Increasing Survivability in a Zombie Epidemic

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Abstract

Once the zombie epidemic has begun, it is not clear which strategy a person or community should adopt to confront the threat. Is it better for an individual to run and hide; or confront the ghouls, gun in hand? Should the community officials encourage citizens to arm themselves and purge the unnatural taint from their neighbourhoods; or keep working and leave the fighting to a well trained militia? Is it better to be in a city, with a high population density; or out in the country where the population density is low?

We have constructed an epidemiological model which we will use to explore these possible scenarios on human and zombie populations. The human population in our model will be divided into three populations classes: workers, who accumulate supplies; militia, who hunt and kill the undead; and moles, who seek to avoid confrontations by hiding. Our models, in addition, keeps track of how many supplies the human community has at hand; where a dwindling supply pool will require the members of the militia and mole classes to join the worker class. We seek to model real communities in a zombie epidemic scenario; where the people face the twin skeletal specters of starvation and the undead.

Our simulations suggest that, whether or not the anthropophagites are actually the reanimated dead, cities are safer than the countryside; exuberant militancy decreases survivability; cowardice is useful if you live in a city; and that our leaders are better off encouraging the population to keep working and leave the zombie fighting to the professionals.

1 Introduction

It is said that the world is only 49 days away from starvation. By this we mean that, given our rates of consumption and global stockpiles of food; if workers were to stop farming or fishing or gathering food, the human population would not survive beyond 2 months.

In the midst of a global zombie epidemic, where national and municipal quarantines would grind trade to a halt; it is safe to assume that famine's skeletal specter would pose as much of a threat as the literal skeletal anthropophagite ghouls. For this reason, survivors would face a morbid calculus as they are forced to choose between gathering food (exposing themselves to slimy teeth and clammy grasping hands); hunting down the zombies in militias (on an empty stomach), or laying low and hiding until the horrific scenario resolves itself (one way or another). Our aim is to build a comprehensive model of this scenario to compare the effectiveness of different strategies at ensuring the survival of humanity.

2 The Model

2.1 Interaction Rates Assuming an Isotropic Population Density

We imagine that the urban or rural landscape in question is divided into N squares; where $N = \text{Geographic Area/UWA}$ where the "Undead Wandering Area" (UWA) is the area through which the average zombie can actively hunt for food over the course of a day. Realistically, the UWA should depend on the geography of the region, as well as the mobility and awareness of the undead. We will, for simplicity sake, assume that the UWA is uniform for all zombies in the geographic region under consideration.

If we assume an isotropic population density, we can quantify the number of people who will, on average, encounter a zombie in the course of a day. If there are S_L living people in the city, and S_Z undead; then over the course of the day there will be $\frac{S_L S_Z}{N}$ encounters between members of the two populations. This model may be overly simple, since it is reasonable to assume that humans will intelligently use geometry and geography to their advantage when confronting the mindless zombies.

Our model keeps track of five different population levels: the undead population, the worker population, the militia population, the mole population, and the total quantity of supplies available to the community. The purpose of dividing the human population into different classes is that we expect that different individual survival strategies will be differentially vulnerable to zombie attack; and will differentially affect the quantity of supplies, and the rate at which the undead population is culled.

Living individuals should be able to change their class according to their circumstance. In the circumstance where a worker encounters a zombie and lives; there will be a chance that this worker will join the militia (to be provided as a "bravado coefficient"), and also a chance that he or she will become a mole, hiding from the zombies (to be provided as a "cowardice coefficient"). We will also assume that an individual who is hunting or in hiding will the act as a drain on the overall stockpile of supplies. When the quantity of supplies is reduced below some threshold, we will force some percentage of the militia and the mole populations to re-join the work-force in order to prevent general starvation. In addition, we will note that if the total number of supplies ever reaches (or dips below) zero; the entire living human population will be completely exterminated.

Our model does not require a population be discrete, since this allows scalability in our results.

2.2 Zombie Population Dynamics

Let S_Z denotes the zombie population and let S_W, S_M,S_H denote the worker population, the militia population and the hiding mole population respectively. Then, on average, in a day the zombie population will change by

$$\frac{\delta S_Z}{\delta t} = Z_1 \frac{S_W S_Z}{N} + Z_2 \frac{S_H S_Z}{N} + (Z_3 - M_1) \frac{S_M S_Z}{N}$$

where the constant coefficient Z_1 (between 0 and 1) is a parameter dictating how effective the average zombie will be at converting a worker; Z_2 (between 0 and 1) is a parameter dictating how effective the average zombie will be at converting a mole (we would expect that $Z_2 < Z_1$). Z_3 dictates how effective a zombie will be at converting a militia member (we would expect that $Z_3 \geq Z_1$, since the militia are less likely to be taken by surprise by a zombie), and M_1 will be dictate the average success with which a militia member will cull a zombie.

2.3 Supply Population Dynamics

In our model, only workers will be able to increase the quantity of supplies. Let R denote the total quantity of supplies held by the human community. We will suppose that, on average, the total quantity of supplies will change by

$$\frac{\delta R}{\delta T} = (R_1 - 1)S_w - (R_2 + 1)S_M - (1 - R_3)S_H$$

Let the supply usage be normalized, assuming that $S = 1$ is the quantity of supplies which a worker will consume per day. R_1 is the rate at which, per day at per worker, supplies are being added to the supply pile. Suppose that the average militia member uses more than 1 supply unit per day ($R_2 > 0$), and that moles will use less than 1 unit of supplies per day ($1 > R_3 > 0$). Parameters R_1, R_2 and R_3 can be fixed to according to the specific scenario we wish to model.

Another important, related quantity, is the number of days of food left. Supposing that workers stopped accumulating supplies, how many days worth of supplies would remain (if population levels remained fixed)? We define this quantity to be:

$$\text{days of food left} = \frac{R}{S_w + (R_2 + 1)S_M + (1 - R_3)S_H} .$$

This quantity can be used to set the thresholds which determine the time when the members of the militia or the mole communities are forced to re-join the worker population.

2.4 Worker Population Dynamics

There will be a variety of factors draining on and replenishing the worker population. A worker who has been scared by a zombie might react by joining the militia or the mole population. There are also natural death rates from disease and old age; and also death by accidents (an untrained militia member with a hair-trigger might easily mistake a worker with his head down for a ghoul). In addition the worker population can be replenished through the natural birth rate and by militia members and moles who are forced to work out of hunger. In our model the worker population changes according to the following equation

$$\frac{\delta S_W}{\delta t} = -\left(Z_1 + \alpha(1 - Z_1) + \beta(1 - Z_1 - \alpha(1 - Z_1))\right)\frac{S_Z S_W}{N}$$

$$+f_1(\mathrm{df})S_M + f_2(\mathrm{df})S_H + F_4 S_W - F_5\frac{S_W S_M}{N}$$

where the parameter α dictates the portion of the populace who will join the mole community after seeing a zombie; β dictates the portion of the remaining survivors who will join the militia. df denotes the days of food left. $f_1(\mathrm{df})$ in this case will be $f_1(df) = \frac{1}{2}H(4 - df)$ where $H(4 - df)$ is a Helmholtz function centred around 4 days (thus, if there are less than 4 days of food left, half of the militia will join the workforce) and $f_2(df) = \frac{1}{2}H(2 - df)$ so that if there are less than 2 days of food left, half the moles will come out of hiding and join the workforce. F_4 will be the overall birth-rate per day (it should be small), and F_5 will describe the odds that a person will be shot accidentally by a militia member.

