War, resource competition, and development

(preliminary)

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Abstract: A growth model is set up where war, population, and technology interact endogenously, capturing some trends observed throughout long-run human history. Agents compete for food for their survival. In environments with scarce resources – meaning high population density, and/or low levels of technology – agents allocate more of their time to fight for resources, which translates into a higher probability of war. Because technology is an input both in food production and conflict, technological progress exerts two opposing effects on killing: on the one hand, it mitigates resource scarcity, making war less likely; on the other hand, *if* war breaks out it is deadlier the more advanced is the level of technology. An economy may transit onto a path of peaceful prosperity where standards of living are rising, and the probability of war approaches zero. In the transition, however, it may pass a phase of excessive killing, as rising living standards have not yet made war an improbable event, but rising levels of technology have made war extremely lethal if and when it breaks out. A preliminary quantitative exercise indicates that the model can replicate an inversely U-shaped pattern of war and genocide deaths seen worldwide over the 20th century. Many of the underlying mechanisms also seem consistent with some important stylized facts of growth and war, in particular in 20th century Europe.

1 Introduction

War is a an important and fascinating macroeconomic phenomenon, but so far not much explored in the macroeconomic literature. In the world today, rich countries (in particular democracies) tend to be less prone to war than poor. Within regions war displays interesting patterns over time: consider e.g. how wars between the European great powers of the 19th and 20th century have been followed by peaceful co-existence between the same nations and peoples today. The very origin of violence and war – especially among poor countries, where conflicts are most common – often seems linked to economic problems, such as competition for land and other scarce resources (e.g. Miguel et al. 2004). This paper tries to formulate a growth theory where conflicts are endogenous, and which fits with long-run macroeconomic evidence from e.g. European history.

More precisely, the task undertaken here is to explain a transition from Malthusian stagnation to modern growth, together with an initial rise and subsequent decline in the human toll in war and genocide occurring in this process. Figure 1 shows the annualized killings from war and genocide based on 218 events listed by Rummel (1997, Table 16.A).[1] As seen, killing shows an upward trend over roughly the first half of the 20th century, and has then been declining. This holds both for the total number of people killed, and (more visibly) for the rate of killings per 100,000 world population. The pattern is driven largely by well known events, in particular the two world wars and the Holocaust; in Europe peace followed after 1945 but genocides continued in e.g. China, Soviet and Cambodia. Although the timing differs, the general pattern in Figure 1 is consistent also with other sources and ways

[1]The deaths reported in Figure 1 refer to both war and genocide, but these are highly correlated in Rummel's data: genocides tend to be committed in times of war. The number of people killed annually in each war/genocide is assumed to be uniformly distributed from the first to the last year in which it took place, as reported by Rummel. In many cases the total number of victims of a genocide is not well established; in Figure 1 the total death toll for each event is chosen as the midpoints of the upper and lower bounds reported.

to measure the costs and intensities of war. For example, Marshall and Gurr (2005) find that the total number of wars fought worldwide peaked in the 1980's.

The starting point of the theory proposed here to explain this pattern is that war and conflict (and by extension genocide) arises through competition for scarce resources. More precisely, war is here thought of in the context of the evolution over time of population, technology, and resource competition, in ways illustrated in the flow chart in Figure 2. The central mechanisms are Malthusian. First of all, low mortality in one period means higher population density in the next. This leads to less food per head, which in turn leads to higher mortality, and thus a check on population. In Figure 2 this is captured by one set of (red solid) arrows.

As explained, a less conventional Malthusian mechanism is that agents here also compete for food for their survival. In environments with scarce resources (associated with high population density, and/or low levels of technology) agents allocate more of their time to fight for resources. It is assumed that the probability of war is increasing with the equilibrium level of violence in society. As a result, in resource scarce and violent environments regular wars keep population in check. In Figure 2 this is captured by another set of arrows (the blue dotted ones).

The model also has a scale effect working from population to technological progress. This is illustrated in Figure 2 as well (by the dashed green lines). An economy can break out of its Malthusian trap as rising population levels generate technological progress which slackens the resource constraint; this generates more population growth and thus more technological progress, and so on.

But technology is not only a force for the good in this model; it is also an input in resource competition and thus affects mortality by worsening the impact of war. Note that war is a random event and technology makes warfare more lethal *if it breaks out*. A phase of peace may generate growth in population and technology, whereafter an outburst of war (if and when it happens) is all the more deadly. Peace must thus prevail for long enough so that technological progress can make resource scarcity – and thus the risk of war – vanish completely. Only then can the economy break out of this Malthusian trap.

The rest of this paper continues in Section 2 by relating it to earlier literature. Thereafter Section 3 relates the workings of the model to a number of facts about war and conflict in human history, in particular Europe over the 19th and 20th centuries. Section 4 sets up the model. One component of the model is that war is a random event which breaks out with a probability which evolves endogenously over time. To fully understand how the model behaves it is thus necessary to simulate it, as is done in Section 5. Finally, Section 6 ends with a concluding discussion.

2 Existing literature

Most economists interested in theories of conflict have taken a microeconomic approach. They try to explain, for instance, the origin of property rights as a means to avoid conflict when agents weigh the option of appropriation (stealing) against production. (See e.g. Grossman 1991; Grossman and Kim 1995; Hirschleifer 1988, 2001.) However, none of these papers applies the results to issues like, for instance, why the 20th century Europe was so war torn, or the trends in worldwide killings shown in Figure 1.

Neither does this literature actually model any link from resource scarcity to violence. An important exception to this, however, is Grossman and Mendoza (2003) who set up a model where competition for resources is induced by a desire for survival, because more consumption means higher probability of survival. Grossman and Mendoza show that if the elasticity of the survival function with respect to consumption is decreasing in consumption, scarcer resources leads to more violence. The survival function used here takes a parametric form which satisfies this Grossman-Mendoze condition.

There is also an empirical literature looking at war and violence within and across countries. See e.g. Collier and Hoeffler (1998, 2004) and many other papers by the same authors. Different from the present study, these do not set up a unified growth model explaining the trends in worldwide killings shown in Figure 1.

Johnson et al. (2005) document that the death toll in many insurgencies (in e.g. Iraq and Colombia) tend to follow a power-law distribution. They also explain this pattern in a model where insurgent units join forces with bigger groups, or break up into smaller. The approach taken here differs by focusing on longer-term time trends in war and genocide, and by linking these trends to growth in population and living standards.

There is also a recent trend in the growth literature trying to explain growth in population and per-capita income, not only over the last couple of decades, but several thousand years back in time. See, among others, Galor and Moav (2002), Galor and Weil (2000), Hansen and Prescott (2002), Jones (2001), Lagerlöf (2003a,b), Lucas (2002), and Tamura (1996, 2002). But, again, these do not model war or resource scarcity. Another difference is that they are all (with the exception of Lagerlöf 2003a,b) deterministic, whereas was is here modelled as a stochastic event.

