely composed of mRNA vaccinations, which we know is not entirely true as there were individuals vaccinated with Johnson and Johnson's vaccine. Our second assumption is that the government paid a price that they thought consumers themselves would pay individually if vaccines were sold on the open market rather than to the government directly. With these assumptions in mind, we see that $\alpha = \frac{19.77}{0.28} = \$70.62$. To solve for β, we note that the total US adult population in October 2021 was around 332 million according to the US Census Bureau[3], and that adults comprised of around 78% of the total population according to the Kids Count Data Center[4]. Thus, the total adult population in October 2021 was around 259 million. We see that in order for our price model to accurately reflect

[1] https://www.statista.com/statistics/1200296/covid-vaccination-willingness-among-us-adults/

[2] https://crsreports.congress.gov/product/pdf/IN/IN11560

[3] https://www.census.gov/popclock/

[4] https://datacenter.kidscount.org/data/tables/99-total-population-by-child-and-adult-populations#detailed/1/any/false/574,1729,37,871,870,573,869,36,868,867/39,40,41/416,417

a vaccination rate of 72% at a price of \$19.77, it must be the case that $\frac{70.62-19.77}{259{,}000{,}000 \cdot 2 \cdot 0.72} = \beta$. We note that we multiply the population by 2 in the denominator as each vaccinated individual consumes 2 vaccines. Thus, $\beta = 0.000000136$. Thus, we have solved for our price model:

$$P(Q) = \begin{cases} 70.62 - 0.000000136Q & \text{if } Q \leq 259{,}000{,}000 \\ 0 & \text{if } Q > 259{,}000{,}000 \end{cases} \tag{1}$$

To solve for each individual firms' cost, we note that the R&D for the development of the mRNA vaccine for Moderna was around 1 billion[5]. We will use this figure as the sunk cost for all firms involved. We note that, according to Public Citizen, the cost per vaccine for Pfizer is $\frac{9.43}{8} = \$1.18$, the cost per vaccine for Moderna is $\frac{22.83}{8} = \$2.85$, and the cost per vaccine for CureVac is $\frac{4.38}{8} = \$0.55$. The difference in cost is mainly attributed to the amount of raw materials used by each company per vaccine: Pfizer's vaccine is a $30\mu g$ dose, Moderna's is a $100\mu g$ dose, and CureVac has a $12\mu g$ dose[6]. We note that these costs do reflect a production schedule aimed at producing 8 billion vaccines in a year; however, for the purposes of our analysis, we will assume that they hold regardless of the production scale. Thus, the cost functions for Pfizer, Moderna, and CureVac, respectively, can be found to be:

$$C_P(q_P) = 1.18q_P + 1{,}000{,}000{,}000 \tag{2}$$

$$C_M(q_M) = 2.85q_M + 1{,}000{,}000{,}000 \tag{3}$$

$$C_C(q_C) = 0.55q_C + 1{,}000{,}000{,}000 \tag{4}$$

We thus define the marginal costs of each firm $c_P = 1.18, c_M = 2.85, c_C = 0.55$.

[5] https://crsreports.congress.gov/product/pdf/IN/IN11560

[6] https://www.citizen.org/article/how-to-make-enough-vaccine-for-the-world-in-one-year/

Results

We will first solve the Nash Equilibrium of our model for the case of two firms, Moderna and Pfizer, as these are the current players in the US market, and then we will solve the Nash Equilibrium of our model for all three firms, as CureVac's vaccine has not yet received emergency authorization status but is nonetheless in stage 3 clinical trials[7]. To solve for the two firm case, we may solve the system of equations

$$q_P^* = \begin{cases} \frac{1}{2}\left(\frac{\alpha - c_P}{\beta} - q_M^*\right) & \text{if } q_M^* \leq \frac{\alpha - c_P}{\beta} \\ 0 & \text{if } q_M^* > \frac{\alpha - c_P}{\beta} \end{cases}$$