2.5 Militia Population Dynamics

The militia population will feel similar stress to the worker population. The population will feel a drain from the loss of some members to the zombie populace, or through accidental homicide. We can also expect that some portion of the militia populace will spook after surviving a zombie encounter and join the mole population in hiding. Daily, we would expect the militia to change according to the equation

$$\frac{\delta S_M}{\delta t} = -Z_3\frac{S_Z S_M}{N} + \beta\left(1 - Z_1 - \alpha(1 - Z_1)\right)\frac{S_Z S_W}{N} - M_3\frac{S_M S_M}{N}$$

$$-f_1(df)S_M - \alpha(1 - Z_3)\frac{S_Z S_M}{N} + \beta(1 - Z_2)\frac{S_H S_Z}{N}$$

where M_3 gives the rate of accidental homicide, and all other parameters have been defined already.

2.6 Mole Population Dynamics

Finally, the population in hiding will feel similar population pressures as the other living human populations. It will follow the equation:

$$\frac{\delta S_H}{\delta t} = -Z_2\frac{S_Z S_H}{N} + \alpha(1 - Z_1)\frac{S_Z S_W}{N} - H_3\frac{S_H S_M}{N}$$

$$-f_2(df)S_H + \alpha(1 - Z_3)\frac{S_Z S_M}{N} - \beta(1 - Z_2)\frac{S_H S_Z}{N}$$

where H_3 will be the rate of accidental homicide.

2.7 Comments

The time resolution of this model is one day, which we feel properly encompasses the rate at which decisions and announcements on a municipal level can be made and it also reflects the amount of time it takes for a living victim to be turned into an undead ghoul. This length of time step is also long enough that the minutiae details of any specific zombie attack can be averaged out and ignored.

3 Modelling Specific Scenarios

The most interesting of the parameters are: N, describing to the population density (or the mobility of zombies); M_1, which relates how effective the militia is at culling zombies; α, the coefficient of cowardice; and β, the coefficient of bravado. We feel that these coefficients are the only ones over which an individual or a government might have any control during a zombie epidemic. An individual might choose to move to a rural area (with a larger N) over an urban one; or a government might encourage the citizens to run and hide (a large α), or to organize themselves and fight (a large β), or it might choose to train its militia to be more effective (a large M_1). All others: the birthrate, the rate of accidental homicide, or the virulence of the zombie epidemic, for example, are determined externally.

Throughout our simulations we will be fixing all these externally controlled parameters to values which we feel are sensible. Let the zombie conversion rate of a worker will be $Z_1 = 0.1$ (an average individual worker has little chance of surviving more than 10 zombie encounters in the course of a day); the zombie conversion rate for a mole will then be $Z_2 = 0.05$; and the conversion rate for a militia member will be $Z_3 = 0.15$. Let the natural birth rate be $F_4 = 0.00006$, while the odds of accidental homicide in these dangerous times will be set to $F_5 = M_3 = H_3 = 0.01$. We will suppose that workers, over the course of the day will add $R_1 = 3$ supply units to the stockpile, while militia members will use an additional $R_2 = 1$ units per day, and a mole will decrease his or her personal consumption by $R_3 = 0.4$.

3.1 Humanity is Exterminated Outright

There are specific scenarios in our phase space where humanity will be effectively extinguished. Consider the following example, occurring in a rural community (N=1000) and where the initial population consists of S_W=3000 workers and $S_M = 100$ militia, and one zombie $S_Z = 1$. Let our population's response to the zombie epidemic follow: $\alpha = 0.1$, $\beta = 0.1$ (where 10% of people prove cowards

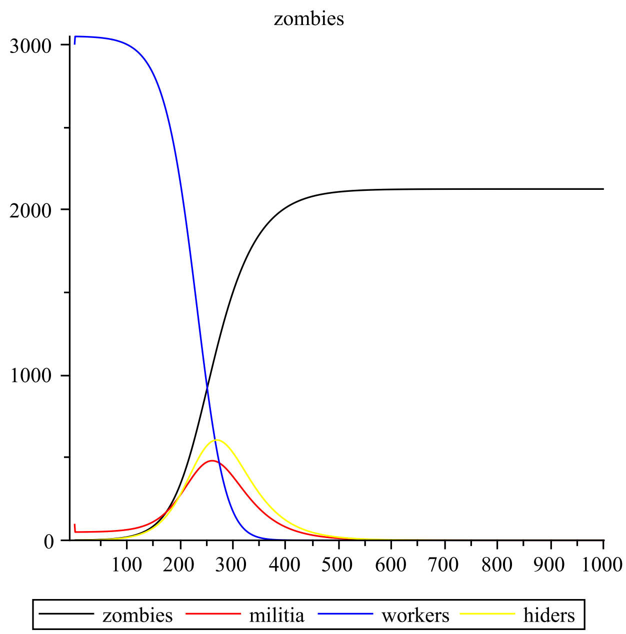

Figure 1: The three human populations, and the zombie population as a function of time. Once zombies become sufficiently common, the militia and mole populations increase, but the militia is not effective at culling the zombie population.

once they have encountered a zombie, and 10% of the remaining people take up arms in the militia) and $M_1 = 0.1$ (where an inexperienced and unskilled militia member will need to shoot at 10 zombies to cull one). The population over time is graphed in Figure (1). In this model, most conflicts between militia and zombies end with the zombies winning; so it's not surprising that the zombies will exterminate the humans outright.

Note that in this scenario, a survivor will be "better off" hiding in a closet (the yellow line denotes the moles); though everyone will die before 2 years are through.

3.2 The Zombie Population is Culled

There are models where the zombies are efficiently and effectively exterminated. The following example is a very rural setting $N = 10000$ where $S_W = 3000$ and $S_Z = 1$. The parameters $\alpha = 0.1$, $\beta = 0.5$ indicate that the population is very eager to fight the zombie threat (almost every male picks up a gun after seeing a zombie), and setting $M_1 = 0.9$ indicates that the militia is very competent at fighting the zombie threat. The degree to which the humans win in this scenario is so outstanding that we needed to graph it on a Log scale (Figure (2))!

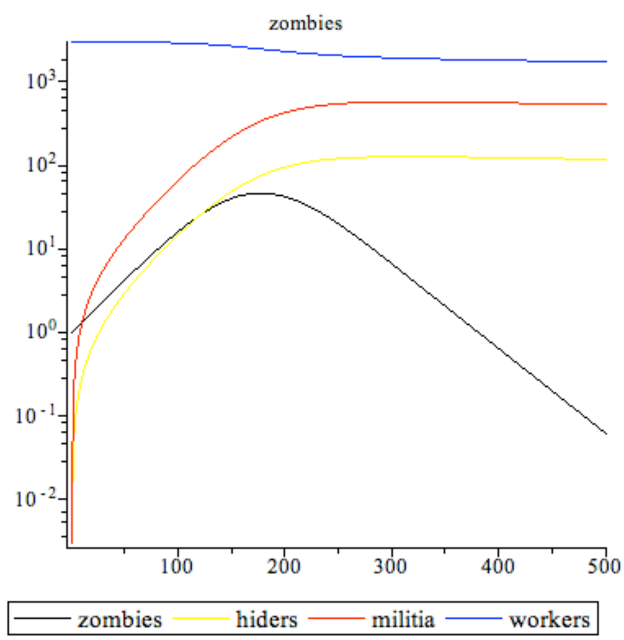

Figure 2: The four populations, on a log scale, showing that once zombies become sufficiently common the militia population will increase and then cull the undead population.