One growth model with endogenous evolution of population and a renewable resource stock is set up by Brander and Taylor (1998), who use the downfall of the ancient civilization on Easter Island as an illustration. However, they do not model violence or conflicts over resources per se, or transitions from Malthusian resource competition to sustained and peaceful growth.

3 Some supporting facts

The model to be presented here is simple and stylized. It does not explicitly allow factors to enter which are known to matter for the likelihood of war: institutions is one example, in particular democracy. The model may nevertheless be a useful starting point. The mechanics that drive the model (as discussed in the introduction and illustrated in Figure 2) seem to have played a role in many phases of human history, and they may also have played a role in institutional development.

Before looking at the model in detail it is thus worth describing how the chains of causality in the model can be interpreted in terms of historical facts. There are essentially two mechanisms that are new here compared to existing literature: the link from resource scarcity and competition to conflict and war; and the role of technology as a factor both in easing resource competition, and raising the lethality of war.

3.1 Resource competition and war

To begin with, the link from resource scarcity to conflict has been documented in the downfall of many ancient civilizations, from the Roman Empire to Easter Island; several more examples are discussed in Jared Diamond's (2005) "Collapse." In modern times, population pressure continues to impact conflict propensity, in particular in poorer regions, more dependent on land and agriculture. For example, Diamond (2005, Ch. 10) points to overpopulation as a factor behind the 1994 genocide in Rwanda.[2]

Another example of how resource scarcity may lead to conflict is given by Miguel et al. (2004), who find a strong negative effect of economic growth on the likelihood of outbreak of civil war among 41 African countries, using rainfall as an exogenous instrument. Friedman (2005) lists numerous examples of how rising living standards have made Western societies more open, democratic, and less prone to conflict.

The model set up here can be understood in the context of European history. For most of the last several centuries, famine and high food prices have been a cause behind many episodes of social unrest in Europe, and elsewhere; one prominent example is the French revolution in 1789 (Ponting

[2]Ethnic divides between Hutus and Tutsis played a role too but that cannot have been the only explanation, argues Diamond. For example, many killings took place where only Hutus lived.

1991, p. 102-110). The European colonization of the rest of the world, and subsequent genocides, can be intrepreted as an outcome of European population pressures and a hardening competition for land (Pomeranz 2001).

It also seems that changes around the 19th century started to make European wars slighly less frequent. From the end of the Franco-Prussian war of 1870-71 to the outbreak of WWI in 1914 Europe went through a phase of relative peace, with no wars fought which involved any of the great powers of Europe. Over these years trade increased, education levels rose, and many new technologies, such as railways and petrochemical inventions, made life better in Europe. (See e.g. Galor 2005 and further references therein.) For the first time in human history sustained growth in living standards had started to get a momentum, what is often called the Industrial Revolution. As a result of rising living standards, reflecting the fact that the economies were still largely in a Malthusian equilibrium, population levels also rose rapidly in most European powers.

However, there was a strong geographical imbalance in population growth rates across Europe. For example, Germany's population rose from about 40 million in 1870 to about 67 million in 1913, at the dawn of WWI. The corresponding population numbers for France was 37 million in 1870 and 40 million in 1913. (These numbers are from Mitchell 2003, Table A5; see also Browning 2002, Table 9). From a state of rough parity, Germany's population had in a few generations outgrown that of France.

As a result of the rapid rate of industrialization and population growth over this period, in all European great powers energy consumption (in particular coal) was rising fast. Again, however, the divergence between e.g. France and Germany is striking: over the period 1890 to 1913 France's energy consumption rose by 80%, whereas that of Germany by 224% (Browning 2002, Table 10).

This was paralleled by Germany's emergence as a colonial power, and its search for "a place in the sun." The competition for natural resources played out both in the colonies and, with the outbreak of WWI, in regions of Europe such as Saar and Silesia, which were highly contested due to their large coal resources. In the Paris peace talks in 1919, France successfully insisted on control over Saar despite its population being predominantly German (thus breaking some of the core principles formulated by U.S. President Wilson). McMillan (2001, p. 195) describes Saar as follows: "What had been a quite farming country with beautiful river valleys in the nineteenth century had become a major coal mining and manufacturing area in the nineteenth century. In 1919, when coal supplied almost all of Europe's fuel needs, that made the region very valuable."

Natural resource competition seems to have played a role in other wars too. Japan's conquest and occupation of Manchuria was partly driven by a need for natural resources, and in the second world war at least some of the Nazi rhetoric seems to have reflected a desire for more land and "space" (*lebensraum*). (See e.g. Ehrlich 2000, p. 270.) It is also worth noting that the most conflict-ridden region of the world today is the oil-rich Middle East.

3.2 Technology

These resources – coal, oil, metals, etc. – are here considered "scarce" in the sense that military powers have found it worthwhile to spend time and money to fight over them. This does not mean that they are, or ever were, running out. In fact, new discoveries have made some of these resources less scarce (or, rather, less important) in ways similar to what happens in this model as technological progress slackens resource scarcity. For example, the replacement of coal by oil as a major energy source seems to have ruled out any military contests over coal today.

As described, over the peaceful years 1871-1914 many new technologies made life better for many people in Europe. But new technologies also made WWI, once it broke out, to the most lethal war seen thus far. The inventions included mines, tanks, chemical weapons, and a number of improvements in existing technologies such as guns, gun powder, explosives, and artillery. Other innovations, such as radio and railways, played a role in mobilizing forces and spreading information and propaganda. (See e.g. Browning 2002, Ch. 4 for an overview.)

Consistent with the model presented here one can thus argue that a long phase of peace in Europe generated population growth and rising levels of technology, which made war more lethal once it eventually broke out. In the model, a longer period of peace and technological progress eventually can make the economy escape the war trap and converge to a balanced growth path where war is in principle very lethal but never breaks out because resource scarcity has vanished. Europe today seems to be on that type of peaceful growth path. Many of the (former) great military powers have more advanced nuclear, chemical and biological weapons technologies, than they ever had before, and these would obviously be very deadly if they were used in large scale warfare. However, no such wars are being fought today, at least among rich countries, arguably for the simple reason that they are rich and prosperous. In sum, the effects of war are huge but the probability of war is vanishingly small.

In this model, one could allow for differences in the timing by which countries, or regions, embark on the peaceful balanced growth path. This would be consistent with the observation that the total number of people killed in war and genocide shows a hump-shaped pattern over time, with a peak around 1945 (the end of WWII). Thereafter, other regions of the world (like the Soviet Union and China) whose economic development has been lagging that of Europe and its offshoots, have gone through murderous phases similar to that of Europe during WWI and WWII. (See Rummel 1997, Figure 23.2.) If, in the limit, all countries end up on the peaceful balanced growth path (as in e.g. Lucas 2002, Ch. 4), this would mean that the world eventually becomes totally peaceful.[3]

[3]This reasoning seems to abstract from terrorist networks working without any distinct home base. However, terrorists tend to be recruited from relatively poor and institutionally backward regions of the world. One may thus argue that there still exists a fully peaceful balanced growth path (which the world may be on in the distant future) where the whole world is rich and prosperous and the risk of terrorist attacks has vanished.

