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Coordination problems, strategic complementarities, and multiple equilibria in an alternative fuel market

Abstract

High energy prices and climate change created public interest in developing alternatives to petroleum-based fuel. Automobiles that operate on alternative fuel require a fixed investment: additional equipment must be installed on traditional engines or must be purchased a new special vehicle. Consumers hesitate to make this fixed investment until they are confident the alternative fuel will be available and convenient to use; this creates strategic complementarity in consumers' alternative fuel investment decisions. Multiple equilibria are present when the equilibrium threshold of the relative payoff is concaved in market penetration of the alternative. Concavity of the threshold follows from the cost of infrastructure investment. The initial cost of alternative infrastructure is high, but once a base level is in place the cost of additional units of the alternative fuel is low. Thus, the threshold of relative payoffs is concave in market penetration of the alternative fuel. Further, the distribution of relative payoffs among consumers affects policymakers' ability to influence market penetration of the alternative. The distribution of relative payoffs represents a population's spatial heterogeneity in cost effectiveness of the alternative technology. This arises from transportation or other geographically relevant investment costs. Therefore, if population centers are clustered in an area of low investment cost, a government incentive to use the alternative fuel is more likely to be effective. However, if the population is uniformly distributed over space or clustered in areas of high cost a much larger government investment is required to achieve widespread adoption of the alternative technology.

Keywords: alternative fuel, energy, multiple equilibria, strategic complementarity.
JEL Classification: Q4, L9.

Introduction

The NYMEX light sweet crude oil futures contract rose to almost $150 per barrel in July 2008 for the first time in history, while concern about greenhouse gas emissions continued to mount. While crude oil prices have since receded from these historic levels, the combination of persistently high energy prices and concern about global climate change has created public interest in developing an alternative to petroleum-based transportation fuel. There are several potential alternatives: ethanol, biodiesel, electric engines, coal liquefaction, fuel cells, and solar power. None of these alternatives have emerged as the clear favorite, but even when one becomes viable on a large scale, people will still hesitate to invest in an automobile that uses the alternative until they believe it will enjoy widespread adoption (Lee, Speight and Loyalka, 2007).

Strategic complementarity may be defined as the phenomena where actions of individual consumers are mutually reinforcing of one another (Topkis, 1979; Bulow, Geanakoplos and Klemperer, 1985; Vives, 1990). When one person adopts the alternative, it increases the benefit to others of adopting. Not wanting to make a significant financial investment from which they will not benefit, people wait to see if the fueling station near their home, near their work, or near their grocery store will supply the alternative. This hesitation is what creates strategic complementarity in the market for alternative fuels.

Diamond and Dybvig wrote the seminal piece on strategic complementarity and coordination failure in an article concerning bank runs and deposit insurance (Diamond and Dybvig, 1983). Subsequent articles explored contexts where strategic complementarity is present; for examples see Frankel et al. (2003) and Goldstein and Pauzner (2005) on technological adoption, arms races, and coordination failures.

The strategic complementarity, or simply the chicken and egg problem, inherent in the transition to an alternative fuel technology has been recognized by energy economists and other scientists for some time. For example, Flynn (2002) and Yeh (2007) both examined the failure of compressed natural gas vehicles. They noted that the price at the pump compared with gasoline and diesel, availability and reliability of the compressed natural gas technology, and profitability of operating natural gas refueling stations were major factors in this alternative technology's demise. Leiby and Rubin (2001) also acknowledged these intricacies in their study that challenged the conclusions of the 1996 report by the United States Department of Energy, Office of Policy and Office of Energy Efficiency and Renewable Energy. They argued that it would require significantly more aggressive policies to meet the goals of the US Energy Policy Act of 1992 that was suggested by the Department of Energy's report.

Schwoon (2006) used an agent based model to simulate the evolution of the market for fuel cell vehicles. He also recognized the problem posed by the simultaneous evolution of consumer demand and producer supply of the alternative fuel. Not surprisingly, he finds that an exogenous public buildup of alternative fuel stations results in a more successful transition to the alternative fuel. This is because if the retail fuel stations are built exogenously, the strategic complementarity is taken away. Consumers will switch as soon as the size of the alternative fuel network is sufficiently large and the cost is at least at par with gasoline. Even public policy, though, is endogenous. A public program designed to increase the size of the network of alternative retail fuel stations without regard for whether or not consumers are actually choosing the alternative fuel would be met with public criticism. Such a program would be difficult to maintain if substantial consumer adoption is not observed early in the program.

Struben and Sterman (2008) develop a model that attempts to capture behavioral factors, scale and scope economies, research and development, learning by doing, driver experience, word of mouth, and complementary resources and supply infrastructure. Their model is dynamic so that they can create co-evolution of consumers' behavior and network size. Similar to my results, they find a threshold adoption level required for sustained adoption of the alternative fuel technology.

While the parameters considered in Struben and Sterman certainly play a role, I argue that strategic complementarity can arise from assuming cost heterogeneity alone in a two period model. A dynamic model requires that both early suppliers and consumers of the alternative fuel persist through a period of low or negative payoff, even in the case where the alternative fuel is successful in the long run.

I apply the basic insights from the strategic complementarity literature and show that these challenges exist in a basic modeling framework under generous assumptions. By modeling the alternative fuel market in this way, this study suggests the inertia required to move away from the traditional petroleum-based system may be greater than is often recognized.

I assume a fixed investment is required in order to use the alternative fuel. This fixed investment potentially can be recovered given that the alternative is less expensive than gasoline or diesel. Therefore, if a person believes the alternative will be widely available, he will incur the fixed cost in order to obtain the benefit of using the cheaper alternative fuel. One person's investment in the alternative increases the benefit to others. This is because the more people who use the alternative, the more likely that there will be a large network of retail supply of the alternative fuel. The model presented is a stylized theoretical model; as such it cannot be empirically tested or verified. It can, however, serve as a thought experiment to predict the way consumers behave in adopting an alternative fuel technology.

The essence of the problem can be illustrated with an example. Ethanol production has increased rapidly in recent years[1]; most ethanol that is produced is utilized as a ten percent ethanol – ninety percent gasoline blend (E10). In order for production to increase much further and still be used domestically, the number of flexible-fuel automobiles would have to increase. There are many makes and models of vehicles offering a flex-fuel option from the factory[2]. Consumers can pay a fixed markup above the standard retail price for the flex-fuel model, and in return they have the option to use either gasoline or as much as an eighty-five percent ethanol-gasoline blend (E85). An ongoing obstacle to widespread E85 adoption is the availability – or lack thereof – of retail fueling stations. People will not invest in a flexible-fuel engine if it is not convenient to fill up with E85. Retail fueling stations, likewise, will not invest in updating the infrastructure required in order to stock E85 if they do not expect to sell a large volume. The E85 story is an example, but the same issue is present for almost all the fuels proposed as an alternative to gasoline and diesel.