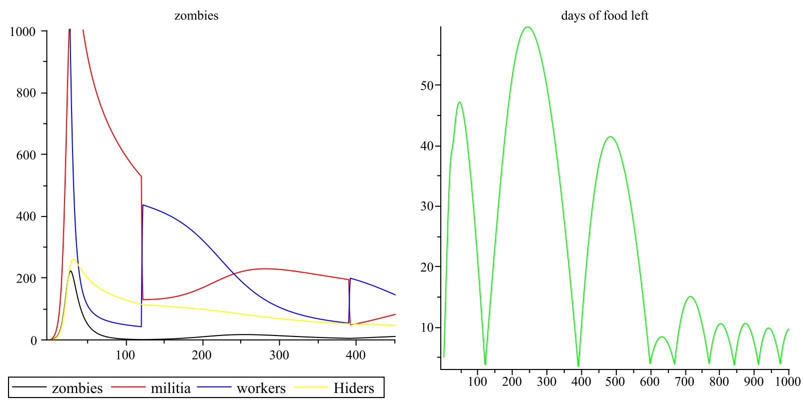

Figure 3: These graphs depict the time evolution of a scenario where the reactionary population cannot completely cull the zombie population before it begins to starve to death. The human population repeatedly switches between dealing with the zombie threat and the threat of starvation, and its numbers dwindle.

Note that in this scenario, once the zombie threat has been dealt with, a large militia population remains. Longer time scale simulations show that the continuing activity of the militia (and the military accidents which result) will result in a gradual decline in overall population.

3.3 Humans Nearly Starve

A third general possible outcome is one where the initial reaction to the zombie threat is overenthusiastic, though ultimately ineffective. The over-consumption of resources by an oversized militia population will lead to a drop in resources; and though the zombie population is partially extinguished, too many people are forced to return to work before the zombie population can be completely extinguished. Eventually, the zombie population re-establishes itself; and the events of the cycle repeats itself, slowly eating away into the total human population until eventual extinction.

Graphs in Figure (3) depicts the simulation of a rural setting, $N = 1000$ $S_W = 3000$, $S_Z = 1$, where $\alpha = 0.1$, $\beta = 0.5$ and $M_1 = 0.25$.

Traditional anti-zombie strategies have relied on quick, strong, universal responses to a zombie epidemic; where a good percentage of the populace is called to arms. We note here, though, that since a zombie epidemic will inevitably cause a quarantine and therefore an inevitable breakdown in trade; a comprehensive response to a zombie threat should additionally account for and respond to the dwindling resources. It is clear that there is a tradeoff between the bravado of a populace and it's productivity; and that with this in mind, an effectively trained militia is more important than a very large (and ineffective) one.

4 How Public Policy Affects Survivability During a Zombie Epidemic

What percentage of zombie survivors should we ask to join the militia? How much training should they be given? Will a rural setting (where the population density is low) require a different strategy than an urban one (with a higher population density)? What difference will it make if the population is cowardly? What difference will it make if the population is stoic?

We have repeatedly run simulations of the type seen in section 3, describing a community starting 1000 people and 5000 units of food with 1 initial zombie for 2000 days (6 years) in the rural scenario; and 1000 days (3 years) in an urban scenario. Over the course of these simulations, we vary the bravado coefficient β and the militia's killing efficiency M_1. We then judge the effectiveness of the zombie cull by ploting the average number of zombies over the last year as a function of the bravado β and the killing efficiency M_1. By looking only at the cases which has an average number of zombies is arbitrarily close to zero, we can identify the minimum bravado required by a population, given the training it provides its soldiers required to completely cull the zombie population.

We then filter these results to differentiate between the scenarios where the final human population is zero, and the scenarios where some humans will survive.

We repeat this process for cases where $\alpha = 0$ (very little cowardice) and $\alpha = 0.3$ (one third of people who see a zombie take to hiding); and for $N = 30$ (corresponding to an urban or suburban environment where you will see 33 people per area unit), and $N = 3000$ (corresponding to a rural environment where you will see only 1 person every 3 area units).

4.1 Managing a Zombie Epidemic in the Urban Scenario

4.1.1 Cowardly City

In this case, the parameters have been set for $\alpha = 0.8$, $N = 30$; corresponding to a situation where a third of the people will panic and become moles after surviving a zombie encounter.

The upper "surface" in Figure (4), where the average number of zombies is -10, depicts the region of the parameter space where no humans are left alive at the end of the simulation. If we focus on the parts of the parameter space where humanity has survived and all the zombies were eliminated, we end up with Figure (5) which demonstrates that, even if most of the populace proves cowardly; so long as the militia is well trained, humanity can survive. Note that this result holds even if less than a quarter of the survivors of a zombie attack who DO NOT run away enlist in the militia.

Average Zombie Population Over the Last Year (Cowardly, Urban)

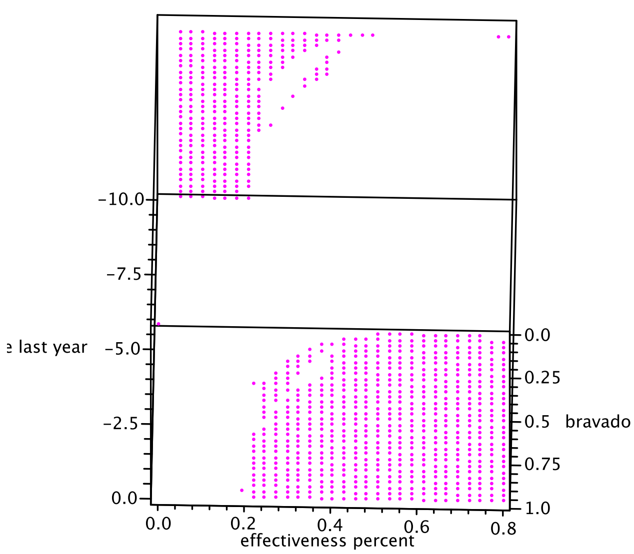

Figure 4: This plot differentiates between the parts of the parameter space where Humanity has survived the zombie epidemic, and the regions where all Humanity is extinct. This represents the outcome for a cowardly urban scenario.

Parameter Space Where the Zombie Population Has Been Culled (Cowardly, Urban)

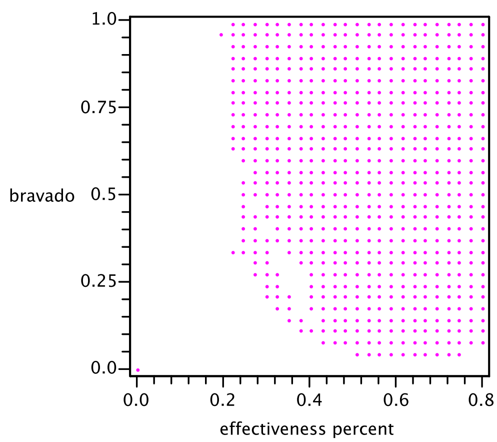

Figure 5: This plot demonstrates the parameter space where the entire zombie population has been culled after 3 years. This represents the outcome for a cowardly urban scenario.