4 The Model

This is a one-sex two-period overlapping-generations model, where agents live first in childhood and then as adults who rear children; these children then grow up to rear own children, and so on. Agents are referred to by the female pronoun, each having $\overline{n}$ offspring, out of whom some survive to rear own children and others die.

The fraction of the offspring born by an agent in period t who survives is denoted s_t, and depends on how much time the mother spends looking after her offspring (e.g. protecting them from dangers and keeping them clean); and on food supplied to the household.[4] How much food the mother can collect in turn depends on the time spent competing for food, and a time constraint by which her nurturing and resource competition activities sum up to unity. The fraction offspring surviving is assumed to be given by

$$s_t = q(c_t)[1 - r_t], \tag{1}$$

where r_t denotes time spent in resource competition (and $1 - r_t$ thus the time spent looking after the offspring). The amount of food procured, c_t, determines survival through the function $q : \mathbb{R}_+ \to [0, 1)$.

The total land area from which food can be procured (i.e., collected, hunted, or produced using agriculture or horticulture), is normalized to one, and total (adult) population is denoted P_t. Although the land area is fixed the technology used to procure food evolves endogenously; A_t denotes the total amount of food generated by the unit-sized land in period t. The total pie of food or resources that agents compete over thus equals A_t, and in a symmetric equilibrium food per agent equals A_t/P_t.

[4]The food collected could be thought of as being used either to feed the mother and thus prolong her life to rear more offspring, or used to feed the offspring directly (and perhaps give her more breast milk to feed her children). The point is that the more is the total amount of food collected, the larger fraction of the offspring survives.

4.1 Resource competition

Let the time spent by the average agent in resource competition be denoted R_t. Food collected by a single agent in period t who fights r_t units of time, while total resource competition by others amounts to $(P_t - 1)R_t$, is given by a Tullock-type of contest function:

$$c_t = \left[\frac{r_t}{r_t + (P_t - 1)R_t} \right] A_t. \tag{2}$$

Note that time spent in resource competition is a social waste, since each agent's time spent competing only lowers the share taken by other agents. The equilibrium condition, $r_t = R_t$, implies that $c_t = A_t/P_t$. If there is only one agent ($P_t = 1$) she takes the whole pie and needs not exert any resources to fight for it.

Agent t chooses r_t so as to maximize $q(c_t)[1 - r_t]$ subject to (2). The solution is given by

$$g(c_t) \left(\frac{\partial c_t}{\partial r_t} \right) \frac{1 - r_t}{c_t} = 1, \tag{3}$$

where $g(c)$ is the elasticity of $q(c)$ with respect to c:

$$g(c_t) = \frac{q'(c_t)c_t}{q(c_t)}. \tag{4}$$

At equilibrium, where $R_t = r_t$ and $c_t = A_t/P_t$, (3) becomes:[5]

$$g\left(\frac{A_t}{P_t} \right) \left(\frac{P_t - 1}{P_t} \right) \left(\frac{1 - R_t}{R_t} \right) = 1, \tag{5}$$

which gives the representative agent's resource competition, R_t, as a function of P_t and A_t.

[5]It can be seen that

$$\frac{\partial c_t}{\partial r_t} \frac{1}{c_t} = \left(\frac{R_t}{r_t} \right) \left[\frac{P_t - 1}{r_t + (P_t - 1)R_t} \right],$$

which equals $(P_t - 1)/(R_t P_t)$ when $R_t = r_t$.

Consider the case when both A_t and P_t are large, so that $(P_t - 1)/P_t \approx 1$, and A_t/P_t is finite and positive. Then the relationship between R_t and per-agent consumption, $c_t = A_t/P_t$, can be positive or negative depending on the sign of $g'(c)$; as shown by Grossman and Mendoza (2003) to ensure that scarcity of resources leads to more fighting one must assume that $g'(c) < 0$. For the rest of this paper the following functional form will be used, which satisfies the Grossman-Mendoza condition:

$$q(c) = \max\left\{0, \frac{c - \overline{c}}{c}\right\}, \tag{6}$$

where $\overline{c}$ will be called subsistence consumption. That is, the parent must procure more than $\overline{c}$ for any of her offspring to survive. If, in any period, A_t/P_t falls below $\overline{c}$ the whole population dies out. Note also that $q(c)$ goes to one as c goes to infinity.

Using (4), (5), and (6), it is seen that equilibrium fighting time equals:

$$R_t = \frac{\overline{c}\,(P_t - 1)}{A_t - \overline{c}} \equiv R(A_t, P_t). \tag{7}$$

Two details are worth noting. First, in an economy which exhibits sustained growth in per-capita consumption, c_t, meaning that A_t grows at a faster rate than P_t, the equilibrium fighting time, R_t, approaches zero. In that sense, this model has the feature that prosperity leads to peace.

The second detail worth noting is that R_t falls between zero and one, as long as $P_t > 1$, and $A_t/P_t < \overline{c}$.

Using (1), together with the equilibrium conditions $R_t = r_t$ and $c_t = A_t/P_t$, and (6) and (7), it is seen that the survival rate is:

$$s_t = q\left(\frac{A_t}{P_t}\right)[R(A_t, P_t) - 1] = \frac{(A_t - \overline{c}P_t)^2}{A_t\,(A_t - \overline{c})}. \tag{8}$$

4.2 War and peace

There are two states of the world, war and peace. In each period t war breaks out with some probability z_t. In the real world, decisions by political leaders about going to war are affected by many factors, and involve complex political and social processes. As argued in Section 3, one factor that seems to have mattered in many historic contexts is competition for land and natural resources. The model presented thus far has a microeconomic link from resource scarcity to conflicts at the individual level, as seen from the expression for equilibrium resource competition in (8). The next step is to think about how such individual-level resource competition may spill over into war. Rather than confronting a host of theoretical issues regarding collective decision making, the link from resource competition to the outbreak of war is here treated in a black-boxed, but arguably quite plausible, fashion: the probability of war is simply assumed to depend on the degree of resource competition, R_t. That is:

$$z_t = Z(R(A_t, P_t)), \tag{9}$$

where it is assumed that $Z'(\cdot) > 0$, and $Z(0) = 0$, i.e., a society without resource competition is peaceful.