In the model, I consider only the case where consumers choose between the status quo, petroleum fuel, and a single alternative fuel. The structure of the problem remains the same regardless of which fuel functions as the alternative, whether it is E85, electric battery, liquefied coal, or something else. Therefore in the analysis below I refer simply to the *alternative fuel* and abstain from specifying which alternative fuel, since it is not important to the analysis.

1. The model

There is a continuum of risk-neutral consumers who are identical, except that they differ in the relative benefit they receive when using the alternative versus gasoline. Assuming consumers are risk neutral is not necessarily realistic, but it is the most conservative assumption we can specify. Assuming risk neutrality allows the results of this paper to be viewed as a 'worst case scenario'; if consumers are instead risk averse, the results would be qualitatively the same and quantitatively more severe.

[1] http://www.eia.doe.gov/oiaf/analysispaper/biomass.html.

[2] As of the 2010 model year as many as 43 models of flexible fuel vehicles were available from Chrysler, Ford Motor Company, General Motors, Nissan, Mercedes-Benz, and Toyota, and Isuzu, http://www.mda.state.mi.us/renewablefuels/documents/FFVlist2007.pdf.

The assumption that consumers are heterogeneous in their benefit of consuming transportation fuel is a parsimonious proxy for spatial heterogeneity in the cost of distributing the alternative transportation fuel to different locations. For example, the Corn-Belt contains more E85 fuel pumps than other parts of the country, making the premium to using E85 for a person living in the Corn-Belt higher than for a person living in Maine[1].

In the model consumers and suppliers participate in a two-stage game. In the first stage, consumers decide whether or not to invest in the alternative fuel technology. Also in the first stage, retail fuel suppliers determine the size of the alternative fuel distribution network. The network's size is determined by the adoption rate, p, of people who invest in the alternative fuel technology. In the second stage consumers enjoy the benefit of consuming fuel. The size of the benefit is determined both by whether or not they invested in the alternative fuel technology and if the alternative fuel is available for them to purchase or not.

Everyone gets a nominal benefit of U from consuming fuel, but if they consume gasoline their nominal payoff is reduced proportionally by the individual specific parameter, α_i. This parameter measures the degree of premium realized from using the alternative and take on values from 0 to 1. Therefore, the payoff to individual i of consuming gasoline is $\alpha_i U$ in order to get the full utility, U, of consuming fuel, consumers must use the alternative. The α_i proxy spatial heterogeneity in the cost of distributing the alternative transportation fuel to individual consumers. α_i are assumed to be distributed among the population of consumers according to, $f(\cdot)$, a probability distribution function whose support is the unit interval. Therefore, consumers with a low α_i receive a large premium if they use the alternative fuel, while consumers with an α_i close to one receive little premium if they use the alternative fuel. In the E85 example, a consumer who has a low α_i might correspond to someone who lives in the Corn-Belt, and a consumer with a high α_i might correspond to someone who lives in Maine.

Consumers must pay a fixed cost, M, in order to have the ability to use the alternative, and there is uncertainty in the payoff of this investment. Not everyone who invests will have the opportunity to use the alternative in the second stage of the game. There is the probability, p, that the alternative will be available and the probability $1-p$ that it will not be available. The probability, p, equals the equilibrium adoption rate of the alternative technology in the economy. If available, the payoff in period 2 to people who invested in period 1 is UM, but if the alternative fuel is not available consumers must use gasoline, even though they already made the fixed investment in the alternative technology. In this case the consumer's period two payoff is $\alpha_i UM$. Thus, there are three possible payoff scenarios: (1) $U-M$, when the consumer invests in the alternative in the first period and it is available in the second period; (2) $\alpha_i UM$, when the consumer invests in the alternative in the first period but it is not available in the second period; and (3) $\alpha_i U$, when the consumer does not invest in the alternative in period 1. The uncertainty in the availability of the alternative fuel, and the fact that the investment cost, M, is sunk before benefits are realized, is what drives strategic complementarity in the model.

To summarize, the timeline of actions is as follows:

- Stage 1: People choose whether or not to invest in the alternative fuel technology for their automobiles, and the network of retail fueling stations that supply the alternative fuel is created. The size of the network depends on the equilibrium adoption rate, p, which is the proportion of the population that invested in the alternative fuel.
- Stage 2: Consumer payoffs are realized as

Invested in alternative:

$$\text{Payoff } = \begin{cases} U-M \text{ with probability } p, \\ \alpha_i U - M \text{ with probability } 1-p. \end{cases}$$

Did not invest: Payoff $\alpha_i U$.

Consider the conditions under which a person would be better off by investing in the alternative. A risk neutral investor will invest if and only if the expected benefit is greater than the certain benefit of using gasoline, i.e., when $E[U_{Alt}] > U_{Gas}$, or when,

$$p \cdot (U-M) + (1-p) \cdot (\alpha_i U - M) > \alpha_i U. \quad (1)$$

After solving for α_i notice that a person will invest in the alternative if and only if:

$$\alpha_i(p) < 1 - \frac{M}{pU}. \quad (2)$$

This means the premium to using the alternative must be sufficiently large before a consumer would

[1] There are currently two thousand fueling stations offering E85 in the United States, with over half of these stations located in the Upper Midwest states of Minnesota, Wisconson, North Dakota, South Dakota, Nebraska, Iowa, Illinois, Indiana and Ohio. Most states have fewer than ten fueling stations offering E85, http://www.eere.energy.gov/ afdc/ethanol locations.html.

be willing to pay M for the opportunity to receive the full benefit, U, of consuming fuel with probability p. Therefore, equality of equation (2) defines the threshold premium below which a person will invest: $\alpha^*(p) = 1 - \frac{M}{pU}$.

In order to show there is strategic complementarity, one needs to verify that $\alpha^*(p)$ is increasing in p, since this means that if the number of people who invest in the alternative is increased, the threshold becomes less restrictive. The derivative of the equilibrium threshold with respect to p, $\frac{d}{dM}\alpha^*(p) = \frac{-M}{pU}$, is positive for all values of p for positive U and M.