Average Zombie Population Over the Last Year (Average Bravery, Urban)

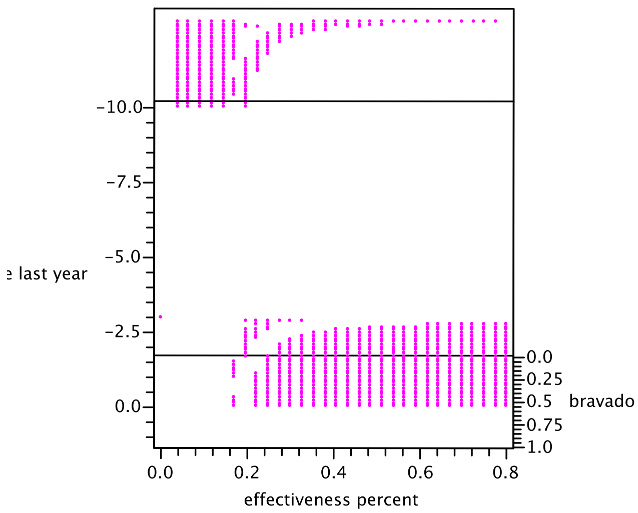

Figure 6: This plot demonstrates the parameter space where the entire zombie population has been culled after 3 years. This represents the outcome for an average urban scenario.

4.1.2 Average City

In this set of simulations, the parameters have been set for $\alpha = 0.3$, $N = 30$; corresponding to a situation where one third of people panic and go into hiding after meeting a zombie. Figure (6) clearly shows the parameter space where the human race has been exterminated.

Again, if we focus only on the parameter space where humanity has survived and has also completely culled the zombie population we end up with Figure (7):

4.1.3 Stoic City

In this case, the parameters have been set for $\alpha = 0$, $N = 30$; corresponding to a situation where no one in the city panics and hides after seeing a zombie. Again, the data points at the “top” surface in Figure (8) corresponds to the parameter space where humanity has died out.

Again the parameter space where humanity has survived and has culled the zombie population is depicted in Figure (9).

Comparing graph in Figure (9) to the graph in Figure (5) (where the city

Parameter Space Where the Zombie Population Has Been Culled (Average Bravery, Urban)

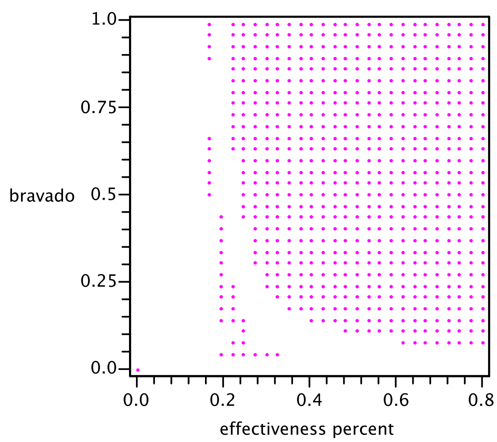

Figure 7: This plot demonstrates the parameter space where the entire zombie population has been culled after 3 years. This represents the outcome for an average urban scenario.

Average Zombie Population Over the Last Year (Stoic, Urban)

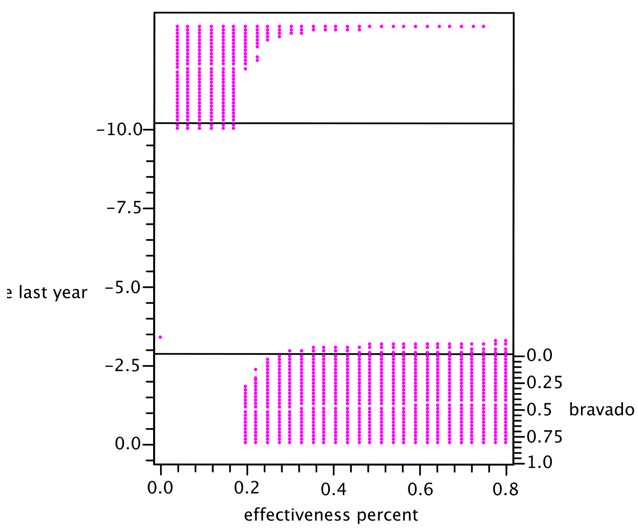

Figure 8: This plot demonstrates the parameter space where the entire zombie population has been culled after 3 years. This represents the outcome for an stoic urban scenario.

Parameter Space Where the Zombie Population Has Been Culled (Stoic, Urban)

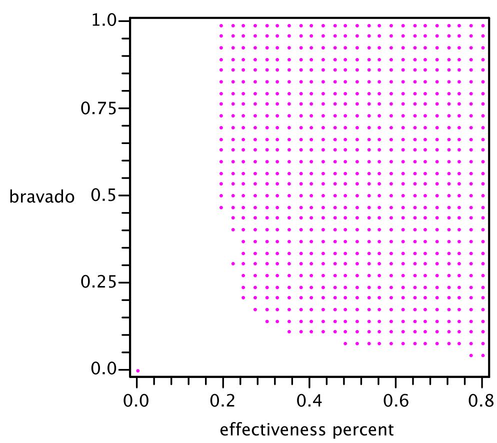

Figure 9: This plot demonstrates the parameter space where the entire zombie population has been culled after 3 years. This represents the outcome for an stoic urban scenario.

was full of cowards) suggests some interesting conclusions. Firstly, a cowardly city requires the use of a (much) smaller militia, (supposing that the militia is well trained). Conversely, if the militia is poorly trained (an effectiveness of about 0.2), a city will have a better chance at surviving if its citizens maintain a "stiff upper lip" and continue working, rather than running away and hiding.

4.2 The Countryside

The dynamics of a zombie epidemic in a rural setting (where both people and zombies are both few and far-between) are different than those in the city: since the rate with which zombies are randomly encountered is relatively low compared to the rate at which supplies are gathered and consumed. Whereas the urban zombie scenarios resolve themselves relatively quickly, it will take a long time for any conclusion to be reached in the rural scenarios.

In our simulated scenarios, we shall take the presence of any zombies after 6 years as a sign that the community has failed to cull the undead from their streets and fields.

4.2.1 Cowardly Countryside

In this scenario, the parameters have been set to $\alpha = 0.8$, $N = 3000$; corresponding to a very rural environment (one person can wander 3 days at random before seeing another person) where eighty percent of the workers who see a zombie will go into hiding. Figure (10) shows the region of the parameter space where all humans have been exterminated after six years.

Figure (11) demonstrates that, even after six years, there is a large are of the parameter space where both humans and zombies remain (with the zombie population numbering in the hundreds)!

Figure (12) plots only the area of the parameter space where humanity has succeeded in culling the undead population, and the results are depressingly small.

We conclude that if humanity is to survive a zombie epidemic in a rural setting; and if most of the human population are cowardly, then most of the few who are not will have to fight, and fight very very skillfully!

4.2.2 Normal Countryside

In this set of simulations, the parameters have been set to be $\alpha = 0.3$, $N = 3000$; corresponding to a very rural environment (you can wander 3 days at random before seeing a person) where one third of the workers who survive a zombie encounter will go into hiding. Figure (13) plots the regions of the parameter space where all of humanity has vanished after six years.

Figure (14) plots the area of the parameter space where some population of humans will remain after six years.

Figure (15) plots the area of the parameter space wherein there are fewer than 0.02 zombies remaining in the last year on average.