$$q_M^* = \begin{cases} \frac{1}{2}\left(\frac{\alpha - c_M}{\beta} - q_P^*\right) & \text{if } q_P^* \leq \frac{\alpha - c_M}{\beta} \\ 0 & \text{if } q_P^* > \frac{\alpha - c_M}{\beta} \end{cases}$$

that we derive from our price and cost functions. We see that the ideal production for each firm, respectively, is thus

$$q_P^* = \frac{1}{3}\left(\frac{\alpha + c_M - 2c_P}{\beta}\right) \tag{5}$$

$$q_M^* = \frac{1}{3}\left(\frac{\alpha + c_P - 2c_M}{\beta}\right) \tag{6}$$

Solving for our given values based on our price and cost functions, we see that Pfizer's Nash Equilibrium production is $\frac{1}{3} \cdot \frac{70.62 + 2.85 - 2 \cdot 1.18}{0.000000136} = 174{,}289{,}216$. Similarly, Moderna's Nash Equilibirum production is $\frac{1}{3} \cdot \frac{70.62 + 1.18 - 2 \cdot 2.85}{0.000000136} = 162{,}009{,}804$. Thus, Pfizer has a market share of $\frac{174{,}289{,}216}{174{,}289{,}216 + 162{,}009{,}804} = 51.8\%$ while Moderna's market share is 48.2%. What is interesting to note here is despite Pfizer's significantly lower cost of production, the firm does not hold a significant majority of the market share, only a slight majority. We note that at these production values, the price

[7] https://www.curevac.com/en/covid-19/

per vaccine is $70.62 - 0.000000136 \cdot (174,289,216 + 162,009,804) = \$24.88$. We also note that only $\frac{174{,}289{,}216+162{,}009{,}804}{2 \cdot 259{,}000{,}000} = 64.9\%$ of people end up vaccinated in this model, as opposed to the 72% of people when the purchase of vaccines was carried out by the government. We see that Pfizer's profits are given by $174,289,216 \cdot (24.88 - 1.18) - 1,000,000,000 = \$3,130,654,419$, which is under the nearly \$5 billion that the firm made in profit from its government contracts. Similarly, Moderna's profits are given by $162,009,804 \cdot (24.88 - 2.85) - 1,000,000,000 = \$2,569,075,982$.

We will now solve for the three firm case. To solve this case, we may solve the system of equations

$$q_P^* = \begin{cases} \frac{1}{2}\left(\frac{\alpha - c_P}{\beta} - (q_M^* + q_C^*)\right) & \text{if } q_M^* + q_C^* \leq \frac{\alpha - c_P}{\beta} \\ 0 & \text{if } q_M^* + q_C^* > \frac{\alpha - c_P}{\beta} \end{cases}$$

$$q_M^* = \begin{cases} \frac{1}{2}\left(\frac{\alpha - c_M}{\beta} - (q_P^* + q_C^*)\right) & \text{if } q_P^* + q_C^* \leq \frac{\alpha - c_M}{\beta} \\ 0 & \text{if } q_P^* + q_C^* > \frac{\alpha - c_M}{\beta} \end{cases}$$

$$q_C^* = \begin{cases} \frac{1}{2}\left(\frac{\alpha - c_C}{\beta} - (q_P^* + q_M^*)\right) & \text{if } q_P^* + q_M^* \leq \frac{\alpha - c_C}{\beta} \\ 0 & \text{if } q_P^* + q_M^* > \frac{\alpha - c_C}{\beta} \end{cases}$$

that we derive from our price and cost functions. We see that the ideal production for each firm, respectively, is thus

$$q_P^* = \frac{\alpha + c_C + c_M - 3c_P}{4\beta} \tag{7}$$

$$q_M^* = \frac{\alpha + c_C - 3c_M + c_P}{4\beta} \tag{8}$$

$$q_C^* = \frac{\alpha - 3c_C + c_M + c_P}{4\beta} \tag{9}$$

Solving for the given values based on our price and cost functions, we see that Pfizer's new Nash equilibrium production is $\frac{70.62+0.55+2.85-3*1.18}{4 \cdot 0.000000136} =$