Also, notice that the fixed cost, M, decreases the threshold value, $\alpha^* p$ since $\frac{d}{dM}\alpha^*(p) = \frac{-M}{pU}$, and this derivative is everywhere negative for positive U. This means that lowering the fixed costs of installing the technology will decrease the threshold below which people will invest.

In a rational expectations equilibrium, agents anticipate the actions of others, and realize that when everyone is using the same rule to invest in the alternative, the proportion of people who invest is exactly equal to $\alpha^* p$. When $\alpha_i \sim f$ (0, 1) this implies: $F(\alpha^*(p^*)) = p^*$, (3) where $F(\cdot)$ is the cumulative probability distribution function of $f(\cdot)$. As an example of how the concavity of the threshold, $\alpha^*(p)$, drives the existence of multiple equilibria in the model, assume that $\alpha_i \sim uniform$ (0,1). The CDF of the uniform probability distribution is linear so that $F(\alpha^*(p)) = \alpha^*(p)$. Assume further that U = 50 and M = 10. Since $\alpha^*(p)$ is concave, equation (3) can have two solutions. Then the high and low equilibrium adoption rates are $p_h^* = 0.724$ and $p_l^* = 0.276$. This example is illustrated in Figure 1 (see Appendix). The distribution of α_i plays an important role in the equilibrium adoption rates, p_h^* and p_l^*, as I will demonstrate in Section 4.

2. Introducing government

Now consider a government whose objective is to decrease gasoline consumption by replacing it with an alternative fuel. I discuss some policy instruments the government has at its disposal in this Section. In the preceding Section I showed that the high equilibrium is decreasing in M, but the low equilibrium is increasing in M. This is because the equilibrium threshold $\alpha^*(p)$ decreases with M, as Figure 2 illustrates (see Appendix). In terms of policy design this means that if the economy tends naturally toward the high equilibrium, subsidies lowering the fixed cost of the alternative will increase the equilibrium adoption rate in the alternative. But, if the economy tends naturally toward the low equilibrium, a subsidy lowering the fixed cost actually will reduce the equilibrium adoption rate.

Rather than subsidize the fixed cost of installing the alternative, the government might tax the use of gasoline. This alters the payoff structure in the following way:

$$\text{Invest in alternative: Payoff} = \begin{cases} U - M \text{ with probability } p, \\ \alpha_i(U - t) - M \text{ with probability } 1 - p. \end{cases}$$

$$\text{Did not invest:} \quad \text{Payoff} = \alpha_i(U - t).$$

An agent's payoff is reduced only if he consumes gasoline, not if he consumes the alternative. That is, he pays the tax, t, if he does not invest or if he invests and it turns out that the alternative is not available in the second period.

With a gasoline tax people invest in the technology if and only if:

$$p(U - M) + (1 - p)((U - t)(U - t) - M) > \alpha_i(U - t). \quad (4)$$

After solving for α_i notice that this means a person will invest if and only if:

$$\alpha_i < \frac{pU - M}{(U - t)}. \quad (5)$$

Notice the new threshold below which people will invest, defined by the equality of equation (5), is higher than the previous case that is:

$$1 - \frac{M}{pU} < \frac{pU - M}{(U - t)p}. \quad (6)$$

Further, strategic complementarity in p still exists since the derivative of the new threshold, $\frac{d}{dp}\alpha^*(p) = \frac{M}{p^2(U - t)}$, is still positive for all values of t such that $U - t > 0$. In fact, the tax effectively decreases α_i for all agents in the economy (recall a decrease α_i means a higher premium to using the alternative).

Again we illustrate with an example where the α_i are distributed uniformly. Then solving for the rational expectations equilibrium (that is, solving equation (3) for p^*), we find the equilibria when a tax on gasoline consumption is introduced. The equilibria are illustrated in Figure 3 (see Appendix). The threshold premium without a gasoline consumption tax is $\alpha^*(p)$ and the threshold premium with a gasoline consumption tax increases for each p to $\alpha^{'*}(p)$.

Compare the equilibrium adoption rates with their no-tax counterparts. The low equilibrium adoption rate is less with a gasoline tax than without, $p_l^{'*} < p_l^*$, while the high equilibrium adoption rate is greater with a gasoline tax than without, $p_h^* < p_h^{'*}$.

Like in the case of subsidizing the fixed cost, taxing gasoline consumption increases the high equilibrium adoption rate, but reduces the low equilibrium adoption rate. The threshold, $\alpha^{'*}(p)$, is higher for every p when a strictly positive tax is imposed, causing the high equilibrium, p_h^*, to increase and the low equilibrium, p_l^*, to decrease.

The policy tools considered have parallel effects on consumer behavior. With the intent of increasing the use of the alternative, both the tax on gasoline consumption and a subsidy to offset part of the fixed cost work as intended when the economy is in the high adoption rate equilibrium. When the economy is in the low adoption rate equilibrium, however, the opposite is true and the equilibrium adoption rate declines.

3. What drives the results?

This paper outlines three qualitative results: multiple equilibria are possible, strategic complementarity is present, and common policy tools can have the opposite of the desired effect. These findings have important implications as programs intended to stimulate adoption of an alternative fuel technology may end up being counterproductive to its very objective. In models that produce multiple equilibria, the initial economic condition and the beliefs of the economic agents are crucial to determining whether an economy will be drawn toward the 'good equilibrium' or the 'bad equilibrium'. If consumers know about the alternative fuel technology, and if they are confident about its availability and performance, then the economy is likely to be drawn to the high adoption rate equilibrium. Subsidizing use of the alternative will make consumers more likely to adopt the technology in this case. Conversely, if consumers are still unsure about whether the technology works well, then the economy is likely to be drawn to the low adoption rate equilibrium. The presence of a subsidy lowers the equilibrium adoption rate in this case. This is because consumers feel that they are being offered a subsidy to adopt the alternative because it is still in an experimental or unverified stage of development.

In the model, multiple equilibria come about because of the curvature of the equilibrium threshold, or more precisely, from the concavity of $\alpha^*(p)$. A threshold α_i exists if there is a large number of people in the economy who are heterogeneous in their benefit from using the alternative. The last person who decides to invest is just indifferent between investing and not. All consumers who would get less benefit from the alternative choose not to invest.