Parameter Space Where the Human Population Has Been Exterminated (Cowardly, Rural)

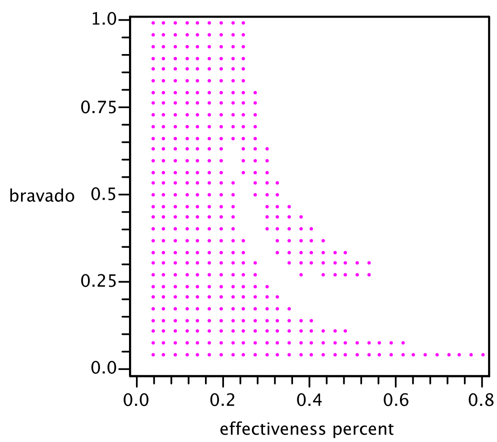

Figure 10: This plot demonstrates the parameter space where the entire human population has been exterminated after 6 years. This represents the outcome for an cowardly rural scenario.

Average Zombie Population Over the Last Year (Cowardly, Rural)

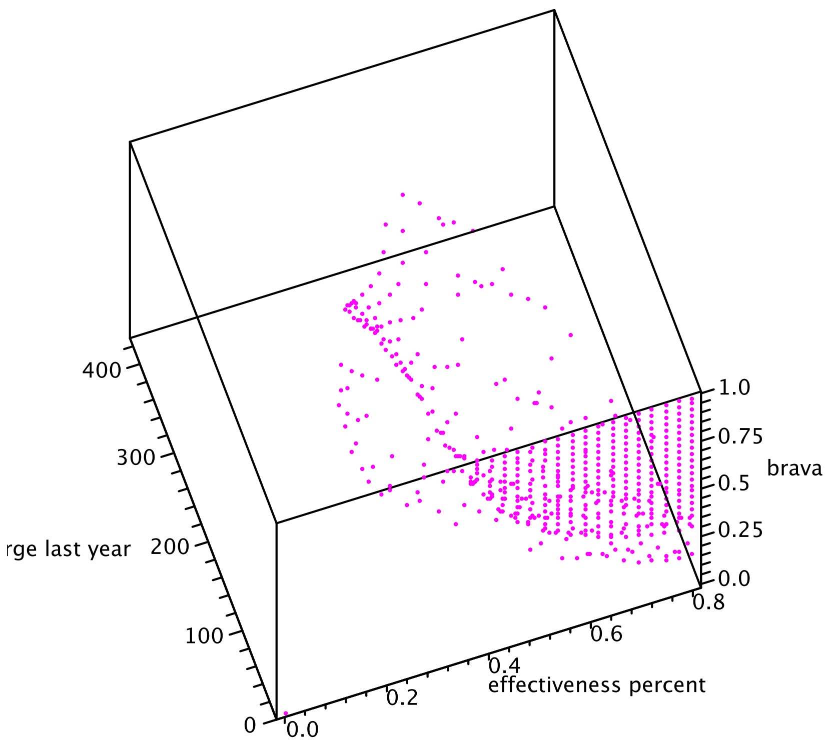

Figure 11: This plot demonstrates average number of zombies remaining during the last year as a function of bravado and the effectiveness of the militia. This represents the outcome for an cowardly rural scenario.

Parameter Space Where the Zombie Population Has Been Culled (Cowardly, Rural)

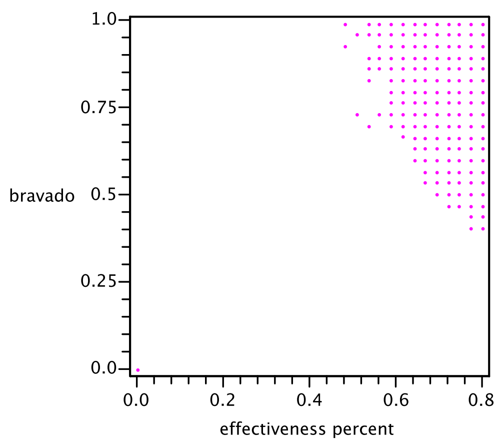

Figure 12: This plot demonstrates the parameter space where the entire zombie population has been culled after 6 years. This represents the outcome for an cowardly rural scenario.

Parameter Space Where the Human Population Has Been Exterminated (Average Bravery, Rural)

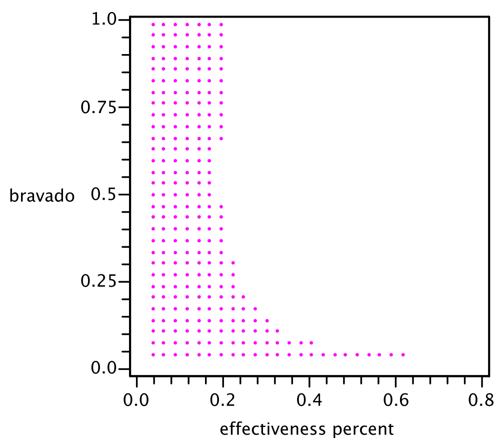

Figure 13: This plot demonstrates the parameter space where the entire human population has been exterminated after 6 years. This represents the outcome for an average rural scenario.

Average Zombie Population Over the Last Year (Average Bravery, Rural)

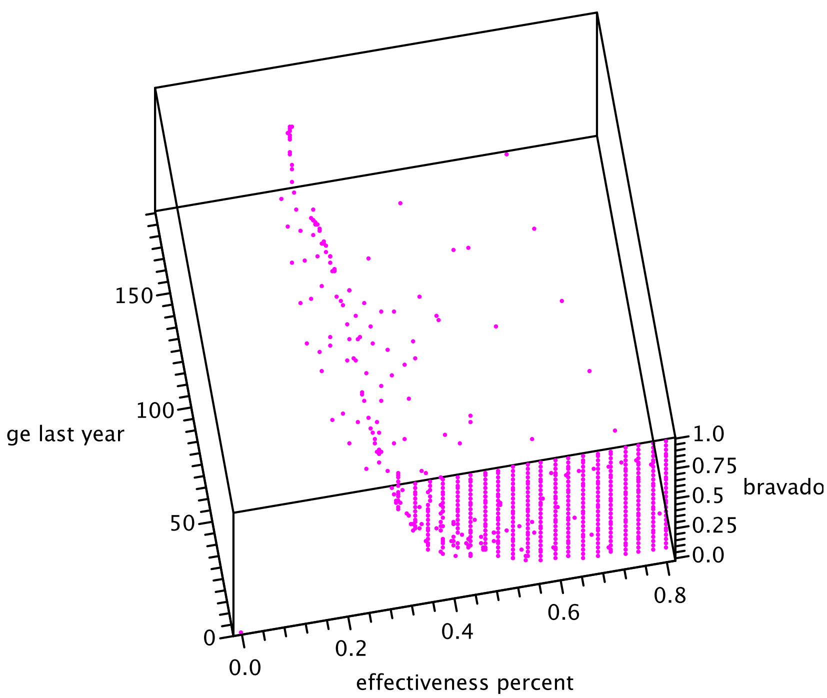

Figure 14: This plot demonstrates average number of zombies remaining during the last year as a function of bravado and the effectiveness of the militia. This represents the outcome for an average rural scenario.