War means that some die, out of those young agents who would otherwise have survived to the next period (which in turn, recall, is a fraction s_t of the $\overline{n}$ born children). The fraction that survives war (if there is a war) is denoted v_t. To capture the idea that rising levels of technology have historically led to more lethal weapons and arms v_t is assumed to be decreasing in the level of technology. This is also treated in a black-boxed fashion, and this functional form generates nice analytical results:

$$v_t = \frac{\lambda + \delta A_t}{\lambda + A_t}, \tag{10}$$

for some $\lambda > 0$ and $\delta \in (0, 1)$. Note that $\lim_{A_t \to \infty} v_t = \delta$; the parameter δ thus measures the fraction of the population which would be killed if war were to break out in an economy with sustained growth in technology.

4.3 Population dynamics

Recall that each adult agent has $\overline{n}$ children, and a fraction s_t of these survive in peace. In a state of war a fraction v_t survives the war, and population thus evolves according to $P_{t+1} = P_t\overline{n}s_tv_t$; if there is no war, $P_{t+1} = P_t\overline{n}s_t$. Using (8), (9), and (10), this gives the following dynamic equation for population:

$$P_{t+1} = \begin{cases} \overline{n}P_t\left[\frac{(A_t-\overline{c}P_t)^2}{A_t(A_t-\overline{c})}\right]\left(\frac{\lambda}{\lambda+A_t}\right) & \text{with probability} \quad Z(R(A_t,P_t)) \\ \\ \overline{n}P_t\frac{(A_t-\overline{c}P_t)^2}{A_t(A_t-\overline{c})} & \text{with probability} \quad 1-Z(R(A_t,P_t)) \end{cases} . \tag{11}$$

4.4 Technology dynamics

The level of technology is assumed to evolve according to:

$$A_{t+1} = A_t^{\alpha}P_t^{\beta} \tag{12}$$

where $\alpha \in (0,1)$, $\beta > 0$, and $\alpha + \beta > 1$.

Letting population enter the dynamic equation for technology may capture a scale effect, à la e.g. Kremer (1993) and Jones (2001); the more people there are to make inventions and discoveries the faster is the rate of technological progress.

The parametric restriction that $\alpha+\beta > 1$ implies that there exists a peaceful balanced growth without resource competition, and where per-capita consumption, A_t/P_t, exhibits sustained growth.

Together, (11) and (12) constitute a stochastic two-dimensional system of difference equations. What path the economy follows depends on whether it is in a state of war or peace, and it switches between these states with the probability $Z(R(A_t, P_t))$, which is in turn evolves endogenously over time.

To understand the workings of the model, first consider what happens if peace always prevails; and if war always prevails.

4.4.1 An always-peace economy

In the always-peace case, the economy exhibits sustained growth in A_t and P_t, as illustrated in Figure 3.

Also, given the parametric assumptions made, A_t/P_t exhibits sustained growth. To see this, note that in the limit the growth rate of technology equals

$$g^* = \overline{n}^{\frac{\beta}{1-\alpha}} > \overline{n} \tag{13}$$

where the inequality follows from $\overline{n} > 1$, $\alpha \in (0, 1)$, and $\alpha + \beta > 1$. Recall that, if A_t/P_t exhibits sustained growth, the survival rate goes to one. Thus, on the balanced growth path population grows at rate $\overline{n}$ and the inequality in (13) ensures that A_t/P_t also goes to infinity.

4.4.2 An always-war economy

Consider next the always-war case, illustrated in the phase diagram in Figure 4. Here population and technology move in endogenous cycles. An economy starting off with a high level of technology and intermediate levels of population experiences lethal forms of warfare, and population and technology fall simultaneously over time. When the levels of technology have declined sufficiently, warfare becomes less lethal, allowing population levels to rise over time. As population levels have risen enough for technological progress to occur population and technology grow in tandem over some periods. Then as technology reaches high enough levels again, and warfare becomes more lethal, population starts to decline. The lethality of warfare continues to make population decline as long as technology levels are high, and the cycle starts all over again.

4.4.3 An economy switching endogenously between war and peace

Consider finally what happens if the economy switches endogenously between war and peace with probability $Z(R(A_t, P_t))$. For many periods the economy can remain in a state where war occurs regularly, because resources are scarce, consumption low, and resource competition therefore intense. This could be approximated by the always-war dynamics (cf Figure 4). If, in some period, peace breaks out, this leads to population expansion, making resources become scarcer. This sooner or later results in two types of Malthusian backlash: food scarcity leads to a rise mortality in a conventional Malthusian fashion; and competition for resources increases, making the risk of war rise.

The economy can break out of this trap due to the scale effect working from population to technological progress. Rising population leads to rising technology through the scale effect which slackens the resource scarcity problem.

At the same time, since technology makes warfare more lethal if it breaks out, the war-inducing type of Malthusian check is greater the higher is the level of technology. A sequence of peaceful periods can thus generate growth in population and technology but if war eventually does break out it will be all the more deadly. What is needed is that peace prevails long enough for technological progress to make resource scarcity completely go away, and thus render war a very improbable event; only then can the economy break out of this Malthusian trap.

5 Quantitative analysis

The description provided in Section 4.4.3 of how the economy behaves when it switches endogenously between war and peace is merely intuitive. To know how the economy actually does behave one needs to simulate it. For comparison, Figures 5 and 6 first show the paths generated by an always-peace economy and an always-war economy. Figure 7 then shows a simulation where the economy switches stochastically between war and peace. In all three simulations, the probability of war (which in the first two simulations is hypothetical) is simply set so that $Z(R(A_t, P_t)) = R(A_t, P_t)$; cf (7).

Figure 5 shows the dynamic path of an always-peace economy, where technology and population exhibit sustained growth. (The starting values, A_0 and P_0, are set so that their ratio is initially equal to what it converges to on the balanced growth path.) Since we impose peace in all periods this is a hypothetical probability; the path shows how the economy would evolve if peace by accident happened to prevail in all periods. Note that the probability of war is declining over time, and the death rate of war (were it to counter-factually occur) is rising. Thus, the implied *expected* war death rate (the probability of war times the death rate if war happens) is inversely U-shaped. It goes to zero in the limit since the probability of war goes to zero and the war death rate is bounded from above.

The lower left panel in Figure 5 shows the expected hypothetical number of people killed in war, that is: total population times the expected war death rate (the latter is shown in the lower right panel). Population exhibits sustained growth and the expected war death rate approaches zero in the limit. The population effect dominates so the expected number of war deaths goes to infinity, even though the economy is completely peaceful.

Figure 6 shows the path of an always war economy. Here there is no sustained growth in population or technology, and thus not in consumption either. Therefore, the probability of war does not approach zero. In this numerical example it converges to a little less than 10%. The number of deaths in war – which are here realized in every period – also converges to a constant in levels.

Consider finally an economy switching endogenously between war and peace. Due to these random events all simulations look slightly differently from one another but the principle shape of the time paths is pretty much the same. As seen, the economy tends to behave largely like an always peace economy, since it takes take off into sustained growth in population, technology, and consumption, and thus sustained peace. Along the way, however, the economy experiences several backlashes, with population reductions due to the outbreak of war. In this particular simulation, a couple of spikes in the total number of deaths stand out; many smaller peaks are harder to see because they are dwarfed by these two spikes. This reflects the two opposing time trends described above. The spikes in total deaths fit with the European time pattern of war and genocide in Figure 1 (see also Rummel 1997).