As the adoption rate increases, people with smaller relative premiums (bigger α_i's) invest in the alternative. Because of the strategic complementarily, a larger adoption rate means people with larger α_i's find it beneficial to invest. This means the equilibrium threshold, $\alpha^*(p)$, is increasing in p. Concavity is implied if $\alpha^*(p)$ is increasing in p, but at a decreasing rate. It should be expected that $\alpha^*(p)$ is increasing at a decreasing rate since once enough infrastructure is in place to supply the alternative fuel, additional users will not motivate suppliers to expand further.

4. Implications of the distribution over α_i

This Section explores the effect of the distribution of α_i on the equilibrium adoption rate. In this model the probability distribution of the α_i's in the economy are a proxy for the spatial heterogeneity of transportation and distribution costs. By varying the nature of the probability distribution, one can calibrate the model so that the proportion of the population whose relative benefit to using the alternative mimics that of the actual population of consumers.

Given the way the payoffs are structured, α_i must take values between zero and one, suggesting that the beta distribution is an appropriate choice for modeling this element of the economy. Equilibrium is found by solving for p^* in the expression $F(\alpha^*(p^*)) = p^*$, where $F(\cdot)$ is the cumulative probability function of the beta distribution. A closed form solution does not exist, but one can numerically solve the equation. A summary of the results under different distributional assumptions is found in Table 1 (see Appendix). Both the high equilibrium and the low equilibrium solutions are provided there.

Figure 4 (see Appendix) illustrates the solution to this equation for the example when $U = 50$, $M = 10$, $A = 1$, and $B = 1$, where A and B are parameters of the beta distribution, this corresponds to the case when $\alpha_i \sim uniform\ (0, 1)$. In this example, $\alpha^*(p) = 0.724$ and $p^* = 0.724$ in the high equilibrium solution. This is interpreted as 72.4% of the population would invest in the alternative fuel technology in this scenario. This example illustrates the model's outcome when all members of the population benefit equally from using the alternative transportation fuel. This roughly corresponds to the situation where all geographic regions are equally likely to have a high relative benefit of using the alternative fuel as they are to have a low relative benefit.

When $A = 2$ and $B = 5$, the beta distribution is skewed to the right. This means that a relatively large proportion of the population enjoys a large premium to using the alternative fuel over gasoline. This is the expected case if the alternative fuel source is naturally inexpensive to distribute to large population centers. Relative to when $\alpha_i \sim uniform\ (0, 1)$, both the threshold premium level and the equilibrium adoption rate increases, $\alpha^*(p^*) = 0.799$ and $p^* = 0.998$; or in other words 99.8% of the population invests in the alternative fuel technology. Figure 5 (see Appendix) illustrates the high equilibrium result in this case. Strategic complementarity is evident here. The distributional assumption alone would cause the equilibrium adoption rate to increase relative to the scenario where α_i are distributed uniformly, but in addition to this, the premium threshold increases. Because there are more people using the alternative, consumers that receive a smaller relative premium find it profitable to invest in the alternative fuel technology.

For $A = 2$ and $B = 2$, the beta distribution is symmetric. Both the threshold premium level and the equilibrium adoption rate increases relative to when α_i is distributed uniformly, $\alpha^*(p^*) = 0.769$ and $p^* = 0.864$. Figure 6 (see Appendix) illustrates the result in this case, and the graphical representation of the low equilibrium is found in Figure 7 (see Appendix). Figure 8 offers the graphical depiction of the solutions to the equation:

$$F(\alpha^*(p^*)) = p^*,$$

when $\alpha_i \sim Beta\ (2, 2)$.

When $A = 1$ and $B = 3$, the beta distribution is decreasing over the entire interval (0, 1). The results in this case are $\alpha^*(p) = 0.798$ and $p^* = 0.992$. This is illustrated in Figure 9 (see Appendix).

None of these examples are calibrated to the U.S. population, but are included elucidate the importance of the distribution of relative premiums (the α_i) on who and how many people invest.

Conclusion

In the transportation fuel market, strategic complementarity is present, multiple equilibria can exist, and common policy tools (such as a gasoline tax or an alternative fuel subsidy) may have the opposite of their intended effect. The equilibrium adoption rates are governed largely by the distribution of the α_i, which is the parameter that determines an individual's relative premium of using the alternative fuel.

A large network of retail suppliers increases the benefit of using the alternative to consumers. The more people who use the alternative, the larger the network of retail suppliers will be in equilibrium. Since consumers and suppliers of the alternative fuel must make investment decisions simultaneously, before they learn about the actions of others, strategic complementarity is present.

Multiple equilibria exist because of the concavity of the equilibrium threshold, $\alpha^*(p)$. Both a subsidy on the fixed cost of investment in the alternative and a tax on gasoline consumption have the same qualitative effect – each lowers the equilibrium threshold. This changes the equilibrium adoption rate of the alternative. In the high equilibrium, the government intervention produces the intended effect – adoption of the alternative fuel increases. In the low equilibrium, however, the adoption rate is reduced. The policy, in this case, has an effect that is the opposite of its intention. Even in the high equilibrium, the ability of policymakers to manipulate the adoption rate is affected by the distribution of the α_i among the population. If the distribution of the α_i is skewed to the right, many people enjoy a large premium from using the alternative. Policymakers' ability to influence the market is greater than it otherwise would be in this case. Conversely, if the distribution of the α_i is skewed to the left, many people receive a relatively small benefit from using the alternative fuel. Influencing the adoption rate in the alternative fuel, in this case, will require significantly more resources.

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Appendix

Table 1. Equilibrium thresholds on the premium to using alternative fuel technology and the adoption rate in the alternative under different distributional assumptions on α

		$A = 1$, $B = 1$	$A = 2$, $B = 5$	$A = 2$, $B = 2$	$A = 1$, $B = 3$
High equilibrium	$\alpha^*(p^*)$	0.724	0.799	0.769	0.798
	p^*	0.724	0.998	0.864	0.992
Low equilibrium	$\alpha^*(p^*)$	0.276	0.156	0.379	0.078
	p^*	0.276	0.237	0.322	0.217