$129,558,824$. Similarly, Moderna's new Nash Equilibrium production is $\frac{70.62+0.55-3*2.85+1.18}{4\cdot 0.000000136} = 117,279,412$. Lastly, CureVac's Nash Equilibrium production is $\frac{70.62-3*0.55+2.85+1.18}{4\cdot 0.000000136} = 134,191,177$. Thus, Pfizer has a market share of $\frac{129,558,824}{129,558,824+117,279,412+134,191,177} = 34\%$. Moderna has a market share of $\frac{117,279,412}{129,558,824+117,279,412+134,191,177} = 30.8\%$, and CureVac has a market share of 35.2%. Once again, despite large difference in cost, the firms have a relatively even share of the market. At these production values, the price per vaccine can be found to be $70.62 - 0.000000136 \cdot (129,558,824 + 117,279,412 + 134,191,177) = \$18.80$. We also note that $\frac{129,558,824+117,279,412+134,191,177}{2\cdot 259,000,000} = 73.56\%$, which is actually higher than the 72% of people vaccinated when the government bought from two firms. Lastly, we see that Pfizer's profit is $129,558,824 \cdot (18.80 - 1.18) - 1,000,000,000 = \$1,282,826,479$, that Moderna's profit is $117,279,412 \cdot (18.80-2.85)-1,000,000,000 = \$870,606,621$, and that CureVac's profit is $134,191,177 \cdot (18.80 - 0.55) - 1,000,000,000 = \$1,448,988,980$.

Conclusion

To conclude, we touch on three discussion topics: the market share of each firm in both cases, the potential for new entrants into the mRNA vaccine market, and the predicted vaccination rate in both cases given the new vaccine price. We see that in the case of two firms, the market share is practically 50/50, despite Pfizer's marginal cost being under half of Moderna's marginal cost. This is due to the high value of α that we calculated, along with the low value of β. When subtracting marginal cost from α throughout our calculations, we see that our result stays very close to α itself. When we divide by our small β, we end up getting a difference in production of millions, as the small β magnifies the difference between α and α minus marginal cost. However, the actual market share for each firm does not stray far from 50% as the marginal cost is so much smaller than α in both cases. Thus, both firms can produce nearly the same amount at equilibrium. The market shares in the case of three firms show a similar trend, with all values hovering around 33%. Note that CureVac's marginal cost is under half of Pfizer's marginal cost and under a fifth of Moderna's marginal cost. Even then, we predict the firm will only capture 2.2% over an even split of 33% of the total market for mRNA vaccines if their candidate passes clinical trials and they begin distributing directly to consumers simply because the marginal cost is very small compared to α.

We see that because of this discrepancy between α and marginal cost, despite a very large start-up fee of $1 billion in R&D, CureVac is still able to enter the mRNA vaccine market and make a profit. Moreover, we see that because the total profit of the firms in the three firm case is over $3.5 billion, there is most likely more than enough room for other entrants to the market even with a $1 billion R&D cost. We leave the exact calculations for this to another paper.

Lastly, we see that in the case of two firms selling directly to consumers, the percentage of vaccinated individuals actually decreases and the cost per vaccine increases when compared to the case where the US Government buys all vaccines. With the severity of COVID, both on public health and on the economy, we recognize that it was almost entirely necessary that the US Government not only bought vaccines, but bought them at quantities over public demand. However, interestingly enough, in the case of three firms selling directly to consumers, a higher percentage of adults end up vaccinated than with the government buying and distributing vaccines, according to our model. This, of course, does not take into account the fact that vaccines are currently free for US residents, and is thus likely not accurate. However, it does demonstrate that, in time, mRNA vaccine distribution may be accomplished at cheaper prices and at larger quantities as more firms enter the market that currently only consists of governments as consumers.