6 Conclusions

To be written...

References

[1] Brander, J.A., and M.S. Taylor, 1998, The simple economics of Easter Island: A Ricardo-Malthus model of renewable resource use, American Economic Review 88, 119-138.

[2] Browning, P., 2002, The changing nature of warfare – the development of land warfare from 1792 to 1945, Cambridge University Press, Cambridge, United Kingdom.

[3] Collier, P. and A. Hoeffler, 1998, On economic causes of civil war, Oxford Economic Papers 50, 563-573.

[4] —–, 2004, Greed and Grievance in Civil Wars, Oxford Economic Papers 56, 663-595.

[5] Diamond, J., 2005, Collapse – how societies choose to fail or succeed, Viking Penguin, New York.

[6] Ehrlich, P.R., 2000, Human natures – genes, cultures, and human prospects, Penguin Books, New York.

[7] Friedman, B.M., 2005, The Moral Consequences of Economic Growth, Alfred A. Knopf, Random House.

[8] Galor, O., 2005, Transitions, in: Aghion, P., and S. Durlauf (eds.), Handbook of Economic Growth, North-Holland.

[9] Galor, O., and O. Moav, 2002, Natural selection and the origin of economic growth, Quarterly Journal of Economics 117, 1133-1192.

[10] Galor, O., and D. Weil, 2000, Population, technology, and growth: from Malthusian stagnation to the demographic transition and beyond, American Economic Review 90, 806-829.

[11] Grossman, H.I., 1991, A general equilibrium model of insurrections, American Economic Review 81, 913-921.

[12] Grossman, H.I., and M. Kim, 1995, Swords and plowshares? A theory of the security of claims to property, Journal of Political Economy 103, 1275-1288.

[13] Grossman, H., and J. Mendoza, 2003, Scarcity and appropriative competition, European Journal of Political Economy 19, 747-758.

[14] Hansen, G.D., and E.C. Prescott, 2002, Malthus to Solow, American Economic Review 92, 1205-1217.

[15] Hirschleifer, J., 1988, The analytics of continuing conflict, Synthese 76, 201-233.

[16] —–, 2001, The dark side of the force - economic foundations of conflict theory, Cambridge University Press.

[17] Johnson, N., M. Spagat, J. Restrepo, J. Bohórquez, N. Suárez, E. Restrepo, and R. Zarama, From old wars to new wars and global terrorism, mimeo, Royal Holloway.

[18] Jones, C., 2001, Was the industrial revolution inevitable? Economic growth over the very long run, Advances in Macroeconomics 1, 1-43.

[19] Kremer, M., 1993, Population growth and technological change: one million B.C. to 1990, Quarterly Journal of Economics 108, 681-716.

[20] Lagerlöf, 2003a, From Malthus to modern growth: can epidemics explain the three regimes?, International Economic Review 44, 2003, pp. 755-777.

[21] —–, 2003b, Mortality and early growth in England, Sweden, and France, Scandinavian Journal of Economics 105, 2003, pp. 419-439.

[22] Lucas, R.E., 2002, Lectures on Economic Growth, Harvard University Press.

[23] Marshall, M.G., and T.Ro. Gurr, 2005, A global survey of armed conflicts, self-determination movements, and democracy peace and conflict, Report published by CIDCM Center for International Development & Conflict Management University of Maryland, College Park, http://www.cidcm.umd.edu.

[24] McMillan, M., 2001, Paris 1919 – six months that changed the world, Random House, New York.

[25] Miguel, E., S. Satyanath, and E. Sergenti, Economic shocks and civil conflict: an instrumental variables approach, Journal of Political Economy 112, 725-753.

[26] Mitchell, B.R., 2003, International historical statistics – Europe 1750-2000, Palgrave-McMillan, New York.

[27] Pomeranz, K., 2001, The great divergence: China, Europe, and the making of the modern world economy, Princeton University Press.

[28] Ponting, C., 1991, A green history of the world – the environment and the collapse of great civilizations, St. Martin's Press, New York.

[29] Rummel, R.J., 1997, Statistics of democide – genocide and mass murder since 1900, University of Virginia, Charlottesville, Virginia 22903-1789.

[30] Tamura, R., 1996, From decay to growth: a demographic transition to economic growth, Journal of Economic Dynamics and Control 20, 1237-1261.

[31] —–, 2002, Human capital and the switch from agriculture to industry, Journal of Economic Dynamics and Control 27, 207-242.