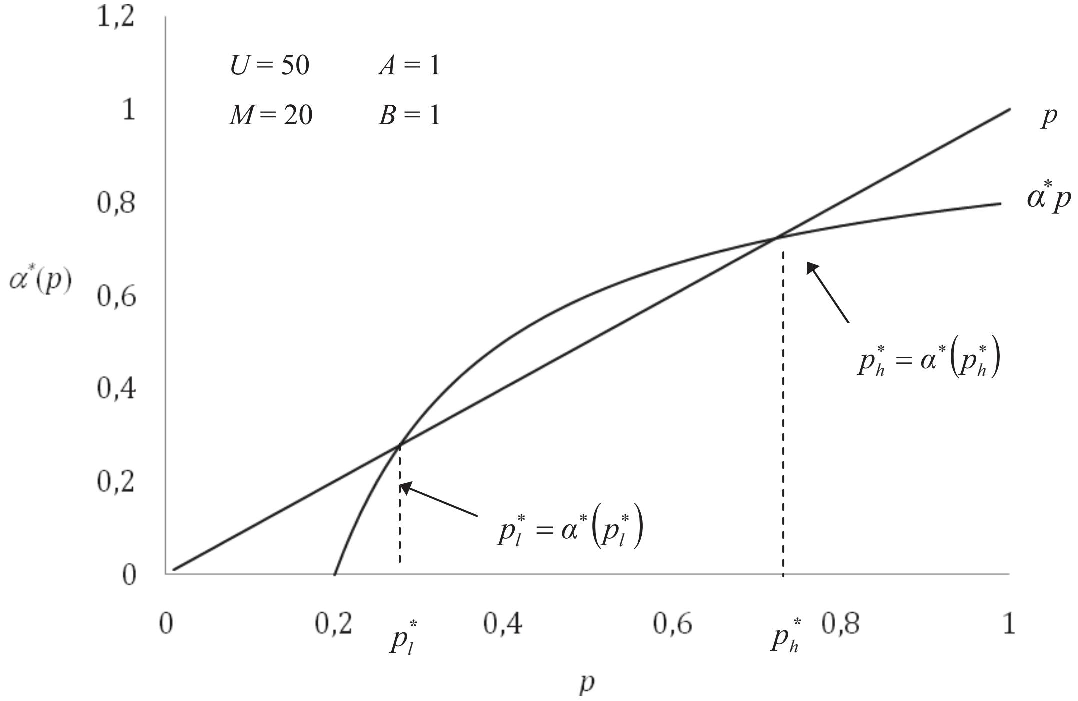
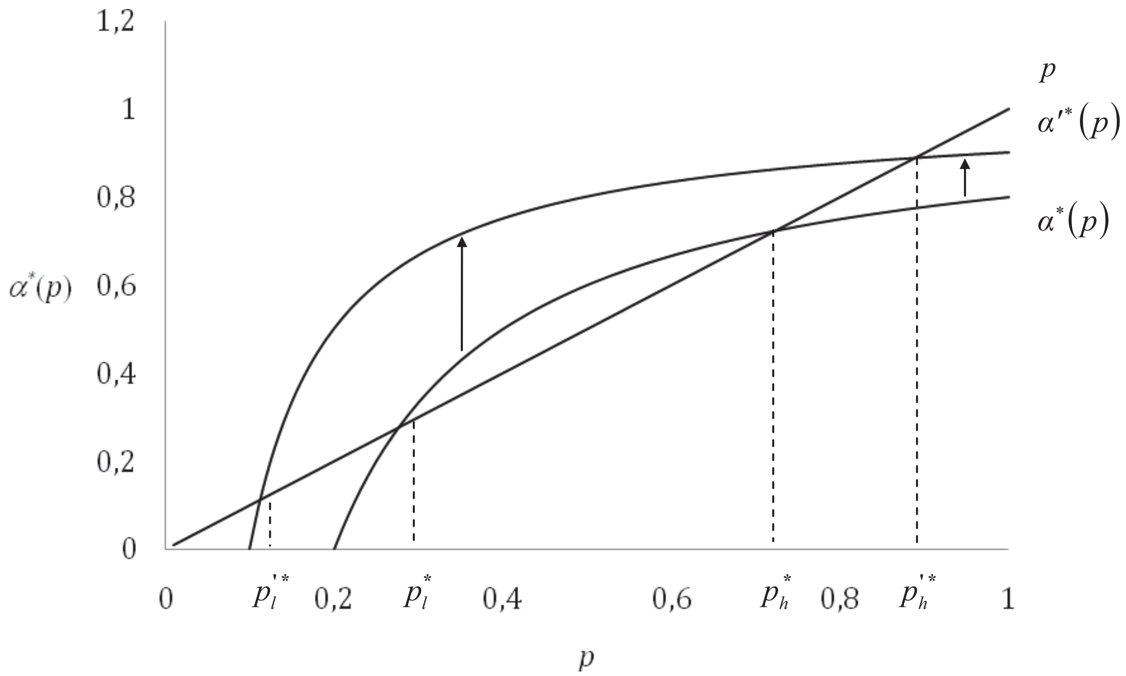
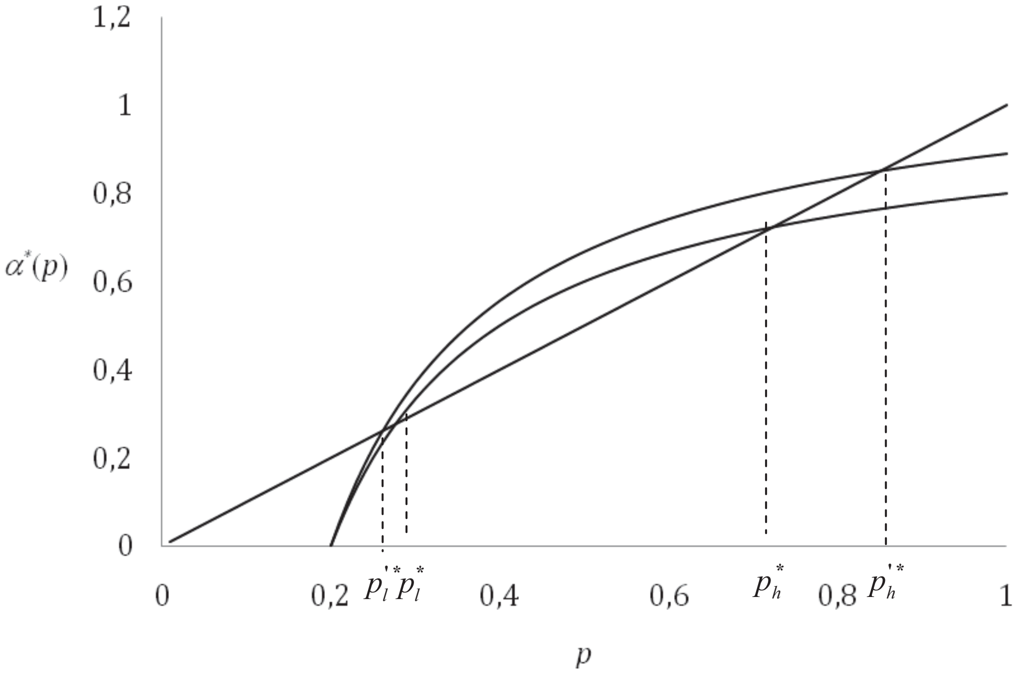