Parameter Space Where the Zombie Population Has Been Culled (Average Bravery, Rural)

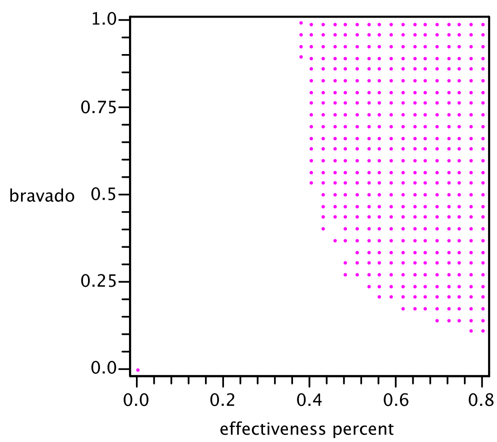

Figure 15: This plot demonstrates the parameter space where the entire zombie population has been culled after 6 years. This represents the outcome for an average rural scenario.

Parameter Space Where the Human Population Has Been Exterminated (Stoic, Rural)

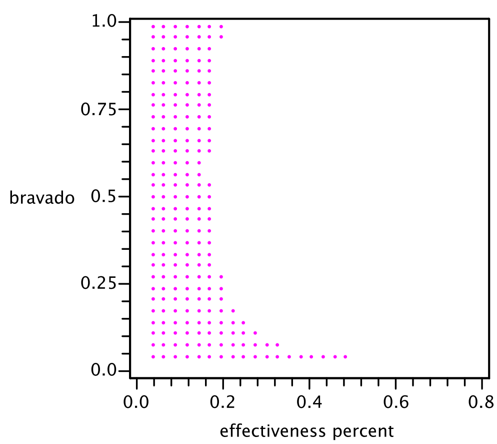

Figure 16: This plot demonstrates the parameter space where the entire human population has been exterminated after 6 years. This represents the outcome for a stoic rural scenario.

4.2.3 Stoic Countryside

In this set of simulations, the parameters have been set to be: $\alpha = 0$, $N = 3000$; corresponding to a very rural environment, where no one who survives a zombie encounter will go into hiding. As before, Figure (16) demonstrates the area of the parameter space where all humanity has died within six years.

Figure (17) plots the average number of zombies remaining over the last year as a function of bravado and the effectiveness of the militia. Figure (18)shows the area of the parameter space where the undead population has been completely culled.

4.2.4 Remarks

It is clear, due to the slower rate at which zombies appear in rural regions, that people need to be a lot BRAVER on average. As in the urban scenario, total eradication of the zombies depends strongly on the efficiency of the militia and has little to do with the bravado of the general populace. Though we note that, in the scenario where most of the rural populace is VERY cowardly, a great deal

Average Zombie Population Over the Last Year (Stoic, Rural)

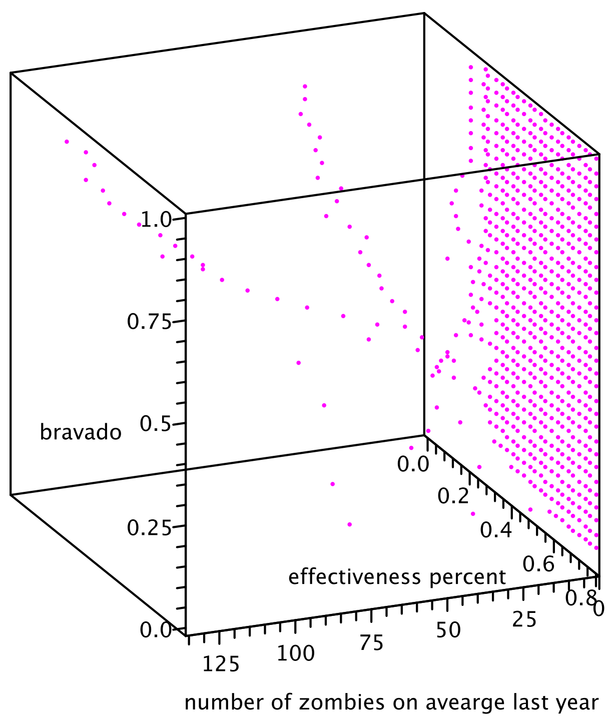

Figure 17: This plot demonstrates average number of zombies remaining during the last year as a function of bravado and the effectiveness of the militia. This represents the outcome for a stoic rural scenario.

Parameter Space Where the Zombie Population Has Been Culled (Stoic, Rural)

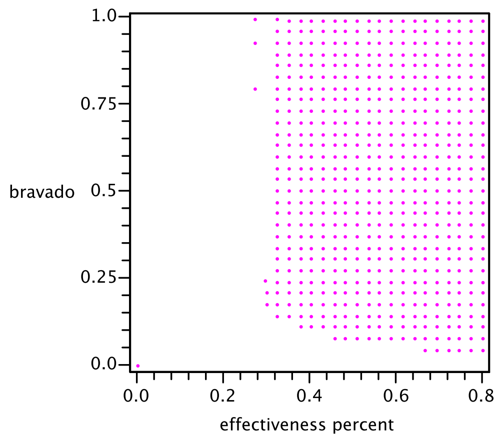

Figure 18: This plot demonstrates the parameter space where the entire zombie population has been culled after 6 years. This represents the outcome for a stoic rural scenario.

of bravado and skill are required of the few who do fight.

5 The Romero Scenario

In the previous model, it is understood that the only cause of zombification of an individual is through a direct physical encounter with a member of the undead population. In these situations, zombification is due to a transmissible agent, and it travels much like a disease. This is not necessarily the ONLY scenario where zombification can occur: there is a well known and far grimmer scenario where zombification is due to the reanimation of the dead!

5.1 Altered Transmission Equations

In this scenario, every human who has died but whose brain has NOT been destroyed will become a ghoul. We refer to this as the *Romero scenario*; and we can model it by using a slightly altered set of equations. Firstly, we should note that in our previous model there was a good deal of mortality due to the dangers of having a militia wander about the community shooting at everything that moves. In the prior model, the victims of accidental death were not added to the zombie population; but in the Romero scenario are.

$$\frac{\delta S_Z}{\delta t} = Z_1 \frac{S_W S_Z}{N} + Z_2 \frac{S_H S_Z}{N} + (Z_3 - M_1) \frac{S_M S_Z}{N}$$

$$+F_5 \frac{S_W S_M}{N} + M_3 \frac{S_M S_M}{N} + H_3 \frac{S_H S_M}{N}$$

In the prior model, accidental homicide was not a dominant effect on the outcomes of the simulations, and so the relevant parameters were fixed by *ansatz*. In the Romero scenario, accidental homicide can act as a mechanism for generating undead. We feel that the values of the coefficients should depend on how much training the militia has had: a well trained and efficient militia will cause fewer accidental homicides, and vice-versa. Thus, as we model the Romero scenario, we will relate the coefficients of accidental homicide H_3, F_5, M_3 to the coefficient of zombie-killing efficiency M_1:

$$F_5 = M_3 = H_3 = \frac{1 - M_1}{10}$$

Let us reconstruct the plots of section 4 for the case of the Romero scenario.

5.2 Simulation Results

5.2.1 Stoic City ($\alpha = 0,\ N = 30$)

The parameter space plot where humanity is exterminated after 6 years is plotted in Figure (19). The parameter space showing the scenarios where humanity has successfully culled the zombies is plotted in Figure (20).