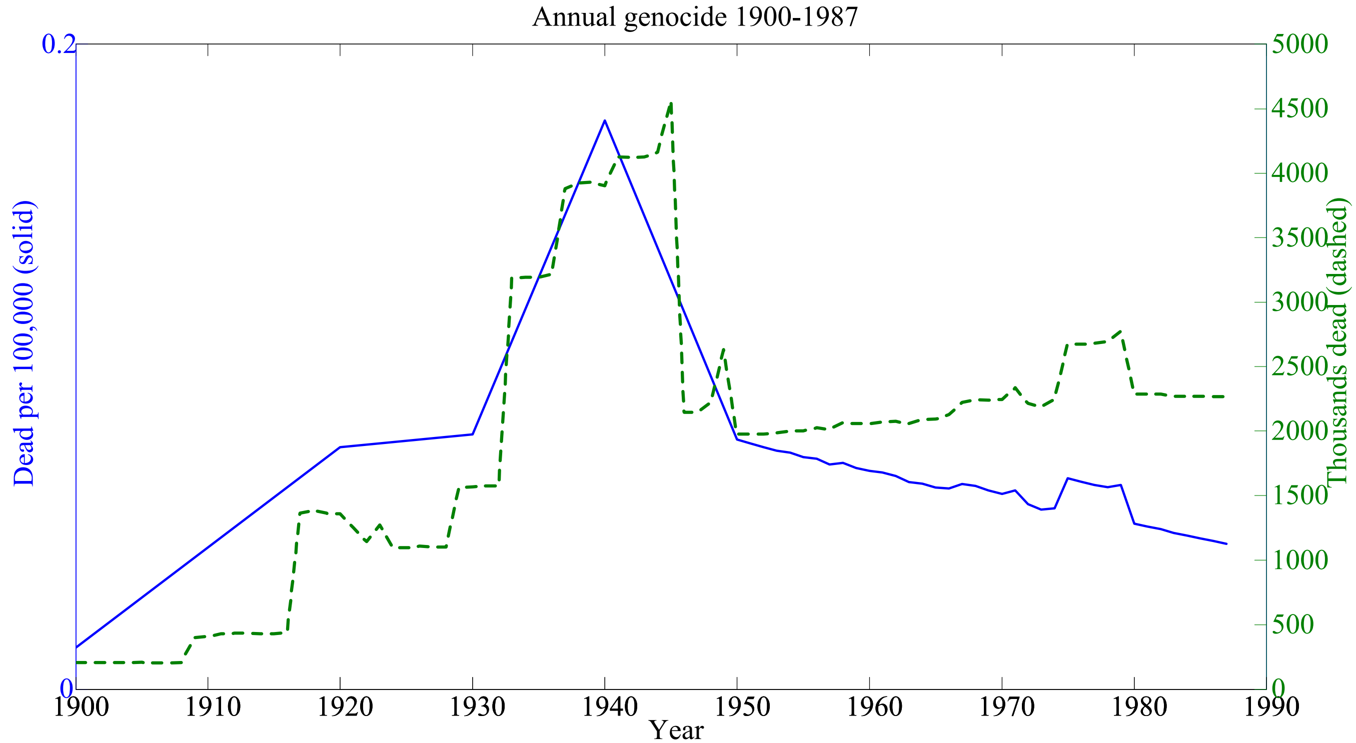

Figure 1: Time path over annual deaths in war and genocide 1900-1987. Sources: deaths: Rummer (1997); population: for 1950-87, the US Census Bureau at http://www.census.gov/ipc/www/world.html, and for 1900, 1920, 1930, and 1940, Kremer (1993)

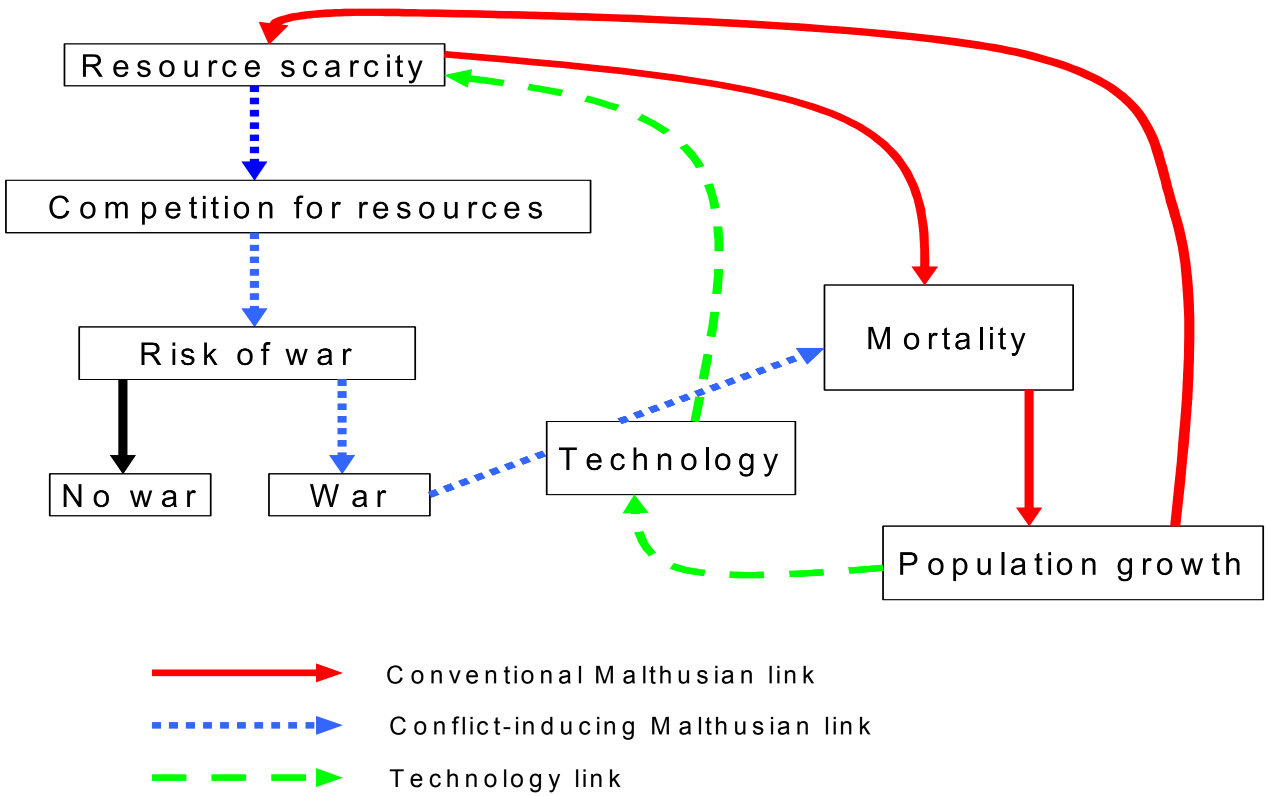

Figure 2: Flow-chart overview of the model.

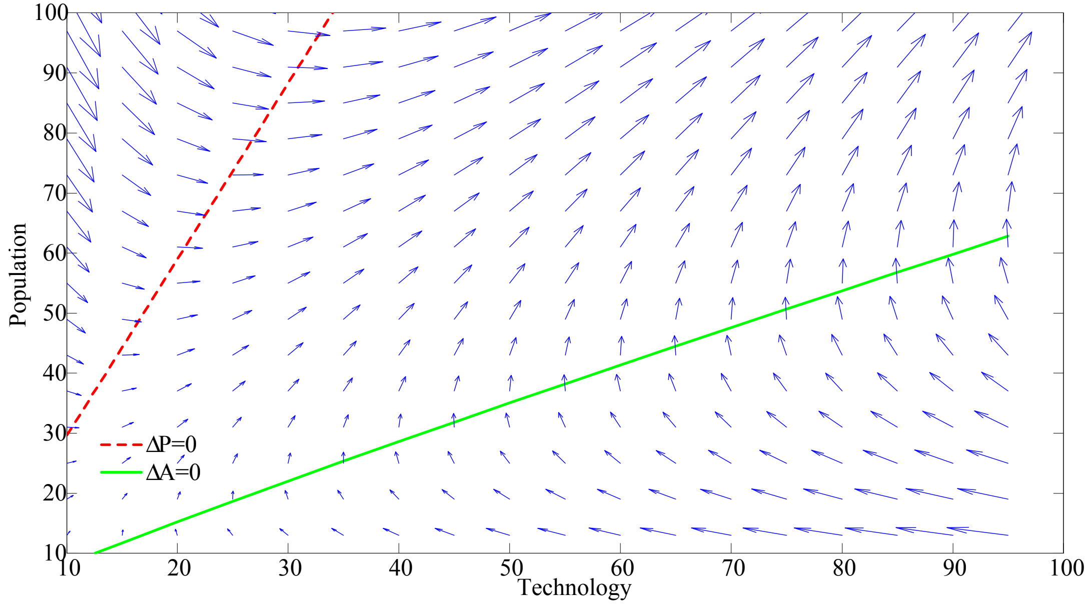

Figure 3: Phase diagram for a perpetual peace economy.