Fig. 1. Multiple equilibria when α distributed uniformly, $\alpha \sim$ *Beta* (1, 1)



Notes: $\downarrow M \Rightarrow\ \uparrow \alpha^*(p)\ \Rightarrow\ \uparrow p_h^*\ \&\downarrow\ p_l^*$

Fig. 2. Subsidizing the fixed cost: effect on equilibrium adoption rates



Notes: $t > 0 \Rightarrow \uparrow \alpha^*(p) \uparrow p_h^* \;\&\downarrow p_l^*$

Fig. 3. Taxing gasoline consumption: the effect on equilibrium adoption rates

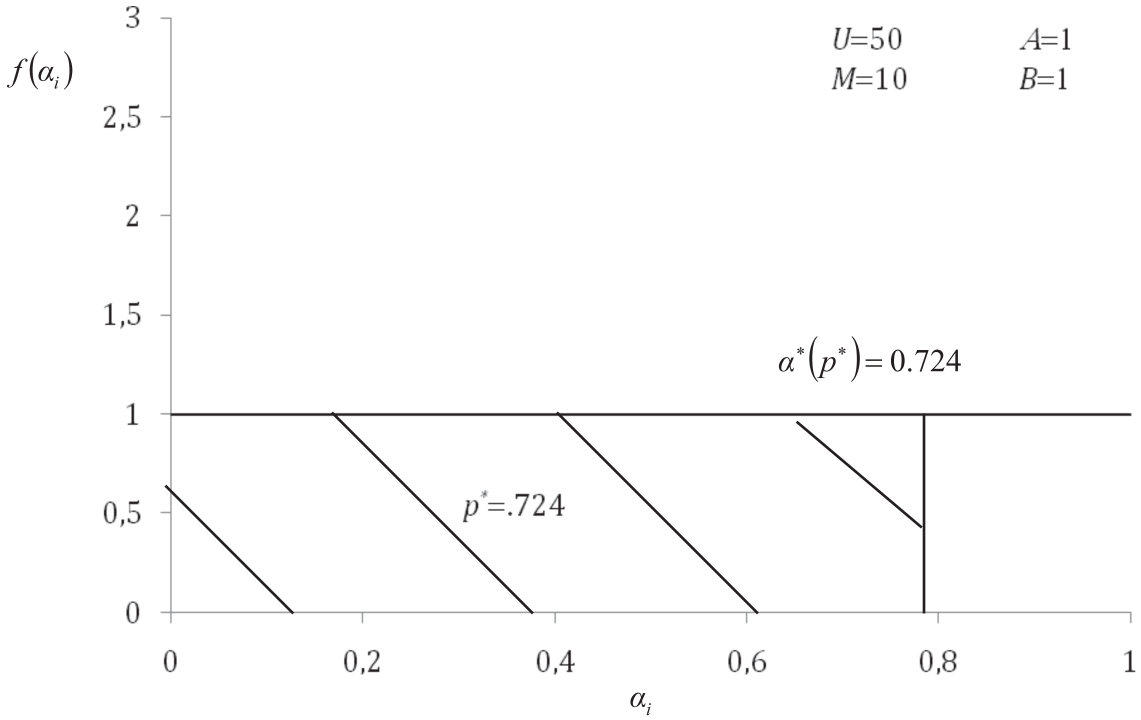


Fig. 4. 'High' equilibrium adoption rate when premiums are distributed uniformly, $\alpha \sim$ *Beta* (1, 1)

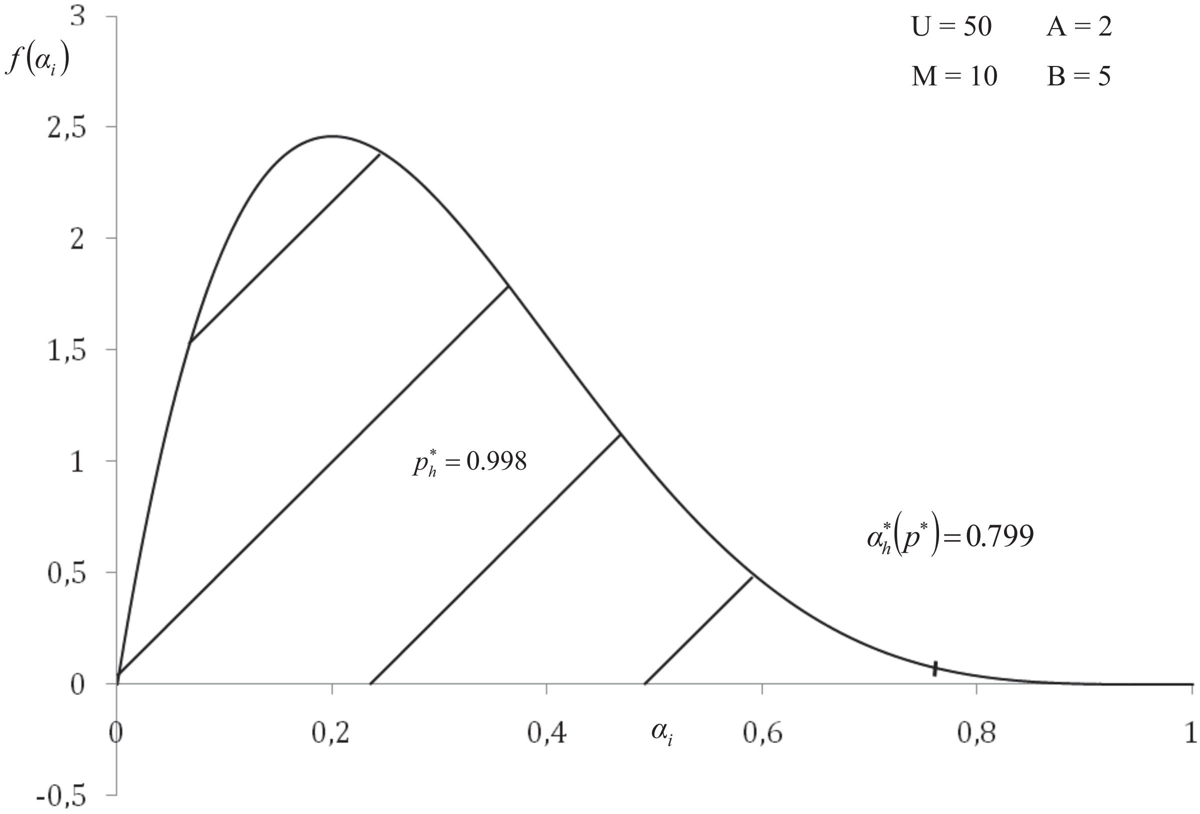


Fig. 5. 'High' equilibrium adoption rate when $\alpha \sim$ *Beta* (2, 5)