Parameter Space Where the Human Population Has Been Exterminated (Stoic, Urban, Romero)

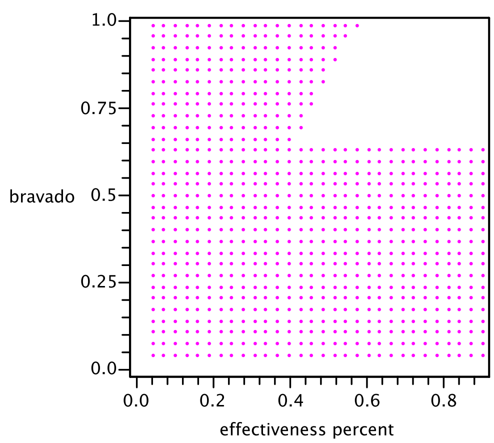

Figure 19: This plot demonstrates the parameter space where the entire human population has been exterminated after 6 years. This represents the outcome for an stoic urban scenario.

Parameter Space Where the Zombie Population Has Been Culled (Stoic, Urban, Romero)

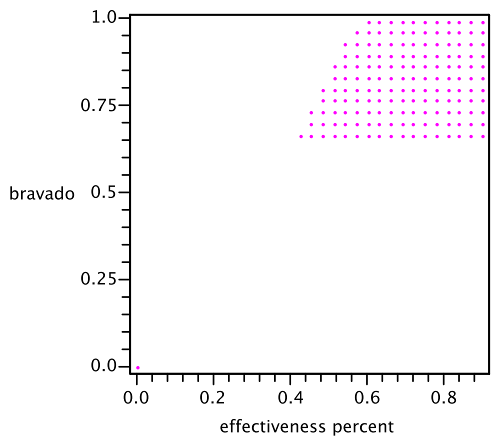

Figure 20: This plot demonstrates the parameter space where the entire zombie population has been culled after 6 years. This represents the outcome for a stoic urban scenario.

Parameter Space Where the Human Population Has Been Exterminated (Cowardly, Urban, Romero)

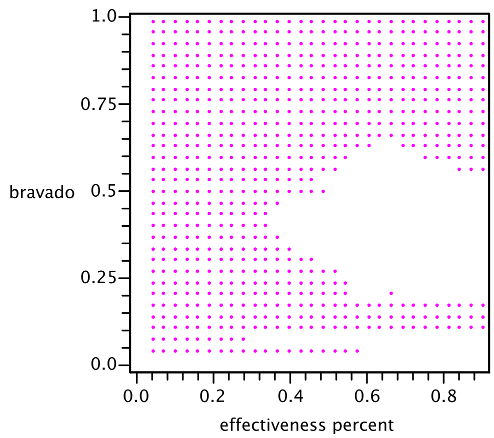

Figure 21: This plot demonstrates the parameter space where the entire human population has been exterminated after 6 years. This represents the outcome for a cowardly urban scenario.

Even in a stoic city, a good deal of bravado and skill is required by the populace to survive a Romero scenario.

5.2.2 Cowardly City ($\alpha = 0.8$, $N = 30$)

The parameter space plot where humanity is exterminated after 6 years is plotted in Figure (21).

The parameter space showing the scenarios where the humans have successfully culled the zombie population after 6 years is plotted in Figure (22)

Note that, while a high efficiency is required from the militia, only a small amount of bravado is required. In this scenario, a bravado of 0.5 corresponds to one out of every 20 people joining the militia after meeting a zombie. Indeed, the lower region of the phase space corresponds to only one out of every 100 people who see a zombie joining the militia. Also, note that in the Romero scenario, a highly stoic attitude in a city offers lower odds at survivability than a cowardly one, since the survivable regions of the parameter space in Figure (22) are more accessible than the survivable regions of the parameter space Figure (20).

Parameter Space Where the Zombie Population Has Been Culled (Cowardly, Urban, Romero)

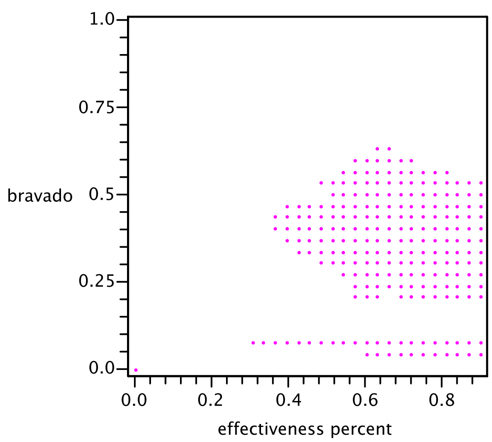

Figure 22: This plot demonstrates the parameter space where the entire zombie population has been culled after 6 years. This represents the outcome for a cowardly urban scenario.

Average Zombie Population Over the Last Year (Stoic, Rural, Romero)

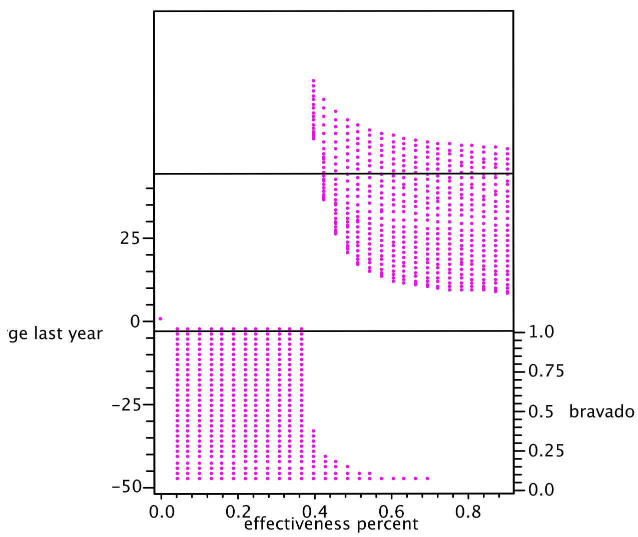

Figure 23: This plot demonstrates average number of zombies remaining during the last year as a function of bravado and the effectiveness of the militia. This represents the outcome for a stoic rural scenario.

5.2.3 Stoic Countryside ($\alpha = 0,\ N = 3000$)

In section 4.2 we encouraged the people in the countryside to adopt a stoic attitude in order to fix a larger parameter space where humanity would succeed. It is not clear, however, that this advice will still hold in the Romero scenario, where

In a rural Romero scenario, where the populace maintains a "stiff upper lip" in the face of a zombie epidemic, the plot of the parameter space where humanity is exterminated is shown in Figure (23). In this plot, the lower surface represents the parameter space where humanity is exterminated. This region is shown explicitly in Figure (24).

Unlike the previous simulations, in this scenario there will be no cases where the zombie population has been completely extinguished (according to the standards we have been using up until now) within siz years. The parameter space where fewer than 10 zombies remain at the end of the 6 years is displayed in Figure (25).

We conclude that in the Romero scenario, the strategy recommended in section 4.2 would lead to, at the most optimistic, an endemic zombie population in rural areas.

Parameter Space Where the Human Population Has Been Exterminated (Stoic, Rural, Romero)

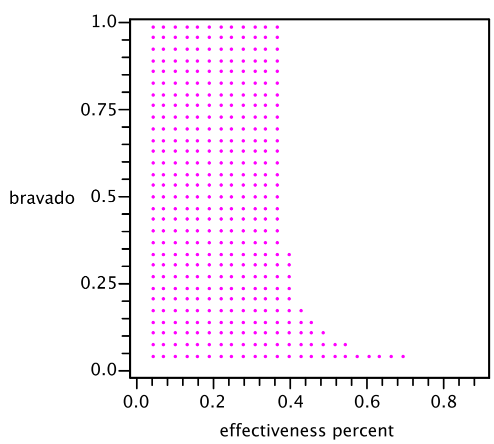

Figure 24: This plot demonstrates the parameter space where the entire human population has been exterminated after 6 years. This represents the outcome for a stoic rural scenario.