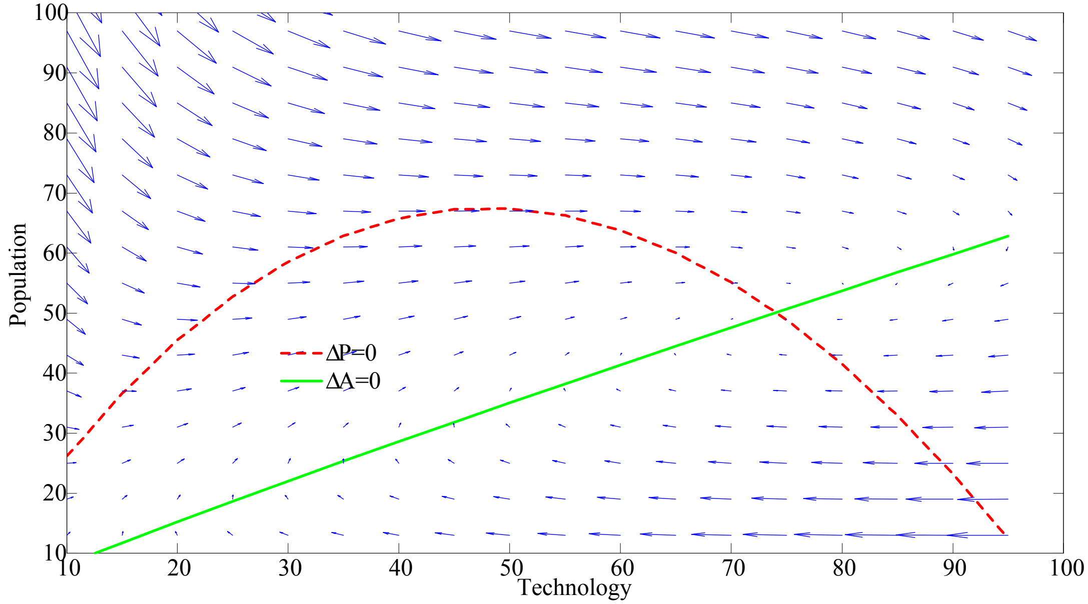

Figure 4: Phase diagram for a perpetual war economy.

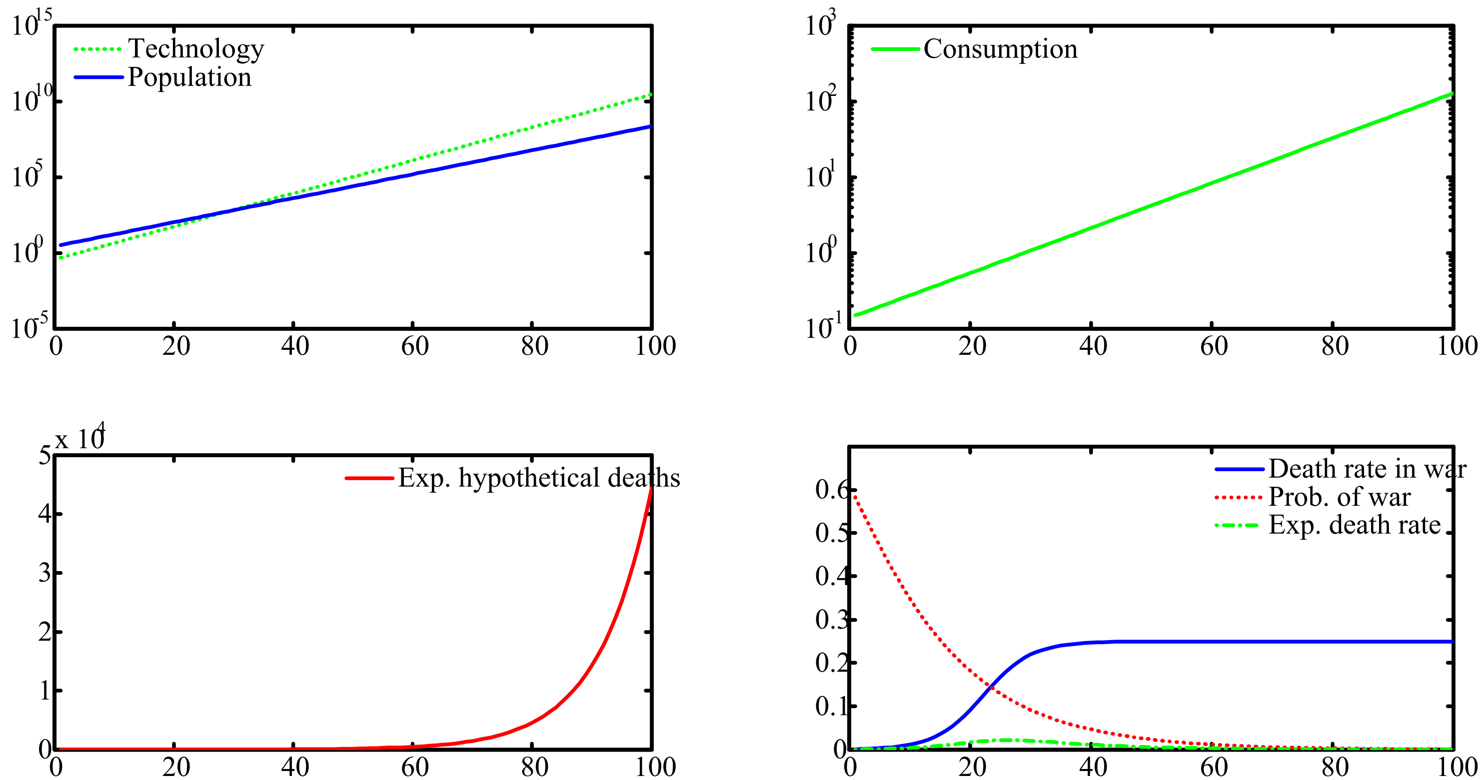

Figure 5: Simulation of a perpetual peace economy.