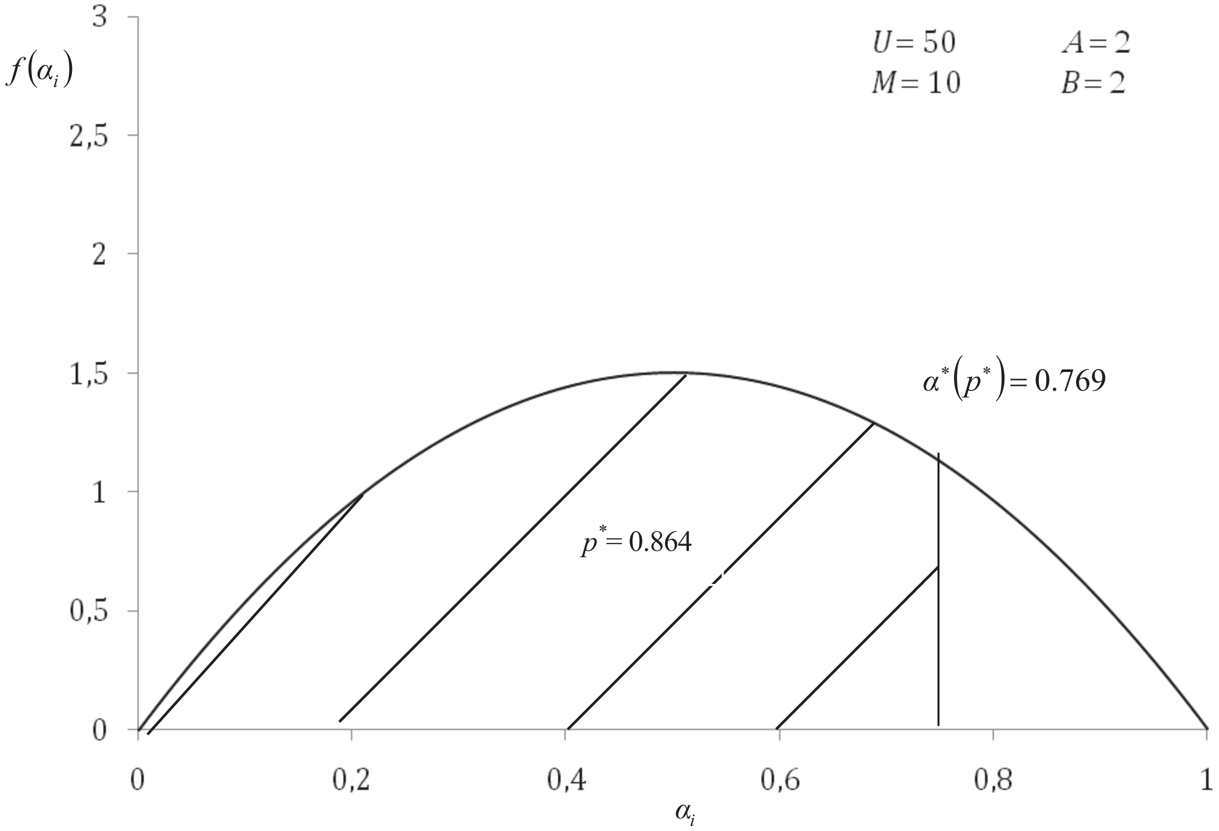


Fig. 6. 'High' equilibrium adoption rate when $\alpha \sim$ *Beta* (2, 2)

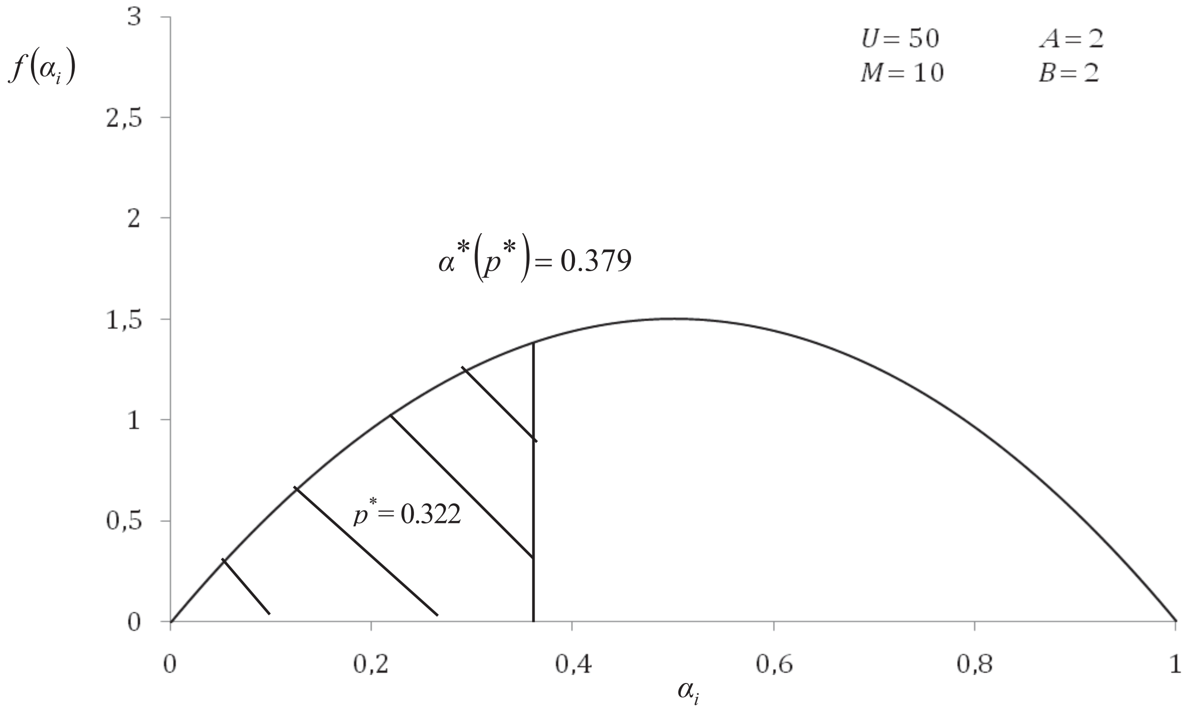


Fig. 7. 'Low' equilibrium adoption rate when $\alpha \sim$ *Beta* (2, 2)