Parameter Space Where the Zombie Population Has *Nearly* Been culled (Stoic, Rural, Romero)

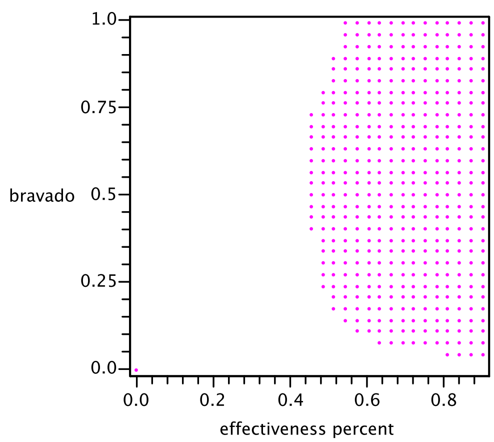

Figure 25: This plot demonstrates the parameter space where the entire zombie population has been maintained at less than 10 at the end of 6 years. This represents the outcome for a stoic rural scenario.

Parameter Space Where the Human Population Has Been Exterminated (Cowardly, Rural, Romero)

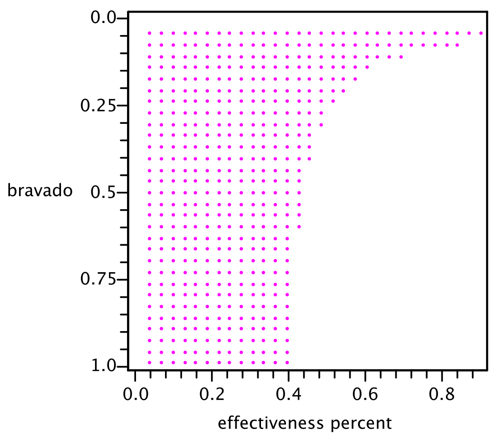

Figure 26: This plot demonstrates the parameter space where the entire human population has been exterminated after 6 years. This represents the outcome for a stoic rural scenario.

5.2.4 Cowardly Countryside ($\alpha = 0.8,\ N = 3000$)

The results of the rural simulation where the workers are very cowardly are similar to the stoic rural simulation: there are no region of the parameter space where zombies have been successfully culled. Consider the parameter space where humanity has been completely exterminated in Figure (26), and compare it with the equivalent plot for a stoic countryside (Figure (24)). It is clear that, even in the Romero scenario, the rural workers are better off stoic than cowardly (though they are still fighting a battle they cannot win).

5.2.5 Standing Military in Cowardly Country ($\alpha = 0.8,\ N = 3000,\ S_M = 100$)

Suppose that there is an army base amid the countryside where a Romero zombie epidemic is underway. How will having a trained militia population at the start of the zombie plague affect the outcome we saw in section 5.2.4? We modeled this scenario by adding an extra 100 militia members at the start of the simulation we performed in section 5.2.4. Again, There was no region of the

Parameter Space Where the Human Population Has Been Exterminated (Cowardly, Rural, Romero, Army Base)

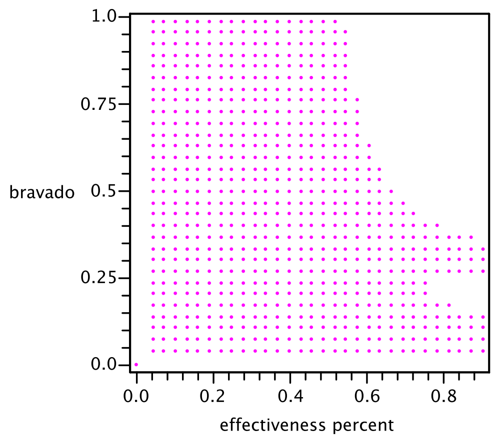

Figure 27: This plot demonstrates the parameter space where the entire human population has been exterminated after 6 years. This represents the outcome for a stoic rural scenario where a reasonable militia population is initially present.

parameter space where the zombie population was culled within 6 years. The parameter space where all of humanity had died out (Figure (27)) seemed quite pessimistic.

In the Romero scenario, having a standing army initially present in rural environment will decrease the worker community's odds at survival.

5.2.6 Military Dictatorship

Could a military dictatorship, which possesses a very large standing army, survive the Romero scenario? By a *military dictatorship*, we will assume that, prior to the zombie epidemic; the country will have the maximum stable military population:

$$\frac{dR}{dt} = 0 \rightarrow S_w \frac{R_1 - 1}{R_2 + 1} = S_M \ .$$

Given our assumed values of R_1,R_2: $\frac{R_1-1}{R_2+1} = \frac{2}{2} = 1$. Thus, given the production levels of the workers: $S_w = S_m$ (initially).

Parameter Space Where the Human Population Has Been Exterminated (Cowardly, Rural, Romero, Saturated Military)

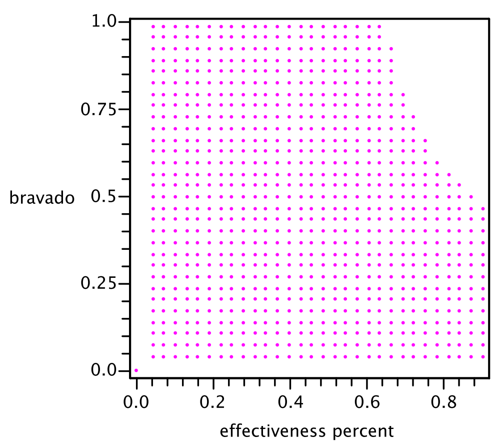

Figure 28: This plot demonstrates the parameter space where the entire human population has been exterminated after 6 years. This represents the outcome for a cowardly rural scenario with a saturated military population.

We repeated our simulation for the cowardly rural scenario with $S_M = 1000$. The parameter space where mankind was completely exterminated out is displayed in Figure (28).

Again, there were no solutions where the zombie population had been successfully culled, and we see that the existance of a very large standing military will decrease the survivability of the scenario.

6 Discussion

Our model successfully modeled the complication of resource management during a zombie epidemic. We showed that the populace's lack of productivity (if workers become consumed with fighting rather than producing) can lead to starvation, which can result in a resurgent zombie population. It is clear that when it comes to successfully culling an undead population, a very efficient and small militia is more effective than a large but poorly trained mob.

In addition, we explored the effect that the cowardliness or bravado of the population had on the overall survivability in a zombie epidemic. In the urban scenario, where the population density was high; it did not matter whether the population was cowardly or stoic. Provided that the militia members are on average at least twice as deadly to the zombies as the zombies are to the militia members, a militia of almost any size would serve to clear the city over the course of a few years.

In a rural scenario, the personal attitudes in the populace played a much more important role in the overall survivability. Since the zombie hunt will *burn* at a much slower rate than in the city, it is important that the population not quit working to hide or fight each time they see a zombie. It seems that stoicism is a requirement of living in the countryside.

We repeated these simulations for the Romero scenario, where the zombie population is made up of the reanimated dead, rather than infected insane anthropophagites. These models will differ from the prior model since victims of accidental homicide will also join the zombie population. Thus, an untrained militia will act as a double edged sword. In the Romero scenarios, we showed that a zombie population will become endemic to rural environments independent of how society reacts to the epidemic. If the dead rise, we would advise individuals to move to the city.