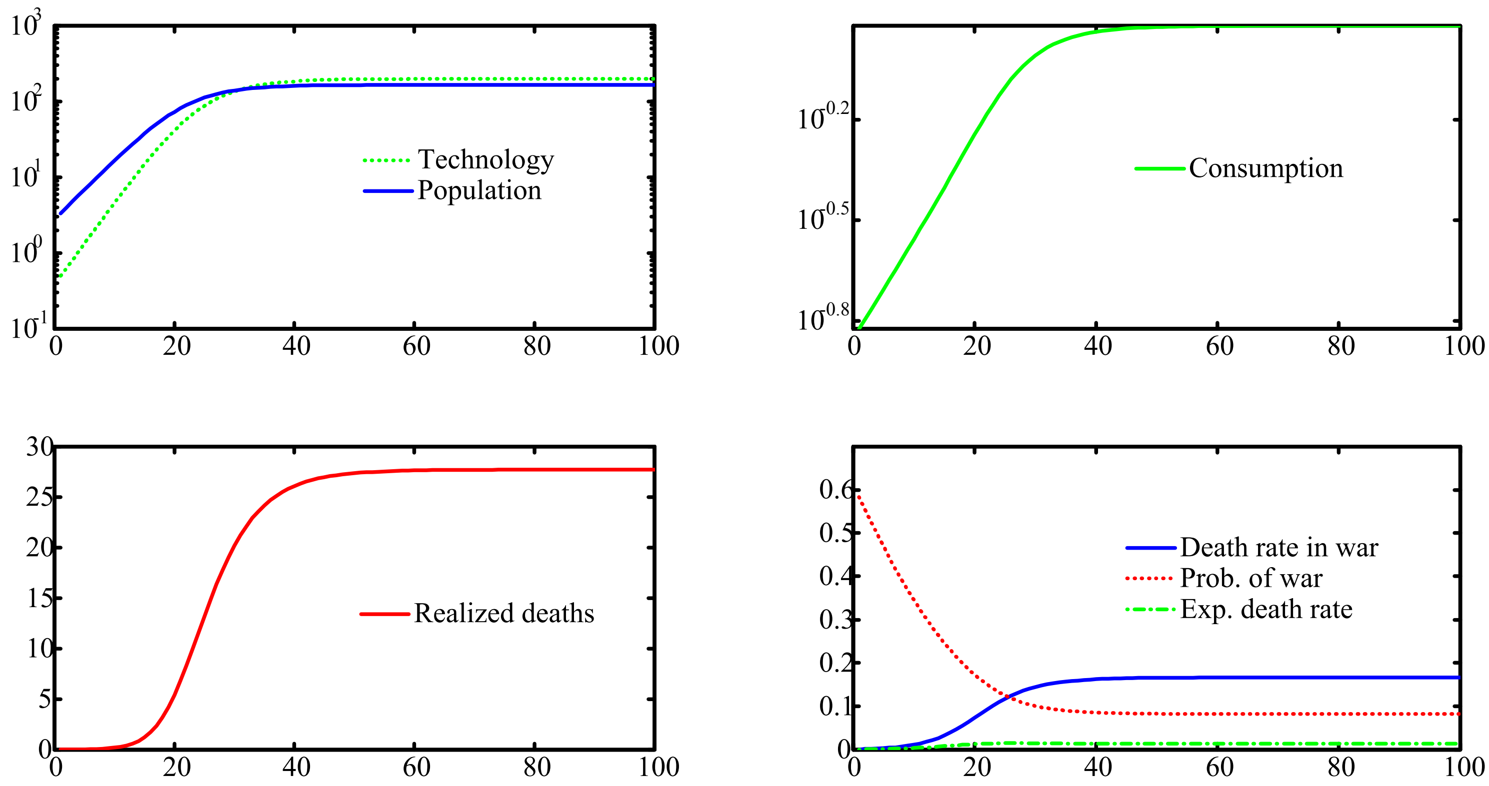

Figure 6: Simulation of a perpetual war economy.

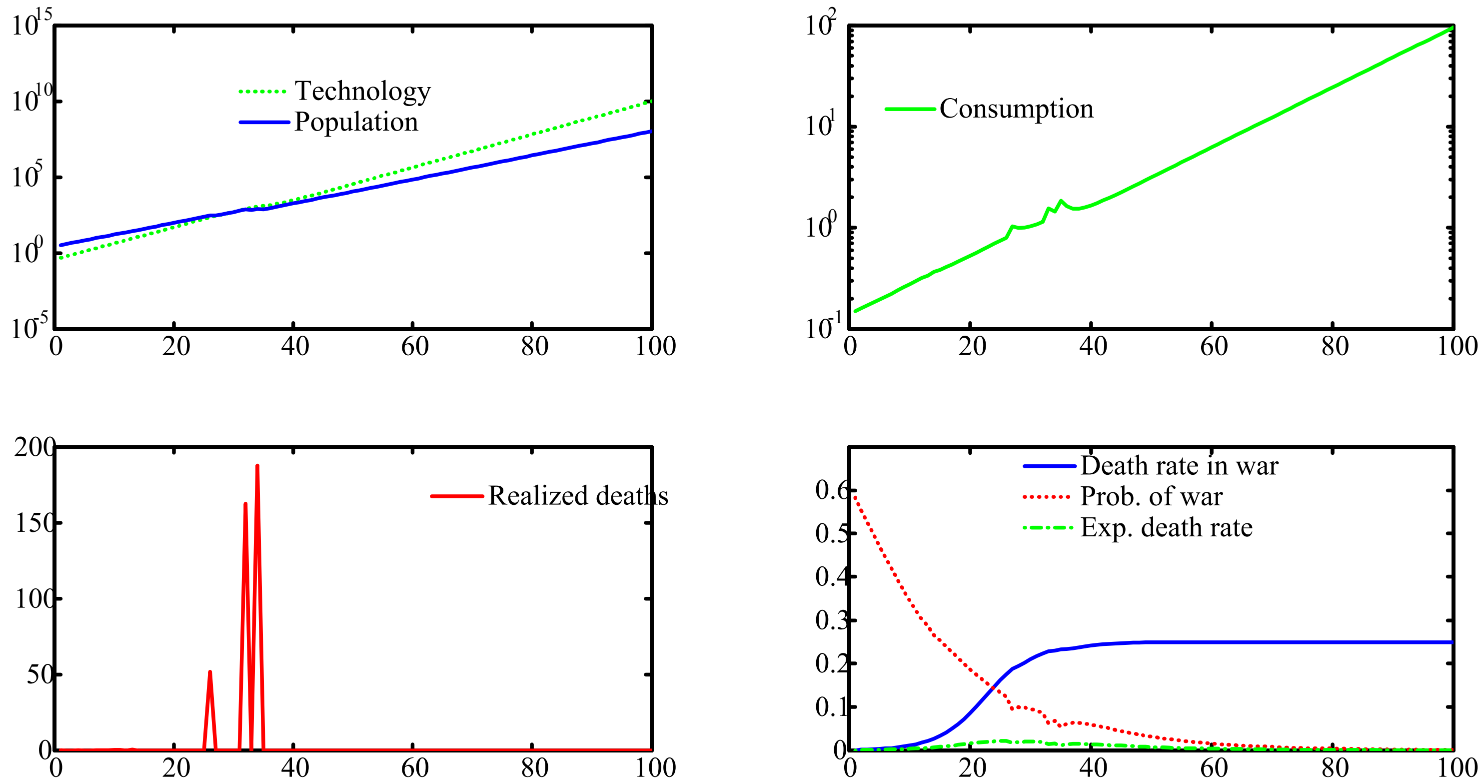

Figure 7: Simulation of an economy switching randomly between war and peace.