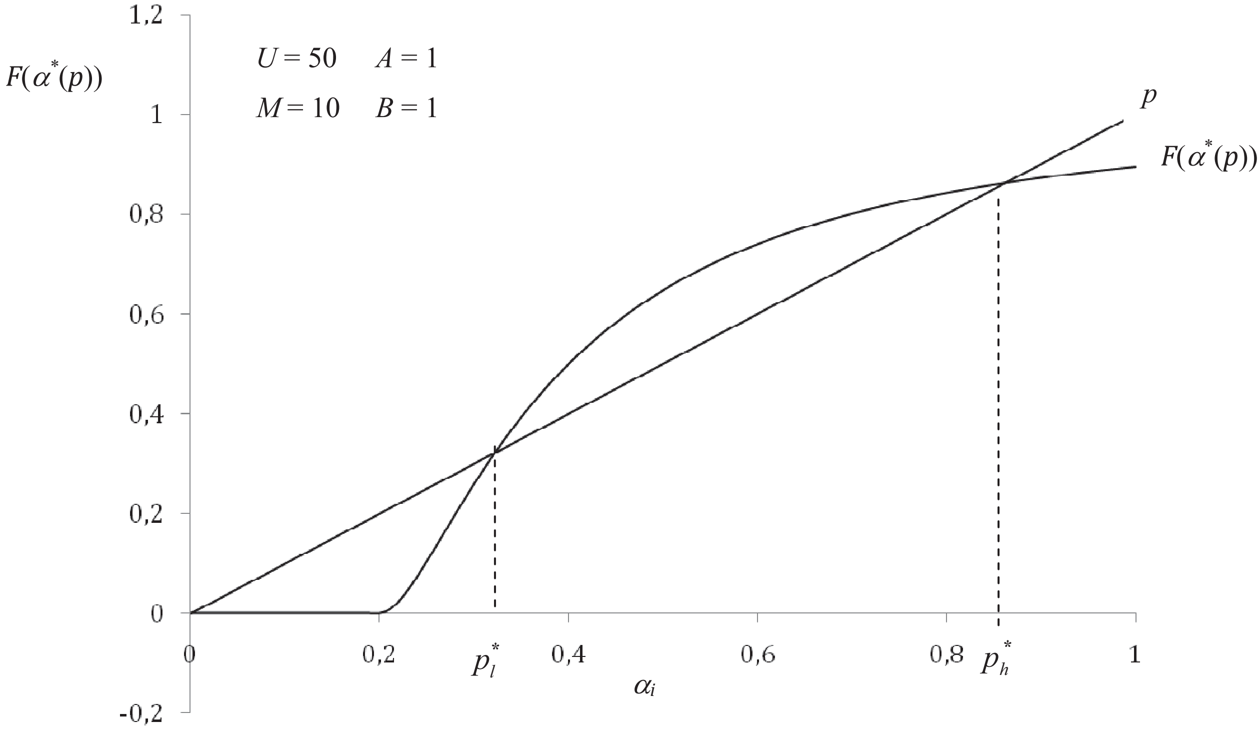


Fig. 8. Multiple equilibria when $\alpha \sim$ *Beta* (2, 2)

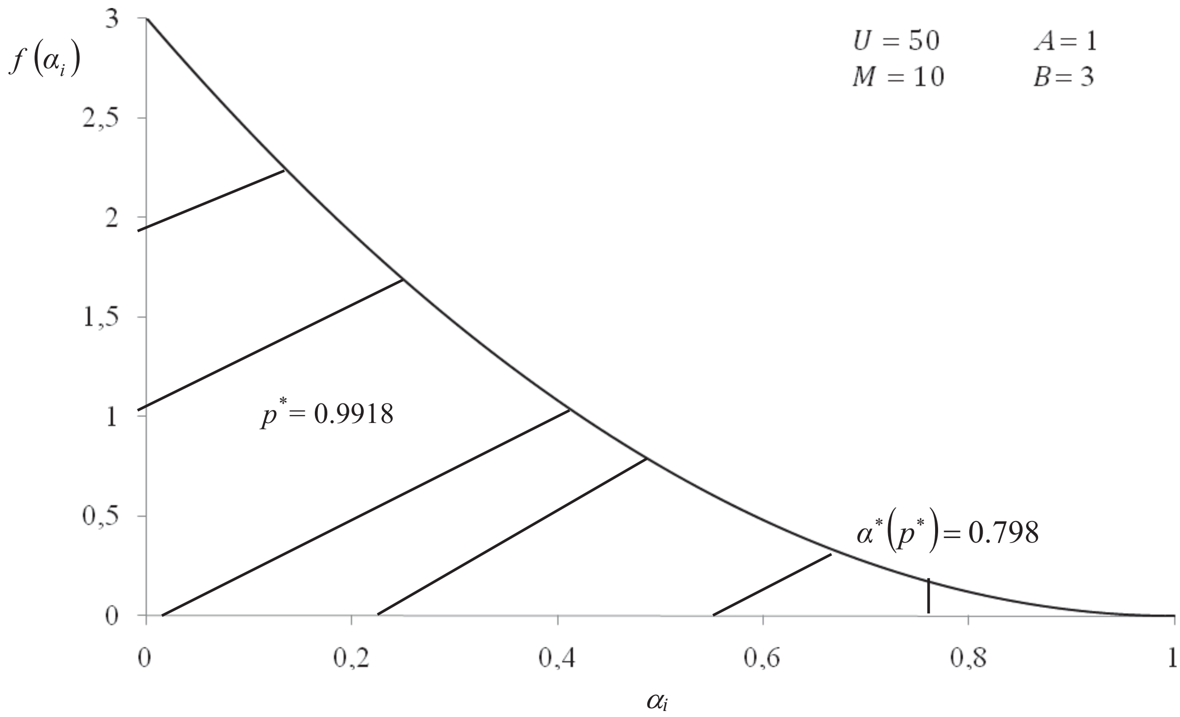


Fig. 9. Equilibrium adoption rate when α ~ *Beta* (1, 3)